

---

# Survey of HEPA Filter Applications and Experience at Department of Energy Sites

E. H. Carbaugh

---

November 1981

Prepared for the U.S. Department of Energy  
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory  
Operated for the U.S. Department of Energy  
by Battelle Memorial Institute



## NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

The views, opinions and conclusions contained in this report are those of the contractor and do not necessarily represent those of the United States Government or the United States Department of Energy.

PACIFIC NORTHWEST LABORATORY  
*operated by*  
BATTELLE  
*for the*  
UNITED STATES DEPARTMENT OF ENERGY  
*Under Contract DE-AC06-76RLO 1830*

Printed in the United States of America  
Available from  
National Technical Information Service  
United States Department of Commerce  
5285 Port Royal Road  
Springfield, Virginia 22151

Price: Printed Copy \$ \_\_\_\_\_\*: Microfiche \$3.00

*Pages	NTIS Selling Price
001-025	\$4.00
026-050	\$4.50
051-075	\$5.25
076-100	\$6.00
101-125	\$6.50
126-150	\$7.25
151-175	\$8.00
176-200	\$9.00
201-225	\$9.25
226-250	\$9.50
251-275	\$10.75
276-300	\$11.00

SURVEY OF HEPA FILTER APPLICATIONS AND EXPERIENCE  
AT DEPARTMENT OF ENERGY SITES

E. H. Carbaugh

November 1981

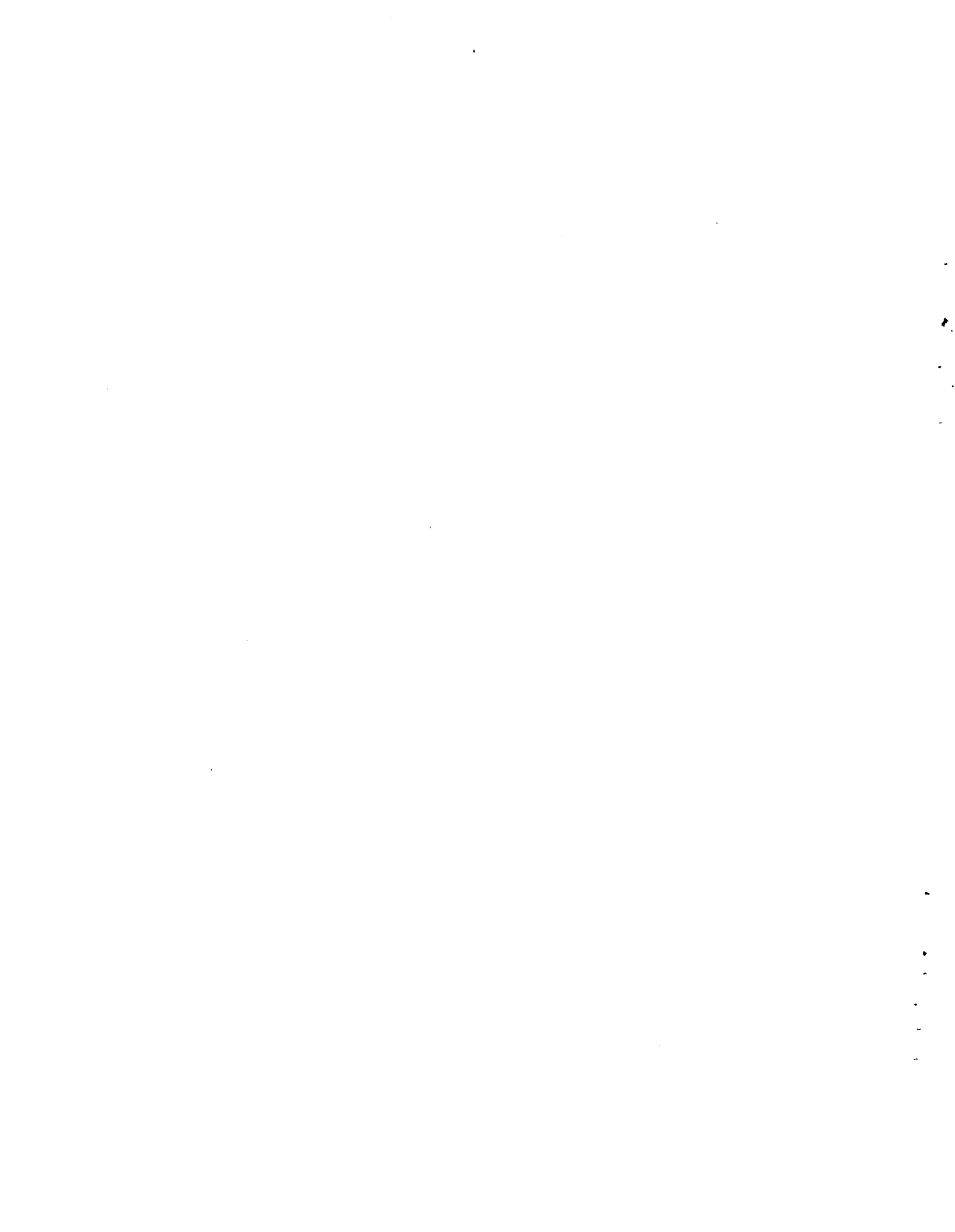
Work supported by  
The U.S. Department of Energy  
under Contract DE-AC06-76 RLO 1830

Pacific Northwest Laboratory  
Richland, Washington 99352



## PREFACE

This work was performed in support of the Airborne Waste Management Program, Department of Energy (DOE), and by the Pacific Northwest Laboratory (PNL), operated for the Department of Energy by Battelle Memorial Institute under contract DE-AC06-76RLO 1830. The purpose of the data collection and presentation was to aid in directing future HEPA filter technology development efforts by providing an initial overview of the reasons and magnitude of HEPA filter changeouts and failures at DOE sites.



## SUMMARY

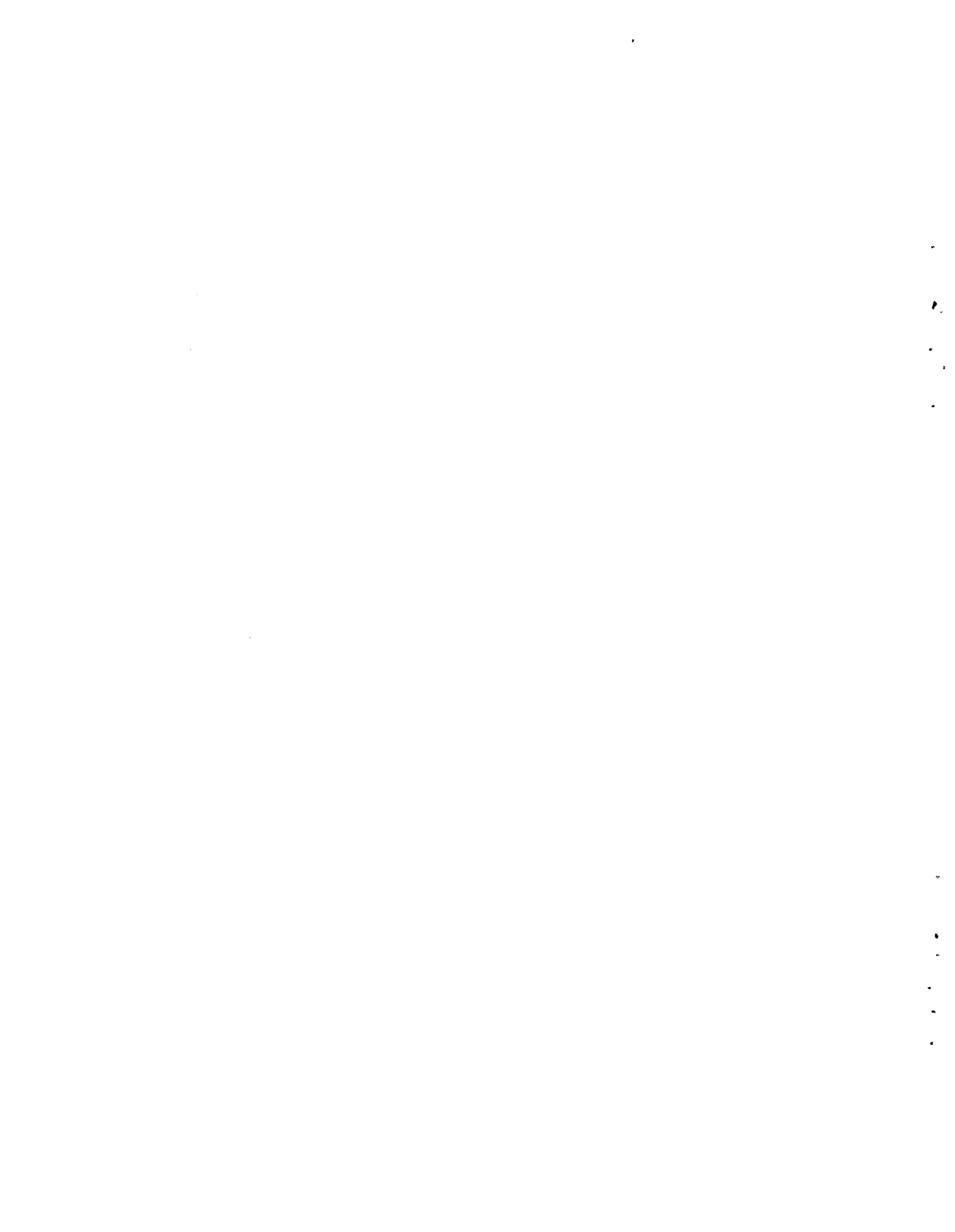
Pacific Northwest Laboratory conducted a survey of high efficiency particulate air (HEPA) filter applications and experience at Department of Energy (DOE) sites. The purpose of the survey was to provide an initial overview of the reasons and magnitude of HEPA filter changeout and failures as an aid in directing future HEPA filter technology development.

Results indicated that approximately 58% of the filters surveyed were changed out in the 1977 to 1979 study period and some 18% of all filters were changed out more than once. Most changeouts (60%) were due to the existence of a high pressure drop across the filter, indicative of filter plugging. The next most recurrent reasons for changeout and their percentage changeouts were leak test failure (15%) and preventive maintenance service life limit (12%). An average filter service life was calculated to be 3.0 years with a 2.0-year standard deviation. The labor required for filter changeout was calculated as 1.5 manhours per filter changed.

Filter failures occurred with approximately 12% of all installed filters. Most failures (60%) occurred for unknown reasons and handling or installation damage accounted for an additional 20% of all failures. Media ruptures, filter frame failures and seal failures occurred with approximately equal frequency at 5 to 6% each.

Subjective responses to the questionnaire provided some indication of problems as perceived by field personnel. These problems included:

- need for improved acid and moisture resistant filters
- filters more readily disposable as radioactive waste
- improved personnel training in filter handling and installation
- need for pretreatment of air prior to HEPA filtration.



CONTENTS

PREFACE . . . . .	iii
SUMMARY . . . . .	v
1.0 INTRODUCTION . . . . .	1.1
2.0 METHOD . . . . .	2.1
3.0 RESPONSE . . . . .	3.1
3.1 QUESTIONNAIRE RESPONSES . . . . .	3.1
3.2 SUBJECTIVE RESPONSES . . . . .	3.1
3.3 DATA OVERVIEW . . . . .	3.4
4.0 RESULTS . . . . .	4.1
4.1 APPLICATIONS EXPERIENCE . . . . .	4.1
4.2 CHANGEOUT EXPERIENCE . . . . .	4.15
4.3 FAILURE EXPERIENCE . . . . .	4.26
4.4 SERVICE LIFE EXPERIENCE . . . . .	4.35
5.0 REFERENCES . . . . .	5.1
APPENDIX A: HEPA FILTER SURVEY . . . . .	A.1

## FIGURES

1.1	Typical HEPA Filter (sealing side view)	. . . . .	1.2
4.1	Normalized Labor for Changeout	. . . . .	4.27
4.2	Typical Filter Service Life	. . . . .	4.37

## TABLES

2.1	HEPA Filter Survey Classification Codes	. . . . .	2.2
4.1	Stage versus Applications Experience	. . . . .	4.2
4.2	Environment Number versus Applications Experience	. . . . .	4.3
4.3	Single Environment versus Applications Experience	. . . . .	4.4
4.4	Combinations of Two Environments versus Applications Experience	. . . . .	4.5
4.5	Combinations of Three Environments versus Applications Experience	. . . . .	4.6
4.6	Combinations of More Than Three Environments versus Applications Experience	. . . . .	4.7
4.7	Source Number versus Applications Experience	. . . . .	4.8
4.8	Single Source versus Applications Experience	. . . . .	4.9
4.9	Two Source Combinations versus Applications Experience	. . . . .	4.10
4.10	Three Or More Source Combinations versus Applications Experience	. . . . .	4.11
4.11	Frame Type Versus Applications Experience	. . . . .	4.12
4.12	Separator Type Versus Applications Experience	. . . . .	4.13
4.13	Sealant Type Versus Applications Experience	. . . . .	4.14
4.14	Seal Type Versus Applications Experience	. . . . .	4.15
4.15	Stage Versus Changeouts	. . . . .	4.16
4.16	Environment Number versus Changeouts	. . . . .	4.16

4.17	Single Environment versus Changeouts	. . . . .	4.17
4.18	Combinations of Two Environments versus Changeouts	. . . . .	4.18
4.19	Combinations of Three Environments versus Changeouts	. . . . .	4.19
4.20	Combinations of Four or More Environments versus Changeouts	. . . . .	4.20
4.21	Source Number versus Changeouts	. . . . .	4.21
4.22	Single Source versus Changeouts	. . . . .	4.21
4.23	Combination of Two Sources versus Changeouts	. . . . .	4.22
4.24	Combinations of Three or More Sources versus Changeouts	. . . . .	4.23
4.25	Frame Type versus Changeouts	. . . . .	4.24
4.26	Separator Type versus Changeouts	. . . . .	4.24
4.27	Sealant Type versus Changeouts	. . . . .	4.25
4.28	Seal Type versus Changeouts	. . . . .	4.25
4.29	Stage versus Failures	. . . . .	4.28
4.30	Environment Number versus Failures	. . . . .	4.28
4.31	Single Environment versus Failures	. . . . .	4.29
4.32	Combinations of Environments versus Failures	. . . . .	4.30
4.33	Source Number versus Failures	. . . . .	4.31
4.34	Single Source versus Failures	. . . . .	4.31
4.35	Combinations of Sources versus Failures	. . . . .	4.32
4.36	Frame Type versus Failures	. . . . .	4.33
4.37	Separator Type versus Failures	. . . . .	4.33
4.38	Sealant Type versus Failures	. . . . .	4.34
4.39	Seal Type versus Failures	. . . . .	4.34
4.40	Changeout Reasons versus Failures	. . . . .	4.36
4.41	Stage versus Service Life	. . . . .	4.37

4.42	Environment Number versus Service Life . . . . .	4.38
4.43	Single Environment Versus Service Life . . . . .	4.38
4.44	Combinations of Two Environments versus Service Life . . . . .	4.39
4.45	Combinations of Three Environments versus Service Life . . . . .	4.39
4.46	Combinations of Four or More Environments versus Service Life . . . . .	4.40
4.47	Number of Sources versus Service Life . . . . .	4.41
4.48	Single Source versus Service Life . . . . .	4.41
4.49	Combinations of Two Sources versus Service Life . . . . .	4.42
4.50	Combinations of Three or More Sources versus Service Life . . . . .	4.43
4.51	Frame Type versus Service Life . . . . .	4.44
4.52	Separator Type versus Service Life . . . . .	4.44
4.53	Sealant Type versus Service Life . . . . .	4.45
4.54	Seal Type versus Service Life . . . . .	4.45

## 1.0 INTRODUCTION

This report presents data on high efficiency particulate air (HEPA) filter applications, changeout reasons, and failure modes experienced at Department of Energy (DOE) sites from 1977 through 1979. Some reflection on experience, problem areas and development needs as expressed by personnel familiar with HEPA filter applications at those sites is also presented.

The use of HEPA filters in nuclear air cleaning systems has been commonplace for many years. Frequently supplemented by other methods such as roughing filters, baghouses, and demisters, HEPA filters have become the accepted method for removing fine particulates from air streams. The technology concerning use, application, and design of nuclear air cleaning systems has been the subject of two revisions of a handbook (Burchsted et al. 1970, 1976), as well as periodic nuclear air cleaning conferences held since 1952 and sponsored by the U.S. Department of Energy (DOE) and its predecessors, the Energy Research and Development Administration and the Atomic Energy Commission (Burchsted 1981).

The major components of a typical HEPA filter are shown in Figure 1.1. The filter media in widest current use is fiberglass paper. Prior to the late 1970's, asbestos fiber media was commonly used for acid environment HEPA filter applications. Since its identification as a carcinogen, use of asbestos in HEPA filters has been discontinued, and a synthetic fiber, Nomex®, in combination with fiberglass is becoming accepted for acid environment applications. The filter media is typically pleated over corrugated separators made from aluminum, plastic, or (formerly) asbestos. The use of aluminum separators coated with a vinyl epoxy copolymer has generally replaced asbestos separators in acid environment applications. In addition, at least one manufacturer is now marketing a separatorless HEPA filter. The media and separator package is sealed into a frame using a sealant, such as polyurethane foam, elastomeric adhesive, silicone, or glass packing. The frame is typically wood (plywood or

---

® Nomex is a registered trademark of DuPont.

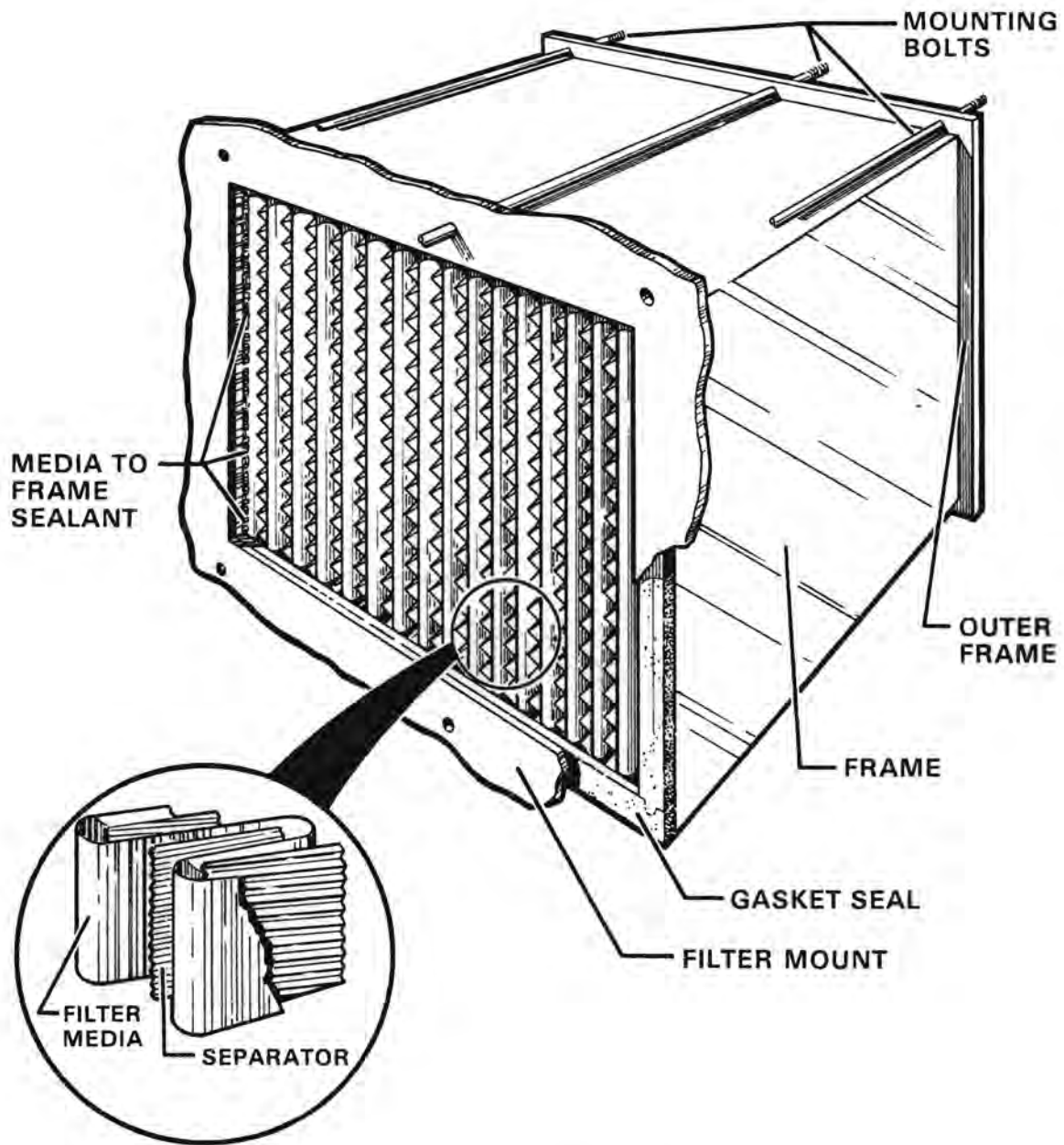


FIGURE 1.1. Typical HEPA Filter (sealing side view)

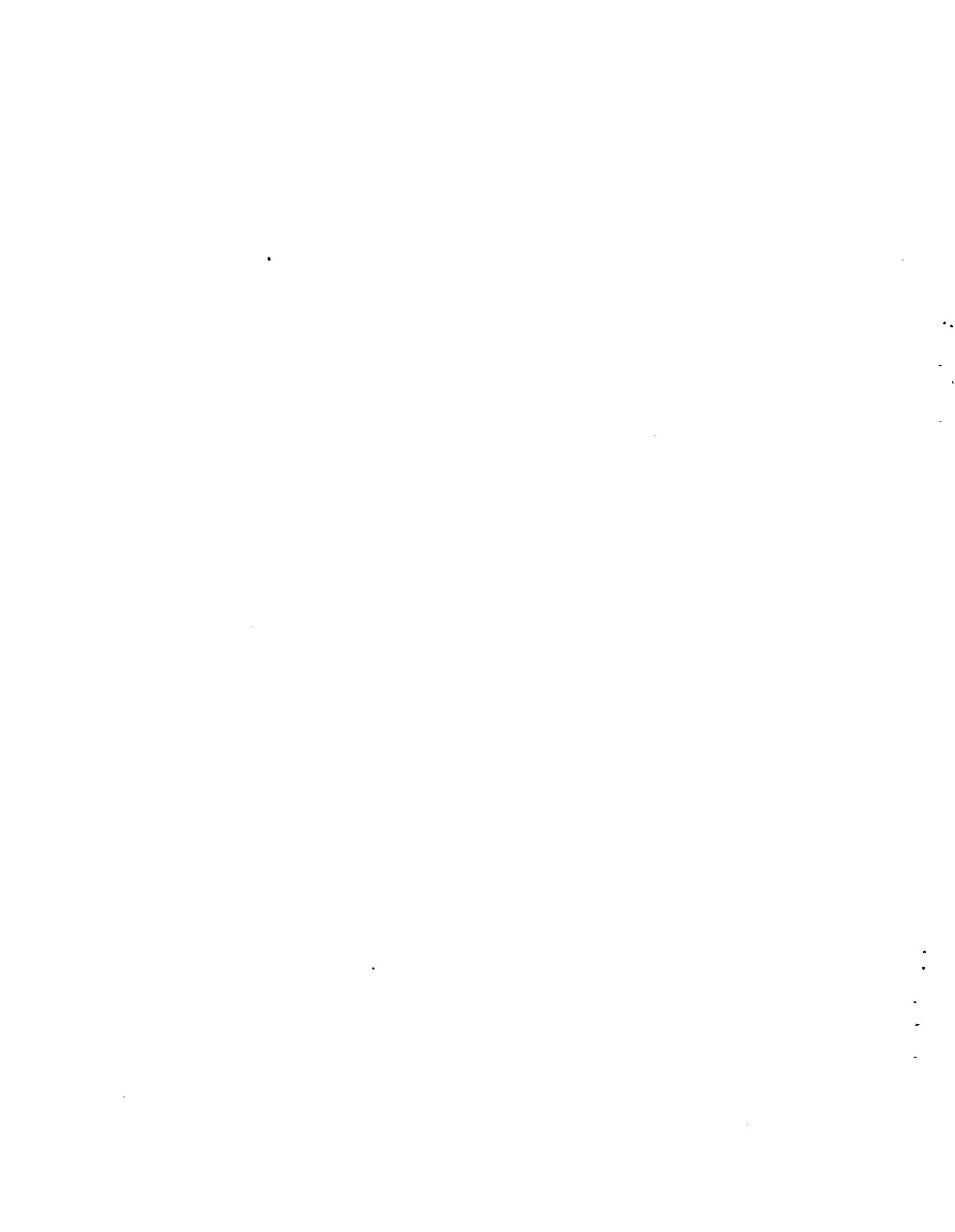
fiberboard), stainless steel, or chromized steel. A gasket or viscous fluid seal is used between the frame and filter mount housing.

HEPA filters may be changed out when evidence of particle penetration past the filter is found or when certain administrative guidelines are exceeded.

The most common method of identifying particle penetration is through the performance of a periodic particle penetration test, or leak test, using a dioctylphthalate (DOP) or similar aerosol. Other evidence of penetration can include detection of radiation downstream of a filter or the existence of an unusually low pressure drop across the filter. Particle penetration is not necessarily indicative of filter failure; it can also result from ventilation system perturbations or design deficiencies. Administrative reasons for filter changeout are preventive maintenance oriented; to replace the filter before it fails. These reasons may include the following:

1. high pressure drop ( $\Delta P$ ) across the filter, indicating filter plugging
2. radiation or radioactivity buildup on the filter which could impact personnel exposure during work on or near the filter (this also includes consideration of criticality limits for fissionable material)
3. suspected filter damage resulting from unusual events within the ventilation system (e.g., fire, explosion)
4. visual examination of filters indicating damage or degradation (e.g., disintegrating media, moisture damage)
5. preventive maintenance service life limit at which point filters are automatically replaced.

HEPA filters can fail in a number of modes. Rupture of the filter media itself is probably the most obvious. Others include degradation of the media to frame sealant, frame failure, faulty construction, and damage resulting from improper handling or installation. In addition, the filter frame to housing gasket or fluid seal can be damaged or improperly installed. These failure modes can occur individually or in any combination. Furthermore, the failure of one filter can impact the performance of an entire bank of multiple or dozens of filters. At some facilities accepted practice is to change out the entire bank of filters, even though only one filter may actually have failed.



## 2.0 METHOD

A questionnaire survey approach was selected as the method to gather HEPA filter experience data from a wide variety of DOE site applications. While extensive data were desired, it was recognized that a lengthy questionnaire could pose unreasonable demands upon recipients and a low rate of return might result. Consequently, considerable effort was made to keep the questionnaire concise. The questionnaire developed was given a trial distribution within PNL and was found to be a reasonable request for information. A copy of this questionnaire is included in Appendix A.

Questionnaires were distributed via DOE Operations offices to all DOE sites and contractors reporting 1979 airborne releases to the DOE Effluent Information System (EIS) Data Base. Data was requested for the period 1977 through 1979, inclusive. Questionnaire recipients were asked to categorize each effluent system into stages using the following definitions:

- Primary stage           - first HEPA filter stage of a multistage system
- Intermediate stage   - all HEPA filter stages between primary and final stages
- Final stage            - last HEPA filter stage before discharge (this stage included all single stage systems).

Information was then requested on HEPA filter application and experience within each stage, including source of air filtered, number of filters in each application, the filter environment exposure, number of filters changed out for various reasons, number of filters failed and their failure mode, and a description of the type of filter used. Table 2.1 indicates classifications used for each of these elements. Recipients were asked to combine or consolidate effluent streams having similar characteristics to the extent practicable. Multiple responses for source and exposure environments were therefore expected. In addition, total man-hours associated with filter changeouts and an estimated service life were requested. A final section of the questionnaire was devoted to subjective responses by recipients concerning experienced or perceived HEPA filter technology problem areas or development needs.

TABLE 2.1. HEPA Filter Survey Classification Codes

STAGE	FILTER TYPE	
	Frame	Separator
Primary: The first HEPA filter stage in a multiple stage HEPA filter system.	Wood Stainless Steel Chromized Steel	Separatorless Asbestos Aluminum Plastic
Secondary: All HEPA filter stages between the primary and final stages.		
Final: The last HEPA filter stage before effluent discharge, including single stage filtration systems.	Media to Frame Sealant Glass packing Silicone Polyurethane foam Elastomeric adhesive	Frame to Housing Seal Gasket Fluid

GAS STREAM SOURCE

General Building Ventilation  
(including reactor containment)  
Dissolver Offgas  
Incinerator  
Vessel Vent  
Laboratory Hood  
Process Hood  
Glove Box  
Hot Cell

CHANGEOUT REASONS

Leak Test Failure  
Other Evidence of Penetration  
High Pressure Drop ( $\Delta P$ )  
Radiation Buildup  
Suspected Damage  
Service Life Limit  
Visual Exam

EXPOSURE ENVIRONMENT

Solvent  
High Moisture  
High Dust  
Grease or Oil  
High Temperature  
Acid - HF  
Acid - HNO<sub>3</sub>  
Acid - Other  
No distinguishing characteristics

FAILURE MODES

Ruptured Media  
Sealant/Adhesive Failure  
Frame Damage  
Gasket or Seal Damage  
Filter Construction  
Handling or Installation Damage  
Unknown/Not Specified

Returned questionnaires were reviewed and data entered for analysis on the PNL Biometrics Computer System using the Minitab statistics package.



## 3.0 RESPONSE

### 3.1 QUESTIONNAIRE RESPONSES

A total 408 questionnaires were sent to the DOE Operations offices for subsequent forwarding to 35 DOE site contractors. Twenty-six contractors returned 327 questionnaires for an approximately 80% return rate. Of the returned questionnaires, 223 (55% of those distributed) contained data suitable for use in the study. The remaining 104 questionnaires returned were excluded from the study due to lack of HEPA filters in the system, lack of operation in 1977-1979, or lack of data. Several site representatives indicated that compiling data to complete the questionnaires was a difficult process because records were not kept in a readily retrievable form or specific records were not available. One contractor indicated that no data regarding filter change-out or failure occurrences were available. In some cases, data were estimated by site representatives based on partial records and discussions with personnel directly involved in HEPA filter maintenance. Other sites did maintain records well suited for questionnaire completion.

Usable data represented 24 DOE site contractors, 342 filter banks ranging from 1 to 790 filters each, and a total of 9154 filter applications within these banks.

### 3.2 SUBJECTIVE RESPONSES

The subjective response section of the questionnaire allowed respondents to summarize their experience, problems, or perceived development needs and opinions. Responses fell into the following five major categories with the number of sites making comments respectively indicated: no significant problems or comments (12), HEPA filter technology (7), HEPA filter design (4), personnel (3), and design or technology for related systems or components (4). A summary of these comments is provided below.

#### HEPA Filter Technology

- Improvement in acid/moisture-resistant filters was the most frequently indicated development need identified by four sites. Acid

and moisture resistances were specified in combination by two sites and independently by one site each.

- The need for a noncombustible HEPA filter for pyrophoric applications was identified by one site: Silicate glass was suggested as a possible media material.
- One site indicated that glass strip gaskets had not proved satisfactory for high temperature applications and that an improved high temperature gasket was desirable.
- The need for improved fluoride resistance was indicated by two sites. One site, a gaseous diffusion plant, identified specific problems with filtration of the uranium hexafluoride ( $UF_6$ ) hydrolysis products, including HF gas and particulate  $UO_2F_2$ . The site reported laboratory studies showing slight decreases in filter efficiency after exposure to 3.2 grams of  $UF_6$  with complete plugging after exposure to 34.7 grams. This site also indicated a study had shown filters that fell below 99.97% efficiency after exposure to 25 grams of HF (corresponding to hydrolysis of 100 grams  $UF_6$ ) and decreases to less than 68% efficiency after 41 grams HF exposure (equivalent to hydrolysis of 180 grams  $UF_6$ ).

The second site reported rapid disintegration of aluminum separators and wire faceguards following HF exposure.

#### HEPA Filter Design

- Three sites indicated concerns with radioactive waste disposal of HEPA filters attributable to filter configuration or design. Two areas for development were suggested: improved compactibility and development of a round shaped filter sized for direct packing in a 55-gallon Type 17-C drum.
- One site suggested development of a filter capable of using either fluid or gasket seals. Such a filter might be reversible, having a fluid seal on one side with a gasket surface on the other.

### Related Systems or Components

- Several sites reported experience related to prefiltering air. One site indicated the use of a roughing filter could extend HEPA service life by a factor of three. Another site indicated greatly prolonged HEPA filter life in glove box applications with the use of a filtered air supply. The need for better quality prefilters was noted by one site which was apparently experiencing collapse of 24 in. x 24 in. x 2 in. prefilters at a 0.5 in. pressure drop. One site indicated extensive clogging of filters in diesel smoke applications. This phenomenon has been discussed in the Nuclear Air Cleaning Handbook (Burchsted 1976).
- Undersized fans were a factor in periodic filter changeouts at one site. During ventilation system design an engineering tradeoff was made, which resulted in a smaller capacity blower. This shortened the effective HEPA filter service life by limiting filter usage to low pressure drops across the filters. Larger capacity fans would extend filter life by allowing their use to a higher pressure drop.
- The need for designs to address on-line filter testing was posed by one site where facility and process operation had to be shut down to allow filter testing.
- A gaseous diffusion plant indicated that an alternative to a fluoride-resistant HEPA filter might be the development of a fluoride trap to protect currently available filters by absorbing  $UF_6$  prior to extensive hydrolysis.
- Some standardization of filter types and sizes was suggested by one site.
- Problems with older filter housing systems, sealing surfaces, and hold-down methods had been experienced at one site; however, subsequent design improvements and the use of fluid seals had reduced the problems.

## Personnel

- Comments from three sites indicated handling and improper installation of filters by maintenance personnel was a recurring problem, especially with regard to inadequate or excessive clamping pressure. The use of wire mesh faceguards on filters had reduced some handling damage.
- One site indicated a continued need for personnel trained in filter handling and testing.

### 3.3 DATA OVERVIEW

The initial overview of HEPA filter experience at DOE sites for the years 1977 to 1979 showed that the primary reasons for filter changeout were a high pressure drop across the filter (indicative of filter plugging), leak test failure, and preventive maintenance service life limits. Changeouts for a high pressure drop accounted for approximately 60% of all changeouts and were four to five times more prevalent than leak test failures (15% of changeouts) and preventive maintenance service life limits (12% of changeouts). Most preventive maintenance changeouts occurred in systems identified as general building ventilation systems having no distinguishing environmental exposure characteristics, and unspecified filter component materials.

An overall filter failure fraction<sup>(a)</sup> of 0.12 (12% of all filter applications) was determined. The failure mode specified for over 60% of these failures was unknown, possibly indicating that many sites do not routinely determine what part of a filter fails, or that retrievable records of filter failures are not maintained. The next most frequent mode of failure was damage attributed to improper handling or installation, which accounted for approximately 20% of all failures. This appeared most common for filters having wood frames, glass packing sealants, plastic separators, and gasket seals.

Subjective responses indicated a need for improved moisture and acid resistant filters. The data compiled from the questionnaires appeared to

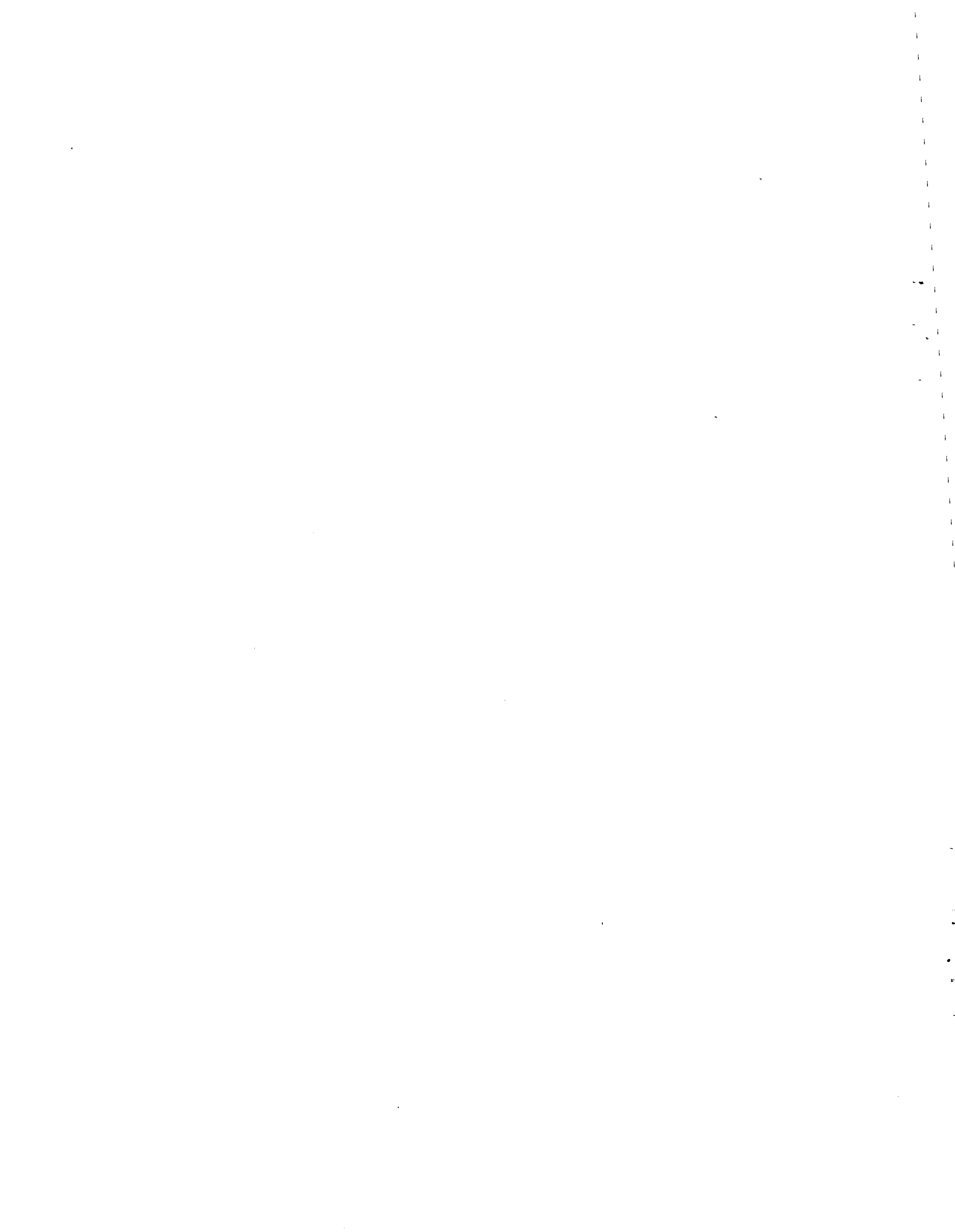
---

(a) See Section 4.0 for definition and explanation.

confirm that single environments of high moisture or HF acid exposure exhibited the highest changeout fractions<sup>(a)</sup> (3.99 and 3.67, respectively). Filter failure data appeared to indicate that HF acid applications had the highest failure fraction (2.17) and appeared attributable to media rupture. The high moisture environment had the second highest failure fraction (1.37); however, filter failure modes were not known.

---

(a) See Section 4.0 for definition and explanation.



## 4.0 RESULTS

Data from the returned questionnaires have been compiled and presented in Tables 4.1 through 4.54. In examining these tables, it should be noted that the Banks column represents a composite of all filter banks having similar characteristics within a single ventilation system, rather than an absolute number of banks (e.g., filters on five separate glove boxes exhausted through a single stack may have been composited into one bank of five filters with similar exposure characteristics, rather than treated as five banks of one filter each). The Filter Applications column represents the number of HEPA filter locations, or slots in a bank or system, rather than the total number of HEPA filters used (e.g., a bank of four filters would be considered four filter applications, even though, because of filter changeout, eight filters may have actually been used). Fractions given in the Banks and Filter Applications columns are columnar fractions calculated using the "All" row entry for the respective column as the common denominator. Fractions in other columns (Changeout, No Changeout, Failure, etc.) are row fractions normalized to the number of filter applications and calculated using the corresponding row entry in the Filter Applications column as the common denominator. It should be noted that a row fraction greater than unity does not necessarily imply all filters were, for example, changed out, but rather that some filters could have been changed out several times while others were not changed out at all. By examining the Changeout and No Changeout fractions together, one can estimate what portion of filter applications were actually affected.

Tables have been organized into four groupings (Sections 4.1 through 4.4). Applications Experience, Changeout Experience, Failure Experience and Service Life Experience using respectively, all data, data only from systems experiencing filter changeouts, and data only from systems experiencing filter failures. Within each grouping, tables identifying stage, environment, source, and filter component types (frame, separator, sealant, seal) with experiences are included.

### 4.1 APPLICATIONS EXPERIENCE

A summary of experience with regard to all HEPA filter applications, changeouts, filters not changed, and filter failures is provided in Tables 4.1

through 4.14. These tables show that for the 9154 filter applications in the study, 3870 (42%) were not changed in a three-year period (no changeout fraction of 0.42). The remaining 5274 (52%) filter applications are those in which changeouts occurred. A total of 6894 filters were changed out in those systems indicating that 1620 (18%) were changed out more than once. When normalized to all filter applications a changeout fraction of 0.75 was determined. In addition, there were a total of 1105 failures giving a calculated failure fraction of 0.12 (when normalized to all applications). This latter number can be expressed as a failure rate for all applications of 12% in three years.

In Table 4.1 it can be noted that most filters were either first or final stages with relatively few (8%) in intermediate stages. No readily distinguishable difference in changeout or failure fractions was apparent between first and final stages; however, intermediate stage fractions were significantly smaller. This came as a surprise, since it was anticipated that final stages might more closely approximate intermediate stages with regard to failure and changeout rates due to the existence of upstream HEPA filtration. This result may be explained in part from the fact that single stage filters were

TABLE 4.1. Stage versus Applications Experience(a)

<u>Stage</u>	<u>Banks</u>	<u>Filter Applications</u>	<u>Filter Changeouts</u>	<u>No Changeouts</u>	<u>Filter Failures</u>
First of Series	112 (0.33)	2105 (0.23)	1803 (0.86)	1092 (0.52)	283 (0.13)
Intermediate	10 (0.03)	749 (0.08)	59 (0.08)	722 (0.96)	21 (0.03)
Final of Series and all Single	220 (0.64)	6300 (0.69)	5032 (0.80)	2056 (0.33)	801 (0.13)
All Applications	342 (1.00)	9154 (1.00)	6894 (0.75)	3870 (0.42)	1105 (0.12)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

treated as final rather than first stage. Future studies should recognize this as possibly biasing results and consider combining single stage systems with first stage systems.

Most filters were exposed to single significant environments. As shown in Table 4.2, the single environment changeout, no changeout, and failure fractions very closely approximated the average for all applications. These single environments are further detailed in Table 4.3, which shows the largest number of filters and banks exposed to an environment having no distinguishing characteristics, again showing agreement with average changeout, no changeout, and failure fractions. Applications in high dust or acid [other than hydrogen fluoride (HF)] environments showed the lowest no changeout fraction, indicating changeouts were most widespread. However, these applications also experienced the lowest frequency of failure, probably indicating that filters are changed frequently enough to prevent failure. Filter changeout fractions were highest for HF acid, high dust, and high moisture applications. Failures appeared most common in HF acid applications with high moisture failures a relatively distant second in frequency. Applications experience for combinations of two,

TABLE 4.2. Environment Number versus Applications Experience<sup>(a)</sup>

<u>Number of Environments</u>	<u>Banks</u>	<u>Filter Applications</u>	<u>Filter Changeouts</u>	<u>No Changeouts</u>	<u>Filter Failures</u>
One	262 (0.77)	5470 (0.60)	4042 (0.74)	2447 (0.45)	620 (0.11)
Combinations of Two	43 (0.13)	1392 (0.15)	1608 (1.16)	40 (0.03)	334 (0.24)
Combinations of Three	14 (0.04)	246 (0.03)	232 (0.94)	67 (0.27)	2 (0.01)
Combinations of More than Three	23 (0.07)	2046 (0.22)	1012 (0.49)	1316 (0.64)	149 (0.07)
All Applications	342 (1.00)	9154 (1.00)	6894 (0.75)	3870 (0.42)	1105 (0.12)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.3. Single Environment versus Applications Experience<sup>(a)</sup>

<u>Environment</u>	<u>Banks</u>	<u>Filter Applications</u>	<u>Filter Changeouts</u>	<u>No Changeouts</u>	<u>Filter Failures</u>
Solvent	5 (0.02)	9 (<0.01)	4 (0.44)	5 (0.56)	-- --
High Moisture	50 (0.19)	192 (0.04)	327 (1.70)	94 (0.49)	48 (0.25)
High Dust	15 (0.06)	98 (0.02)	199 (2.03)	19 (0.19)	1 (0.01)
Grease/Oil	2 (0.01)	12 (<0.01)	6 (0.50)	6 (0.50)	-- --
High Temperature	2 (0.01)	12 (<1.01)	12 (1.00)	-- --	1 (0.08)
HF Acid	5 (0.02)	19 (<0.01)	44 (2.32)	7 (0.37)	26 (1.37)
Other Acid	10 (0.04)	121 (0.02)	114 (0.94)	13 (0.11)	12 (0.10)
No Distinguishing Characteristics	173 (0.66)	5007 (0.92)	3336 (0.67)	2303 (0.46)	532 (0.11)
All Single Environments	262 (1.00)	5470 (1.00)	4042 (0.74)	2447 (0.45)	620 (0.11)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

three and four or more environments are detailed in Tables 4.4 through 4.6. Caution should be exercised in drawing conclusions from these tables, due to possible synergistic effects of multiple environments and apparently significant fractions, which are calculated from only a few banks or applications responses.

The applications experience for air or gas stream sources is shown in Table 4.7 through 4.10. While of some value in describing filter application

TABLE 4.4. Combinations of Two Environments versus Applications Experience(a)

<u>Environment</u>	<u>Banks</u>	<u>Filter Applications</u>	<u>Filter Changeouts</u>	<u>No Changeouts</u>	<u>Filter Failures</u>
Solvent and Other Acids	1 (0.02)	14 (0.01)	2 (0.14)	12 (0.86)	-- --
High Moisture and High Dust	5 (0.12)	338 (0.24)	486 (1.44)	-- --	161 (0.48)
High Moisture and Grease/Oil	2 (0.05)	24 (0.02)	-- --	24 (1.00)	-- --
High Moisture and HNO <sub>3</sub> Acid	2 (0.05)	2 (<0.01)	2 (1.00)	-- --	2 (1.00)
High Dust and Other Acids	31 (0.72)	986 (0.71)	995 (1.01)	4 (<0.01)	171 (0.17)
High Dust and Grease/Oil	1 (0.02)	24 (0.02)	99 (4.13)	-- --	-- --
HNO <sub>3</sub> Acid and Other Acid	1 (0.02)	4 (<0.01)	24 (6.00)	-- --	-- --
All Combinations of Two Environments	43 (1.00)	1392 (1.00)	1608 (1.16)	40 (0.03)	334 (0.24)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.5. Combinations of Three Environments versus Applications Experience<sup>(a)</sup>

<u>Environment</u>	<u>Banks</u>	<u>Filter Applications</u>	<u>Filter Changeouts</u>	<u>No Changeouts</u>	<u>Filter Failures</u>
Solvent, HF, HNO <sub>3</sub> Acids	1 (0.07)	6 (0.02)	18 (3.00)	-- --	-- --
Solvent, HNO <sub>3</sub> , Other Acid	5 (0.36)	164 (0.67)	196 (1.20)	9 (0.05)	-- --
High Moisture, HNO <sub>3</sub> , Other Acid	1 (0.07)	8 (0.03)	5 (0.63)	3 (0.38)	-- --
High Dust, HNO <sub>3</sub> Other Acid	3 (0.21)	52 (0.21)	13 (0.25)	39 (0.75)	2 (0.04)
HF, HNO <sub>3</sub> , Other Acids	4 (0.29)	16 (0.07)	-- --	16 (1.00)	-- --
All Combinations of Three	14 (1.00)	246 (1.00)	232 (0.94)	67 (0.27)	2 (0.01)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.6. Combinations of More Than Three Environments versus Applications Experience<sup>(a)</sup>

<u>Environment</u>	<u>Banks</u>	<u>Filter Applications</u>	<u>Filter Changeouts</u>	<u>No Changeouts</u>	<u>Filter Failures</u>
Solvent, HF, HNO <sub>3</sub> Other Acids	3 (0.13)	57 (0.03)	20 (0.35)	37 (0.65)	-- --
Solvent, High Dust, HF, HNO <sub>3</sub> , Other Acid	6 (0.26)	78 (0.04)	105 (1.35)	31 (0.40)	-- --
Solvent, HF, HNO <sub>3</sub> , Other Acid, No Distinguishing Characteristics	1 (0.04)	400 (0.20)	301 (0.75)	-- --	-- --
High Moisture, High Dust, HF, HNO <sub>3</sub> , Other Acid	2 (0.09)	38 (0.02)	66 (1.74)	-- --	-- --
High Moisture, Grease/Oil, HF, HNO <sub>3</sub> , Other Acids	4 (0.17)	42 (0.02)	267 (6.36)	-- --	-- --
Solvent, High Dust, High Temperature, HNO <sub>3</sub> , Other Acids	6 (0.26)	1400 (0.068)	152 (0.11)	1248 (0.89)	147 (0.11)
High Moisture, High Dust, High Temperature, HF, HNO <sub>3</sub> , No Distinguishing Characteristics	1 (0.04)	31 (0.02)	101 (3.26)	-- --	2 (0.06)
All Combinations of More Than Three	23 (1.00)	2046 (1.00)	1012 (0.49)	1316 (0.64)	149 (0.07)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.7. Source Number versus Applications Experience<sup>(a)</sup>

<u>Number of Source</u>	<u>Banks</u>	<u>Filter Applications</u>	<u>Filter Changeouts</u>	<u>No Changeouts</u>	<u>Filter Failures</u>
Single Source	290 (0.85)	5212 (0.57)	4831 (0.93)	1911 (0.37)	790 (0.15)
Two Source Combinations	20 (0.06)	1080 (0.12)	512 (0.47)	599 (0.55)	32 (0.03)
Combinations of Three or More Sources	32 (0.09)	2862 (0.31)	1551 (0.54)	1360 (0.48)	283 (0.10)
All Applications	342 (1.00)	9154 (1.00)	6894 (0.75)	3870 (0.42)	1105 (0.12)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.8. Single Source versus Applications Experience(a)

<u>Source</u>	<u>Banks</u>	<u>Filter Applications</u>	<u>Filter Changeouts</u>	<u>No Changeouts</u>	<u>Filter Failures</u>
General Building Ventilation	113 (0.39)	3485 (0.67)	2864 (0.82)	900 (0.26)	623 (0.18)
Incinerator	1 (<0.01)	8 (<0.01)	8 (1.00)	-- --	-- --
Vessel Vent	58 (0.20)	274 (0.05)	364 (1.33)	163 (0.59)	59 (0.22)
Laboratory Hood	44 (0.15)	883 (0.17)	548 (0.62)	620 (0.70)	39 (0.04)
Process Hood	32 (0.11)	272 (0.05)	543 (2.00)	98 (0.36)	17 (0.06)
Glove Box	39 (0.13)	214 (0.04)	504 (2.36)	54 (0.25)	52 (0.24)
Hot Cell	3 (0.01)	76 (0.01)	-- --	76 (1.00)	-- --
All Single Sources	290 (1.00)	5212 (1.00)	4831 (0.93)	1911 (0.37)	790 (0.15)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.9. Two Source Combinations versus Applications Experience<sup>(a)</sup>

Source	Banks	Filter Applications	Filter Changeouts	No Changeouts	Filter Failures
General Building and Vessel Vent	1 (0.05)	6 (0.01)	6 (1.00)	-- --	-- --
General Building and Laboratory Hood	6 (0.30)	45 (0.04)	27 (0.60)	27 (0.60)	-- --
General Building Glove Box	4 (0.20)	42 (0.04)	12 (0.29)	30 (0.71)	-- --
General Building Hot Cell	1 (0.05)	79 (0.07)	32 (0.41)	47 (0.59)	-- --
Laboratory and Process Hood	1 (0.05)	11 (0.01)	33 (3.00)	-- --	-- --
Laboratory Hood and Glove Box	5 (0.25)	865 (0.80)	378 (0.44)	487 (0.56)	8 (0.01)
Process Hood and Incinerator	1 (0.05)	6 (0.01)	-- --	6 (1.00)	-- --
Process Hood and Glove Box	1 (0.05)	26 (0.02)	24 (0.92)	2 (0.08)	24 (0.92)
All Two Source Combinations	20 (1.00)	1080 (1.00)	512 (0.47)	599 (0.55)	32 (0.03)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.10. Three Or More Source Combinations versus Applications Experience<sup>(a)</sup>

Source	Banks	Filter Applications	Filter Changeouts	No Changeouts	Filter Failures
General Building, Vessel Vent and Laboratory Hood	1 (0.03)	80 (0.03)	60 (0.75)	30 (0.38)	-- --
General Building, Vessel Vent and Glove Box	3 (0.09)	69 (0.02)	167 (2.42)	-- --	2 (0.03)
General Building, Laboratory and Process Hood	1 (0.03)	34 (0.01)	68 (2.00)	-- --	-- --
General Building, Process Hood and Glove Box	6 (0.19)	1400 (0.49)	152 (0.11)	1248 (0.89)	147 (0.11)
Laboratory Hood, Process Hood, Glove Box	18 (0.56)	850 (0.30)	777 (0.91)	79 (0.09)	134 (0.16)
General Building, Vessel Vent, Process Hood, Glove Box	1 (0.03)	400 (0.14)	301 (0.75)	-- --	-- --
General Building, Vessel Vent, Laboratory Hood, Glove Box	1 (0.03)	9 (<0.01)	6 (0.67)	3 (0.33)	-- --
Dissolver Off Gas, Laboratory Hood, Process Hood, Glove Box	1 (0.03)	20 (0.01)	6 (0.30)	3 (0.15)	-- --
All Combinations of Three or More Sources	32 (1.00)	2862 (1.00)	1551 (0.54)	1360 (0.48)	283 (0.10)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

at DOE sites, these tables were not considered as significant to determining reasons for changeout or failure as were the environment tables, which more clearly define factors pertinent to filter experience.

Tables 4.11 through 4.14 summarize applications experience based on the type of material used in various filter components. Table 4.11 indicates wood frames are the most widely used and are associated with a majority of systems experiencing failure. The no change fractions showed little difference for various frame types, indicating that the likelihood of changeout in any application was approximately equal.

Table 4.12 shows aluminum and plastic separators in the most frequent application, with aluminium also having the highest frequency of changeout. Of specific separator types, plastic appeared most associated with failures, although other types of separators (not specified) also showed a failure correlation.

TABLE 4.11. Frame Type Versus Applications Experience<sup>(a)</sup>

<u>Frame Type</u>	<u>Banks</u>	<u>Filter Applications</u>	<u>Filter Changeouts</u>	<u>No Changeouts</u>	<u>Filter Failures</u>
Wood	175 (0.51)	4459 (0.49)	3549 (0.80)	1861 (0.42)	579 (0.13)
Stainless Steel	6 (0.02)	497 (0.05)	300 (0.60)	197 (0.40)	1 (<0.01)
Chromized Steel	22 (0.06)	1195 (0.13)	1203 (1.01)	491 (0.41)	8 (0.01)
Not Specified	139 (0.41)	3003 (0.33)	1842 (0.61)	1321 (0.44)	517 (0.17)
All Applications	342 (1.00)	9154 (1.00)	6894 (0.75)	3870 (0.42)	1105 (0.12)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.12. Separator Type Versus Applications Experience<sup>(a)</sup>

<u>Separator</u>	<u>Banks</u>	<u>Filter Applications</u>	<u>Filter Changeouts</u>	<u>No Changeouts</u>	<u>Filter Failures</u>
Separatorless	17 (0.05)	316 (0.04)	107 (0.34)	211 (0.67)	10 (0.03)
Asbestos	22 (0.06)	73 (0.01)	54 (0.74)	33 (0.45)	3 (0.04)
Aluminum	113 (0.33)	3415 (0.37)	3653 (1.07)	1057 (0.31)	87 (0.03)
Plastic	47 (0.14)	2513 (0.28)	1240 (0.49)	1292 (0.51)	331 (0.13)
Other ("Nonmetallic")	11 (0.03)	396 (0.04)	373 (0.94)	54 (0.14)	160 (0.40)
Not Specified	132 (0.39)	2441 (0.27)	1467 (0.60)	1223 (0.50)	514 (0.21)
All	342 (1.00)	9154 (1.00)	6894 (0.75)	3870 (0.42)	1105 (0.12)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

In Table 4.13, silicone sealant showed a relatively small percentage of applications but a high degree of changeout (high changeout fraction and low no change fraction). Silicone sealant also showed a relatively high filter failure fraction. Differences between glass packing, polyurethane foam, and elastomeric adhesives were much smaller by comparison. Finally, Table 4.13 shows gasket seals used more widely than fluid seals. Changeouts and failures appeared more common in systems having fluid seals rather than gaskets. This was a surprise since the questionnaire subjective responses and verbal comments from site personnel indicated fluid seals had reduced sealing problems.

TABLE 4.13. Sealant Type Versus Applications Experience<sup>(a)</sup>

<u>Sealant</u>	<u>Banks</u>	<u>Filter Applications</u>	<u>Filter Changeouts</u>	<u>No Changeouts</u>	<u>Filter Failures</u>
Glass Packing	40 (0.12)	2398 (0.26)	1159 (0.48)	1253 (0.52)	315 (0.13)
Silicone	14 (0.04)	426 (0.05)	441 (1.04)	21 (0.05)	172 (0.40)
Polyurethane Foam	88 (0.26)	2280 (0.25)	1647 (0.72)	881 (0.39)	56 (0.02)
Elastomeric Adhesive	16 (0.05)	553 (0.06)	310 (0.56)	249 (0.45)	3 (0.01)
Not Glass, (specific type not specified)	48 (0.14)	999 (0.11)	1857 (1.86)	199 (0.20)	43 (0.04)
Not Specified	136 (0.40)	2498 (0.27)	1480 (0.59)	1267 (0.51)	516 (0.21)
All Applications	342 (1.00)	9154 (1.00)	6894 (0.75)	3870 (0.42)	1105 (0.12)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.14. Seal Type Versus Applications Experience<sup>(a)</sup>

<u>Seal</u>	<u>Banks</u>	<u>Filter Applications</u>	<u>Filter Changeouts</u>	<u>No Changeouts</u>	<u>Filter Failures</u>
Gasket	173 (0.51)	3920 (0.43)	4248 (1.08)	936 (0.24)	422 (0.11)
Fluid	16 (0.05)	151 (0.02)	326 (2.16)	13 (0.09)	14 (0.09)
Not Specified	153 (0.45)	5083 (0.55)	2320 (0.46)	2921 (0.57)	669 (0.13)
All Applications	342 (1.00)	9154 (1.00)	6894 (0.75)	3870 (0.42)	1105 (0.12)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

#### 4.2 CHANGEOUT EXPERIENCE

Reasons for filter changeout are listed in Tables 4.15 through 4.28. The data contained in these tables are the subset of data for only those filter banks and applications in which changeouts were experienced. Hence, the numbers listed in the banks and filter applications columns of Tables 4.15 through 4.28 are less than those for the applications experience data of Tables 4.1 through 4.14. Calculated fractions are normalized to the changeout subset of filter applications rather than to all applications. Not unexpectedly, the largest majority of filter changeouts were attributed to a high pressure drop across the filter, indicative of filter plugging. For high pressure drops, an average changeout fraction of 0.60 was determined based on all filters in banks experiencing changeouts. This was four to five times larger than the next most prevalent causes of filter changeout, which were leak test failure (changeout fraction of 0.14) and preventive maintenance service life (changeout fraction of 0.12). Two exceptions to the high pressure drop cause for changeout were noted. In Table 4.26, separatorless filters and those with separators of unspecified types appeared to be changed out for leak test failure with frequencies comparable to, or greater than changeouts for a high pressure drop.

TABLE 4.15. Stage Versus Changeouts(a)

<u>Stage</u>	<u>Banks</u>	<u>Filter Applications</u>	<u>Total Changes</u>	<u>Leak Test</u>	<u>Other Penet.</u>	<u>High ΔP</u>	<u>Radiation Buildup</u>	<u>Suspect Damage</u>	<u>Service Life</u>	<u>Visual</u>
First of Series	68 (0.33)	1699 (0.24)	1803 (1.06)	210 (0.12)	-- --	1219 (0.72)	204 (0.12)	48 (0.03)	112 (0.07)	10 (0.01)
Intermediate	4 (0.02)	160 (0.02)	59 (0.37)	8 (0.05)	-- --	50 (0.31)	-- --	-- --	1 (0.01)	-- --
Final of Series and all single	135 (0.65)	5346 (0.74)	5032 (0.94)	802 (0.15)	15 (<0.01)	3064 (0.57)	52 (0.01)	328 (0.06)	758 (0.14)	13 (<0.01)
All Changeouts	207 (1.00)	7205 (1.00)	6894 (0.96)	1020 (0.14)	15 (<0.01)	4333 (0.60)	256 (0.04)	376 (0.05)	871 (0.12)	23 (<0.01)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.16. Environment Number versus Changeouts(a)

<u>Environment</u>	<u>Banks</u>	<u>Filter Applications</u>	<u>Total Changes</u>	<u>Leak Test</u>	<u>Other Penet.</u>	<u>High ΔP</u>	<u>Radiation Buildup</u>	<u>Suspect Damage</u>	<u>Service Life</u>	<u>Visual</u>
Single	142 (0.69)	4190 (0.58)	4042 (0.96)	623 (0.15)	14 ( 0.01)	2059 (0.49)	192 (0.05)	376 (0.09)	766 (0.18)	12 ( 0.01)
Combination of Two	41 (0.20)	1368 (0.19)	1608 (1.18)	336 (0.25)	1 ( 0.01)	1225 (0.90)	36 (0.03)	-- --	9 (0.01)	1 ( 0.01)
Combination of Three	8 (0.04)	191 (0.03)	232 (1.22)	-- --	-- --	207 (1.08)	5 (0.03)	-- --	20 (0.10)	-- --
Combination of Four or more	16 (0.08)	1456 (0.20)	1012 (0.70)	61 (0.04)	-- --	842 (0.58)	23 (0.02)	-- --	76 (0.05)	10 (0.01)
All Changeouts	207 (1.00)	7205 (1.00)	6894 (0.96)	1020 (0.14)	15 ( 0.01)	4333 (0.60)	256 (0.04)	376 (0.05)	871 (0.12)	23 ( 0.01)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.17. Single Environment versus Changeouts(a)

Environment	Banks	Filter Applications	Total Changes	Leak Test	Other Penet.	High $\Delta P$	Radiation Buildup	Suspect Damage	Service Life	Visual
Solvent	4 (0.03)	5 ( $<0.01$ )	4 (0.80)	-- --	-- --	4 (0.80)	-- --	-- --	-- --	-- --
High Moisture	28 (0.20)	82 (0.02)	327 (3.99)	60 (0.73)	-- --	134 (1.63)	107 (1.30)	1 (0.01)	25 (0.30)	-- --
High Dust	11 (0.08)	85 (0.02)	199 (2.34)	6 (0.07)	-- --	129 (1.52)	18 (0.21)	-- --	46 (0.54)	-- --
Grease/Oil	1 (0.01)	6 ( $<0.01$ )	6 (1.00)	-- --	-- --	6 (1.00)	-- --	-- --	-- --	-- --
High Temperature	2 (0.01)	12 ( $<1.01$ )	12 (1.00)	1 (0.08)	-- --	-- --	-- --	11 (0.92)	-- --	-- --
HF Acid	3 (0.02)	12 ( $<0.01$ )	44 (3.67)	26 (2.17)	-- --	18 (1.50)	-- --	-- --	-- --	-- --
HNO <sub>3</sub> Acid	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --
Other Acid	7 (0.05)	108 (0.03)	114 (1.06)	6 (0.06)	-- --	108 (1.00)	7 (0.06)	-- --	-- --	-- --
No Distinguishing Characteristics	86 (0.61)	3880 (0.93)	3336 (0.86)	524 (0.14)	14 ( $<0.01$ )	1660 (0.43)	67 (0.02)	364 (0.09)	695 (0.18)	12 ( $<0.01$ )
All Single Environment	142 (1.00)	4190 (1.00)	4042 (0.96)	623 (0.15)	14 ( $<0.01$ )	2059 (0.49)	192 (0.05)	376 (0.09)	766 (0.18)	12 ( $<0.01$ )

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.18. Combinations of Two Environments versus Changeouts(a)

Environment Combination	Banks	Filter Applications	Total Changes	Leak Test	Other Penet.	High $\Delta P$	Radiation Buildup	Suspect Damage	Service Life	Visual
Solvent and Other Acids	1 (0.02)	14 (0.01)	2 (0.14)	1 (0.07)	-- --	1 (0.07)	-- --	-- --	-- --	-- --
High Moisture and High Dust	5 (0.12)	338 (0.25)	486 (1.44)	320 (0.95)	-- --	156 (0.46)	-- --	-- --	9 (0.03)	1 (<0.01)
High Moisture and HF Acid	2 (0.05)	2 (<0.01)	2 (1.00)	2 (1.00)	-- --	-- --	-- --	-- --	-- --	-- --
High Dust and Other Acids	31 (0.76)	986 (0.72)	995 (1.01)	13 (0.01)	1 (<0.01)	981 (0.99)	-- --	-- --	-- --	-- --
High Dust and Grease/Oil	1 (0.02)	24 (0.02)	99 (4.13)	-- --	-- --	63 (2.63)	36 (1.50)	-- --	-- --	-- --
HNO <sub>3</sub> Acid and Other Acid	1 (0.02)	4 (<0.01)	24 (6.00)	-- --	-- --	24 (6.00)	-- --	-- --	-- --	-- --
All Two Environment Combinations	41 (1.00)	1368 (1.00)	1608 (1.18)	336 (0.25)	1 (<0.01)	1225 (0.90)	36 (0.03)	-- --	9 (<0.01)	1 (<0.01)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

**TABLE 4.19. Combinations of Three Environments versus Changeouts(a)**

<u>Environment Combination</u>	<u>Banks</u>	<u>Filter Applications</u>	<u>Total Changes</u>	<u>Leak Test</u>	<u>Other Penet.</u>	<u>High <math>\Delta P</math></u>	<u>Radiation Buildup</u>	<u>Suspect Damage</u>	<u>Service Life</u>	<u>Visual</u>
Solvent, HF, HNO <sub>3</sub> Acids	1 (0.13)	6 (0.03)	18 (3.00)	-- --	-- --	18 (3.00)	-- --	-- --	-- --	-- --
Solvent, HNO <sub>3</sub> , and Other Acids	5 (0.63)	164 (0.86)	196 (1.20)	-- --	-- --	176 (1.07)	5 (0.03)	-- --	15 (0.09)	-- --
High Moisture, HNO <sub>3</sub> and Other Acids	1 (0.13)	8 (0.04)	5 (0.63)	-- --	-- --	-- --	-- --	-- --	5 (0.63)	-- --
High Dust, HNO <sub>3</sub> and Other Acids	1 (0.13)	13 (0.07)	13 (1.00)	-- --	-- --	13 (1.00)	-- --	-- --	-- --	-- --
All Combinations of Three Environ	8 (1.00)	191 (1.00)	232 (1.21)	-- --	-- --	207 (1.08)	5 (0.03)	-- --	20 (0.10)	-- ment

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.20. Combinations of Four or More Environments versus Changeouts(a)

Environment Combination	Banks	Filter Applications	Total Changes	Leak Test	Other Penet.	High ΔP	Radiation Buildup	Suspect Damage	Service Life	Visual
Solvent, HF, HNO <sub>3</sub> and Other Acids	1 (0.06)	38 (0.03)	20 (0.53)	-- --	-- --	-- --	20 (0.53)	-- --	-- --	-- --
Solvent, High Dust, HF, HNO <sub>3</sub> and Other Acids	3 (0.19)	63 (0.04)	105 (1.67)	-- --	-- --	26 (0.41)	3 (0.05)	-- --	76 (1.21)	-- --
Solvent, HF, HNO <sub>3</sub> and Other Acids, No Distinguishing Characteristics	1 (0.06)	400 (0.27)	301 (0.75)	1 (<0.01)	-- --	300 (0.75)	-- --	-- --	-- --	-- --
High Moisture, High Dust, HF, HNO <sub>3</sub> , Other Acids	2 (0.13)	38 (0.03)	66 (1.74)	-- --	-- --	66 (1.74)	-- --	-- --	-- --	-- --
High Moisture, Grease/Oil, HF, HNO <sub>3</sub> , Other Acids	4 (0.25)	42 (0.03)	267 (6.36)	-- --	-- --	267 (6.36)	-- --	-- --	-- --	-- --
Solvent, High Dust, High Temperature, HNO <sub>3</sub> and Other Acid	4 (0.25)	844 (0.58)	152 (0.18)	58 (0.07)	-- --	84 (0.10)	-- --	-- --	-- --	10 (0.01)
High Moisture, High Dust, High Temperature, HF, HNO <sub>3</sub> , Other Acids, No Distinguishing Characteristics	1 (0.06)	31 (0.02)	101 (3.26)	2 (0.06)	-- --	99 (3.19)	-- --	-- --	-- --	-- --
All Combinations of Four or More Environments	16 (1.00)	1456 (1.00)	1012 (0.70)	61 (0.04)	-- --	842 (0.58)	23 (0.02)	-- --	76 (0.05)	10 (0.01)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.21. Source Number versus Changeouts(a)

Number of Sources	Banks	Filter Applications	Total Changes	Leak Test	Other Penet.	High ΔP	Radiation Buildup	Suspect Damage	Service Life	Visual
One	170 (0.82)	3984 (0.55)	4831 (1.21)	921 (0.23)	15 (<0.01)	2449 (0.61)	186 (0.05)	376 (0.09)	871 (0.22)	13 (<0.01)
Two	10 (0.05)	990 (0.14)	512 (0.52)	32 (0.03)	-- --	410 (0.41)	70 (0.07)	-- --	-- --	-- --
Three or More	27 (0.13)	2231 (0.31)	1551 (0.70)	67 (0.03)	-- --	1474 (0.66)	-- --	-- --	-- --	10 (<0.01)
All Changeouts	207 (1.00)	7205 (1.00)	6894 (0.96)	1020 (0.14)	15 (<0.01)	4333 (0.60)	256 (0.04)	376 (0.05)	871 (0.12)	23 (<0.01)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.22. Single Source versus Changeouts(a)

Source	Banks	Filter Applications	Total Changes	Leak Test	Other Penet.	High ΔP	Radiation Buildup	Suspect Damage	Service Life	Visual
General Building Ventilation	71 (0.42)	2862 (0.72)	2864 (1.00)	752 (0.26)	-- --	1129 (0.39)	4 (<0.01)	373 (0.13)	593 (0.21)	13 (<0.01)
Incinerator	1 (0.01)	8 (<0.01)	8 (1.00)	-- --	-- --	8 (1.00)	-- --	-- --	-- --	-- --
Vessel Vent	34 (0.20)	110 (0.03)	364 (3.31)	71 (0.65)	-- --	173 (1.57)	111 (1.01)	2 (0.02)	7 (0.06)	-- --
Laboratory Hood	19 (0.11)	612 (0.15)	548 (0.90)	41 (0.07)	-- --	480 (0.78)	14 (0.02)	-- --	15 (0.02)	-- --
Process Hood	19 (0.11)	212 (0.05)	543 (2.56)	15 (0.07)	-- --	339 (1.60)	57 (0.27)	1 (<0.01)	131 (0.62)	-- --
Glove Box	26 (0.15)	180 (0.05)	504 (2.80)	44 (0.24)	15 (0.08)	320 (1.78)	-- --	-- --	125 (0.69)	-- --
All Single Sources	170 (1.00)	3984 (1.00)	4831 (1.21)	921 (0.23)	15 (<0.01)	2449 (0.61)	186 (0.05)	376 (0.09)	871 (0.22)	13 (<0.01)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.23. Combination of Two Sources versus Changeouts (a)

Source Combination	Banks	Filter Applications	Total Changes	Leak Test	Other Penet.	High ΔP	Radiation Buildup	Suspect Damage	Service Life	Visual
General Building Ventilation, and Vessel Vent System	1 (0.10)	6 (0.01)	6 (1.00)	-- --	-- --	6 (1.00)	-- --	-- --	-- --	-- --
General Building Vent and Laboratory Hood	2 (0.20)	18 (0.02)	27 (1.50)	-- --	-- --	27 (1.50)	-- --	-- --	-- --	-- --
General Building Vent and Glove Box	1 (0.10)	12 (0.01)	12 (1.00)	-- --	-- --	12 (1.00)	-- --	-- --	-- --	-- --
General Building Vent Hot Cell	1 (0.10)	79 (0.08)	32 (0.47)	-- --	-- --	32 (0.47)	-- --	-- --	-- --	-- --
Laboratory and Process Hoods	1 (0.10)	11 (0.01)	33 (3.00)	-- --	-- --	33 (3.00)	-- --	-- --	-- --	-- --
Laboratory and Glove Box	3 (0.30)	838 (0.85)	378 (0.45)	8 (0.01)	-- --	300 (0.36)	70 (0.08)	-- --	-- --	-- --
Process Hood and Glove Box	1 (0.10)	26 (0.03)	24 (0.92)	24 (0.92)	-- --	-- --	-- --	-- --	-- --	-- --
All Two Source Combinations	10 (1.00)	990 (1.00)	512 (0.52)	32 (0.03)	-- --	410 (0.41)	70 (0.07)	-- --	-- --	-- --

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.24. Combinations of Three or More Sources versus Changeouts(a)

Source Combination	Banks	Filter Applications	Total Changes	Leak Test	Other Penet.	High ΔP	Radiation Buildup	Suspect Damage	Service Life	Visual
General Building Vent, Vessel Vent, Laboratory Hood	1 (0.04)	80 (0.04)	60 (0.75)	-- --	-- --	60 (0.75)	-- --	-- --	-- --	-- --
General Building Vent, Vessel Vent, Glove Box	3 (0.11)	69 (0.03)	167 (2.42)	2 (0.03)	-- --	165 (2.39)	-- --	-- --	-- --	-- --
General Building Vent, Laboratory Hood, Process Hood	1 (0.04)	34 (0.02)	68 (2.00)	-- --	-- --	68 (2.00)	-- --	-- --	-- --	-- --
General Building Vent, Process Hood, Glove Box	4 (0.15)	844 (0.38)	152 (0.18)	58 (0.07)	-- --	84 (0.10)	-- --	-- --	-- --	10 (0.01)
Laboratory Hoods, Process Hoods, Glove Box	15 (0.55)	775 (0.35)	777 (1.00)	6 (0.01)	-- --	771 (0.99)	-- --	-- --	-- --	-- --
General Building Vent, Vessel Vent, Process Hoods, Glove Box	1 (0.04)	400 (0.18)	301 (0.75)	1 ( $<0.01$ )	-- --	300 (0.75)	-- --	-- --	-- --	-- --
General Building Vent, Laboratory Hood, Glove Box, Vessel Vent	1 (0.04)	9 ( $<0.01$ )	6 (0.6)	-- --	-- --	6 (0.67)	-- --	-- --	-- --	-- --
Dissolver Off gas Laboratory Hood, Process Hood, Glove Box	1 (0.04)	20 (0.01)	20 (1.00)	-- --	-- --	20 (1.00)	-- --	-- --	-- --	-- --
All Combination of Three or More Sources	27 (1.00)	2231 (1.00)	1551 (0.70)	67 (0.03)	-- --	1474 (0.66)	-- --	-- --	-- --	10 ( $<0.01$ )

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

**TABLE 4.25. Frame Type versus Changeouts (a)**

Frame	Banks	Filter Applications	Total Changes	Leak Test	Other Penet.	High ΔP	Radiation Buildup	Suspect Damage	Service Life	Visual
Wood	117 (0.57)	3455 (0.48)	3549 (1.03)	486 (0.14)	15 (<0.01)	2382 (0.69)	78 (0.02)	287 (0.08)	279 (0.08)	22 (0.01)
Stainless Steel	5 (0.02)	492 (0.07)	300 (0.61)	1 (<0.01)	--	288 (0.58)	--	11 (0.02)	--	--
Chromized Steel	18 (0.09)	1174 (0.16)	1203 (1.02)	8 (0.01)	--	993 (0.85)	58 (0.05)	--	144 (0.12)	--
Not Specified	67 (0.32)	2084 (0.29)	1842 (0.88)	525 (0.25)	--	670 (0.32)	120 (0.06)	78 (0.04)	448 (0.22)	1 (<0.01)
All Changeouts	207 (1.00)	7205 (1.00)	6894 (0.96)	1020 (0.14)	15 (<0.01)	4333 (0.60)	256 (0.04)	376 (0.05)	871 (0.12)	23 (<0.01)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

4.24

**TABLE 4.26. Separator Type versus Changeouts (a)**

Separator	Banks	Filter Applications	Total Changes	Leak Test	Other Penet.	High ΔP	Radiation Buildup	Suspect Damage	Service Life	Visual
Separatorless	11 (0.05)	217 (0.03)	107 (0.49)	33 (0.15)	--	38 (0.18)	20 (0.09)	12 (0.06)	3 (0.01)	1 (<0.01)
Asbestos	15 (0.07)	62 (0.01)	54 (0.87)	4 (0.06)	--	50 (0.81)	--	--	--	--
Aluminum	71 (0.34)	3077 (0.43)	3653 (1.187)	62 (0.02)	14 (<0.01)	2745 (0.89)	116 (0.04)	286 (0.09)	418 (0.14)	12 (<0.01)
Plastic	42 (0.20)	1917 (0.27)	1240 (0.65)	77 (0.04)	1 (<0.01)	1152 (0.60)	--	--	--	10 (<0.01)
Other ("Nonmetallic")	5 (0.02)	342 (0.05)	373 (1.09)	320 (0.94)	--	51 (0.15)	--	--	2 (<0.01)	--
Not Specified	63 (0.30)	1590 (0.22)	1467 (0.92)	524 (0.33)	--	297 (0.19)	120 (0.08)	78 (0.05)	448 (0.28)	--
All Changeouts	207 (1.00)	7205 (1.00)	6894 (0.96)	1020 (0.14)	15 (<0.01)	4333 (0.60)	256 (0.04)	376 (0.05)	871 (0.12)	23 (<0.01)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.27. Sealant Type versus Changeouts(a)

Sealant	Banks	Filter Applications	Total Changes	Leak Test	Other Penet.	High ΔP	Radiation Buildup	Suspect Damage	Service Life	Visual
Glass Packing	37 (0.18)	1841 (0.26)	1159 (0.63)	73 (0.04)	-- --	1065 (0.58)	-- --	11 (0.01)	-- --	10 (0.01)
Silicone	11 (0.05)	405 (0.06)	441 (1.09)	323 (0.80)	1 (<0.01)	111 (0.27)	-- --	-- --	5 (0.01)	1 (<0.01)
Polyurethane Foam	42 (0.20)	1990 (0.28)	1647 (0.83)	69 (0.04)	-- --	1194 (0.60)	70 (0.04)	286 (0.14)	16 (0.01)	12 (0.01)
Elastomeric Adhesive	11 (0.05)	518 (0.07)	310 (0.60)	4 (0.01)	-- --	306 (0.59)	-- --	-- --	-- --	-- --
Not Glass but specific sealant not specified	42 (0.20)	848 (0.12)	1857 (2.19)	27 (0.03)	14 (0.02)	1347 (1.59)	66 (0.08)	1 (<0.01)	402 (0.47)	-- --
Not Specified	64 (0.31)	1603 (0.22)	1480 (0.92)	524 (0.33)	-- --	310 (0.19)	120 (0.07)	78 (0.05)	448 (0.28)	-- --
All Changeouts	207 (1.00)	7205 (1.00)	6894 (0.96)	1020 (0.14)	15 (<0.01)	4333 (0.60)	256 (0.04)	376 (0.05)	871 (0.12)	23 (<0.01)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.28. Seal Type versus Changeouts(a)

Frame to Housing Seal	Banks	Filter Applications	Total Changes	Leak Test	Other Penet.	High ΔP	Radiation Buildup	Suspect Damage	Service Life	Visual
Gasket	115 (0.56)	3388 (0.47)	4248 (1.25)	419 (0.12)	15 (<0.01)	3067 (0.91)	27 (0.01)	298 (0.09)	409 (0.12)	13 (<0.01)
Fluid	14 (0.07)	149 (0.02)	326 (2.19)	10 (0.07)	-- --	243 (1.63)	59 (0.40)	-- --	14 (0.09)	-- --
Not Specified	78 (0.38)	3668 (0.51)	2320 (0.63)	591 (0.16)	-- --	1023 (0.28)	170 (0.05)	78 (0.02)	448 (0.12)	10 (<0.01)
All Changeouts	207 (1.00)	7205 (1.00)	6894 (0.96)	1020 (0.14)	15 (<0.01)	4333 (0.60)	256 (0.04)	376 (0.05)	871 (0.12)	23 (<0.01)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

In Table 4.27 filters with silicone sealant and those with unspecified sealants also showed changeout fractions for leak test failure greater than those for a high pressure drop.

Preventive maintenance service life changeouts are of special interest because they assume changeout is made only on the basis of filter age and not because of particular evidence of failure or plugging. Service life changeouts were the third predominant reason for filter changeout, accounting for approximately 12% of all changeouts. This reason for changeout appeared most common for final or single stage filter banks, single exposure environments (particularly those with no distinguishing characteristics), single source gas streams (most frequently identified as general building ventilation), and, as often as not, unspecified filter component types.

Total labor manhours for the indicated filter changeouts were provided by 151 questionnaire responses. This data was normalized to a manhours per filter basis for each response. A histogram of the normalized data is shown in Figure 4.1. From the normalized data, an average (mean) value of 1.5 manhours per filter changed was calculated, having a standard deviation of 2.25 man hours.

### 4.3 FAILURE EXPERIENCE

Tables 4.29 through 4.39 show failure modes as a function of several filter and bank characteristics. The data contained in these tables are the subset of data only for those filter banks and applications in which failures were experienced. Hence, the numbers listed in the banks and filter applications columns of Tables 4.29 through 4.39 are less than those for either the preceding applications experience or changeout experience data tables. Calculated fractions are normalized to the failure subset of filter applications rather than to all applications.

It is apparent from Tables 4.29 through 4.39 that unknown failure modes constituted the largest failure fraction (0.177). This would seem to indicate that most filter failures are not investigated as to cause or, if such an investigation is performed at the time of occurrence, it is not documented in a sufficiently retrievable manner.

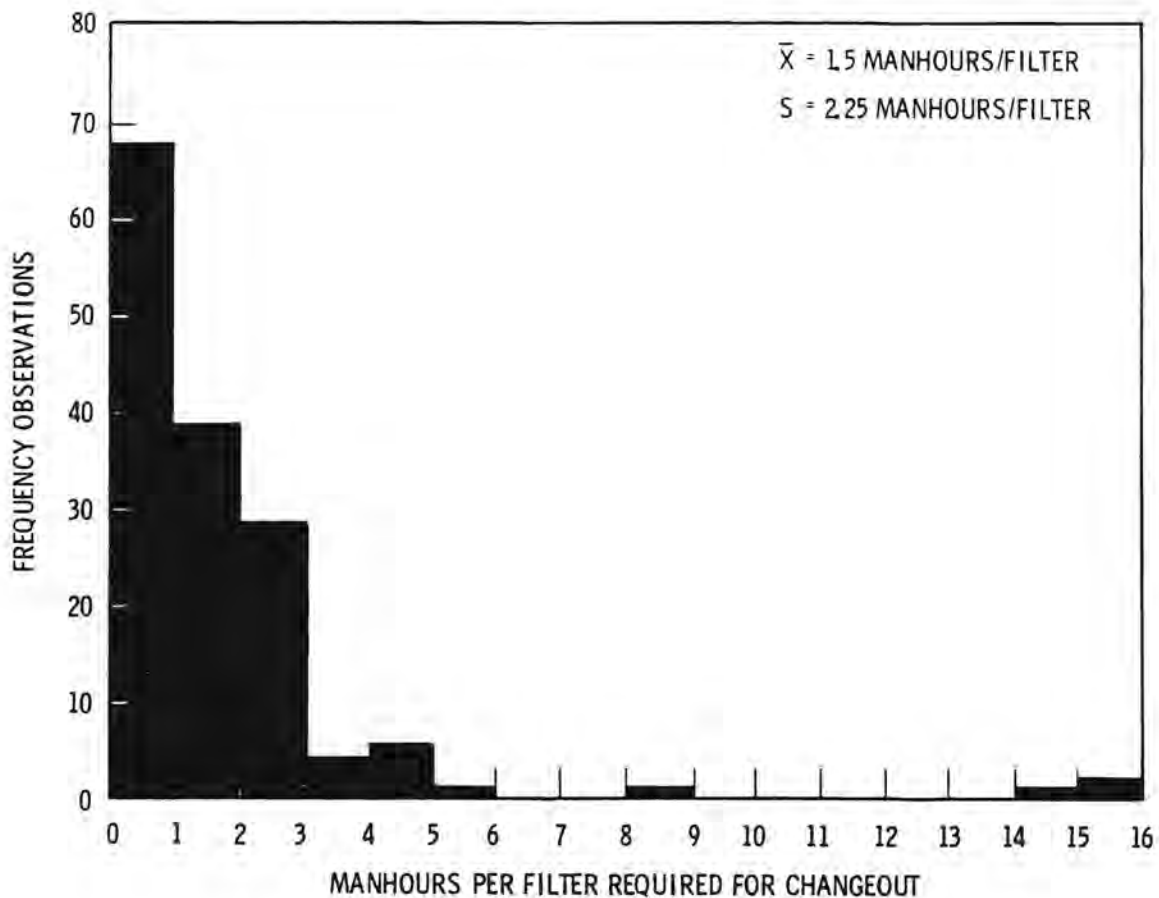


FIGURE 4.1. Normalized Labor for Changeout

The second most frequent cause of failure appeared to be handling or installation damage (failure fraction 0.054). Media, frame, and gasket failure were approximately equal in occurrence having failure fractions from 0.014 to 0.016.

Where ruptured media filter modes were identified, the following factors appeared predominant: HF environment, final or single stage filter bank, aluminum separators, polyurethane foam sealants, and wood frames. For frame failures, Table 4.36 shows that these were almost entirely limited to wood frames. Failures resulting from sealant failure or faulty filter construction were identified as almost nonexistent in the corresponding failure mode columns of Tables 4.37 and 4.38. Table 4.39 presents some interesting data on gasket versus fluid seal failure. Whereas gasket seals appeared to be in much wider use than fluid seals, the calculated seal failure fraction was higher for fluid seals.

**TABLE 4.29. Stage versus Failures(a)**

Stage	Banks	Filter Applications	Filter Failed	FAILURE MODE						
				Media Rupture	Sealant Failure	Frame Failure	Gasket or Seal Failure	Filter Construction	Handling or Installation Damage	Unknown
First of Series	28 (0.32)	1019 (0.26)	283 (0.28)	4 (0.004)	1 (0.001)	1 (0.001)	36 (0.035)	-- --	106 (0.104)	135 (0.132)
Intermediate	1 (0.01)	140 (0.04)	21 (0.15)	-- --	-- --	-- --	-- --	-- --	21 (0.150)	-- --
Final of Series and all single	58 (0.67)	2802 (0.71)	801 (0.29)	50 (0.018)	2 (0.001)	64 (0.023)	26 (0.009)	6 (0.002)	86 (0.031)	567 (0.202)
All Failures	87 (1.00)	3961 (1.00)	1105 (0.28)	54 (0.014)	3 (0.001)	65 (0.016)	62 (0.016)	6 (0.002)	213 (0.054)	702 (0.177)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

**TABLE 4.30. Environment Number versus Failures(a)**

Environment	Banks	Filter Applications	Filter Failed	FAILURE MODE						
				Media Rupture	Sealant Failure	Frame Failure	Gasket or Seal Failure	Filter Construction	Handling or Installation Damage	Unknown
Single	55 (0.63)	2017 (0.51)	620 (0.31)	48 (0.024)	2 (0.001)	7 (0.003)	6 (0.003)	2 (0.001)	19 (0.009)	536 (0.266)
Combination of Two	26 (0.30)	1056 (0.27)	334 (0.32)	4 (0.004)	1 (0.001)	-- --	42 (0.040)	4 (0.004)	119 (0.113)	164 (0.155)
Combination of Three	1 (0.01)	13 (<0.01)	2 (0.15)	-- --	-- --	-- --	-- --	-- --	2 (0.154)	-- --
Combination of Four or More	5 (0.06)	875 (0.22)	149 (0.17)	2 (0.002)	-- --	58 (0.066)	14 (0.016)	-- --	73 (0.083)	2 (0.002)
All Failures	87 (1.00)	3961 (1.00)	1105 (0.28)	54 (0.014)	3 (0.001)	65 (0.016)	62 (0.016)	6 (0.002)	213 (0.054)	702 (0.177)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.31. Single Environment versus Failures(a)

Environment	Banks	Filter Applications	Filter Failed	FAILURE MODE						
				Media Rupture	Sealant Failure	Frame Failure	Gasket or Seal Failure	Filter Construction	Handling or Installation Damage	Unknown
High Moisture	13 (0.24)	35 (0.02)	48 (1.371)	-- --	-- --	-- --	-- --	-- --	1 (0.029)	47 (1.343)
High Dust	1 (0.02)	1 (<0.01)	1 (1.000)	-- --	-- --	-- --	1 (1.000)	-- --	-- --	-- --
High Temperature	1 (0.02)	6 (<0.01)	1 (0.167)	-- --	-- --	-- --	-- --	-- --	-- --	1 (0.167)
HF Acid	3 (0.05)	12 (0.01)	26 (2.167)	26 (2.167)	-- --	-- --	-- --	-- --	-- --	-- --
Other Acid	4 (0.07)	63 (0.03)	12 (0.190)	-- --	-- --	-- --	-- --	-- --	10 (0.159)	2 (0.032)
No Distinguishing Characteristics	33 (0.60)	1900 (0.94)	532 (0.280)	22 (0.012)	2 (0.001)	7 (0.004)	5 (0.003)	2 (0.001)	8 (0.004)	486 (0.256)
All Single Environments	55 (1.00)	2017 (1.00)	620 (0.307)	48 (0.024)	2 (0.001)	7 (0.003)	6 (0.003)	2 (0.001)	19 (0.009)	536 (0.266)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.32. Combinations of Environments versus Failures(a)

Environment Combinations	Banks	Filter Applications	Filter Failed	FAILURE MODE						
				Media Rupture	Sealant Failure	Frame Failure	Gasket or Seal Failure	Filter Construction	Handling or Installation Damage	Unknown
<u>TWO ENVIRONMENTS</u>										
High Moisture, High Dust	2 (0.08)	321 (0.30)	161 (0.502)	-- --	1 (0.003)	-- --	-- --	-- --	-- --	160 (0.498)
High Moisture, HNO <sub>3</sub> Acid	2 (0.08)	2 (<0.01)	2 (1.00)	-- --	-- --	-- --	-- --	-- --	-- --	2 (1.00)
High Dust, Other Acids	22 (0.84)	733 (0.69)	171 (0.233)	4 (0.005)	-- --	-- --	42 (0.057)	4 (0.005)	119 (0.162)	2 (0.003)
All Two Environment Combinations	26 (1.00)	1056 (1.00)	334 (0.316)	4 (0.004)	1 (0.001)	-- --	42 (0.040)	4 (0.004)	119 (0.113)	164 (0.155)
<u>THREE ENVIRONMENTS</u>										
High Dust, HNO <sub>3</sub> Acid, Other Acid	1 (1.00)	13 (1.00)	2 (0.154)	-- --	-- --	-- --	-- --	-- --	2 (0.154)	-- --
<u>FOUR OR MORE ENVIRONMENTS</u>										
Solvent, High Dust, High Temperature, HNO <sub>3</sub> Acid, Other Acid	4 (0.80)	844 (0.96)	147 (0.174)	2 (0.002)	-- --	58 (0.069)	14 (0.017)	-- --	73 (0.086)	-- --
High Moisture, High Dust, High Temperature HF Acid, HNO <sub>3</sub> Acid, Other Acid, No Distinguishing Characteristics	1 (0.20)	31 (0.04)	2 (0.065)	-- --	-- --	-- --	-- --	-- --	-- --	2 (0.065)
All Combinations of Four or More Environments	5 (1.00)	875 (1.00)	149 (0.170)	2 (0.002)	-- --	58 (0.066)	14 (0.016)	-- --	73 (0.083)	2 (0.002)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

**TABLE 4.33. Source Number versus Failures(a)**

Number of Sources	FAILURE MODE									
	Banks	Filter Applications	Filter Failed	Media Rupture	Sealant Failure	Frame Failure	Gasket or Seal Failure	Filter Construction	Handling or Installation Damage	Unknown
One	68 (0.78)	1965 (0.50)	790 (0.40)	50 (0.025)	3 (0.002)	7 (0.004)	26 (0.013)	6 (0.003)	24 (0.012)	674 (0.343)
Two	2 (0.02)	526 (0.13)	32 (0.06)	-- --	-- --	-- --	-- --	-- --	8 (0.015)	24 (0.046)
Three or More	17 (0.20)	1470 (0.37)	283 (0.19)	4 (0.003)	-- --	58 (0.040)	36 (0.024)	-- --	181 (0.123)	4 (0.003)
All Failures	87 (1.00)	3961 (1.00)	1105 (0.28)	54 (0.014)	3 (0.001)	65 (0.016)	62 (0.016)	6 (0.002)	213 (0.054)	702 (0.177)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

**TABLE 4.34. Single Source versus Failures(a)**

Source	FAILURE MODE									
	Banks	Filter Applications	Filter Failed	Media Rupture	Sealant Failure	Frame Failure	Gasket or Seal Failure	Filter Construction	Handling or Installation Damage	Unknown
General Building Ventilation	33 (0.49)	1454 (0.74)	623 (0.428)	12 (0.008)	2 (0.001)	7 (0.005)	21 (0.014)	6 (0.004)	23 (0.016)	552 (0.380)
Vessel Vent	16 (0.24)	55 (0.03)	59 (1.073)	-- --	-- --	-- --	-- --	-- --	1 (0.018)	58 (1.055)
Laboratory Hood	8 (0.12)	394 (0.20)	39 (0.099)	-- --	1 (0.003)	-- --	-- --	-- --	-- --	38 (0.096)
Process Hood	4 (0.06)	39 (0.02)	17 (0.436)	9 (0.231)	-- --	-- --	5 (0.128)	-- --	-- --	3 (0.077)
Glove Box	7 (0.10)	23 (0.01)	52 (2.261)	29 (1.261)	-- --	-- --	-- --	-- --	-- --	23 (1.000)
All Single Sources	68 (1.00)	1965 (1.00)	790 (0.402)	50 (0.025)	3 (0.002)	7 (0.004)	26 (0.013)	6 (0.003)	24 (0.012)	674 (0.343)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

TABLE 4.35. Combinations of Sources versus Failures(a)

Source Combinations	FAILURE MODE									
	Banks	Filter Applications	Filter Failed	Media Rupture	Sealant Failure	Frame Failure	Gasket or Seal Failure	Filter Construction	Handling or Installation Damage	Unknown
<u>TWO SOURCES</u>										
Laboratory Hood and Glove Box	1 (0.50)	500 (0.95)	8 (0.016)	-- --	-- --	-- --	-- --	-- --	8 (0.016)	-- --
Process Hood and Glove Box	16 (0.50)	55 (0.06)	59 (0.923)	-- --	-- --	-- --	-- --	-- --	-- --	24 (0.923)
All Two Source Combinations	2 (1.00)	526 (1.00)	32 --	-- --	-- --	-- --	-- --	-- --	8 (0.015)	24 (0.046)
<u>THREE SOURCES</u>										
General Building Ventilation, Vessel Vent, and Glove Box	1 (0.06)	31 (0.02)	2 (0.065)	-- --	-- --	-- --	-- --	-- --	-- --	2 (0.065)
General Building Ventilation, Process Hood, and Glove Box	4 (0.24)	844 (0.57)	147 (0.174)	2 (0.002)	-- --	58 (0.069)	14 (0.017)	-- --	73 (0.086)	-- --
Laboratory Hood, Process Hood, and Glove Box	12 (0.71)	595 (0.40)	134 (0.225)	2 (0.003)	-- --	-- --	22 (0.037)	-- --	108 (0.182)	2 (0.003)
All Three Sources Combinations	17 (1.00)	1470 (1.00)	283 (0.193)	4 (0.003)	-- --	58 (0.039)	36 (0.024)	-- --	181 (0.123)	4 (0.003)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

**TABLE 4.36. Frame Type versus Failures(a)**

Frame Type	Banks	Filter Applications	Filter Failed	FAILURE MODE						Unknown
				Media Rupture	Sealant Failure	Frame Failure	Gasket or Seal Failure	Filter Construction	Handling or Installation Damage	
Wood	43 (0.49)	2058 (0.52)	579 (0.28)	54 (0.026)	-- --	58 (0.028)	57 (0.028)	4 (0.002)	200 (0.097)	206 (0.100)
Stainless Steel	1 (0.01)	6 ( $<0.01$ )	1 (0.17)	-- --	-- --	-- --	-- --	-- --	-- --	1 (0.167)
Chromized Steel	1 (0.01)	500 (0.13)	8 (0.02)	-- --	-- --	-- --	-- --	-- --	8 (0.016)	-- --
Not Specified	42 (0.48)	1397 (0.35)	517 (0.37)	-- --	3 (0.002)	7 (0.005)	5 (0.004)	2 (0.001)	5 (0.004)	495 (0.354)
All Failures	87 (1.00)	3961 (1.00)	1105 (0.28)	54 (0.014)	3 (0.001)	65 (0.016)	62 (0.016)	6 (0.002)	213 (0.054)	702 (0.177)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

4.33

**TABLE 4.37. Separator Type versus Failures(a)**

Separator Type	Banks	Filter Applications	Filter Failed	FAILURE MODE						Unknown
				Media Rupture	Sealant Failure	Frame Failure	Gasket or Seal Failure	Filter Construction	Handling or Installation Damage	
No Separator	4 (0.05)	23 (0.01)	10 (0.44)	-- --	1 (0.043)	-- --	-- --	-- --	-- --	9 (0.391)
Asbestos	1 (0.01)	12 ( $<0.01$ )	3 (0.25)	-- --	-- --	-- --	-- --	-- --	-- --	3 (0.250)
Aluminum	10 (0.12)	584 (0.15)	87 (0.15)	48 (0.082)	-- --	-- --	-- --	-- --	8 (0.014)	31 (0.053)
Plastic	31 (0.36)	1639 (0.41)	331 (0.20)	6 (0.004)	-- --	58 (0.035)	57 (0.035)	4 (0.002)	202 (0.123)	4 (0.002)
Other ("Non-metallic")	1 (0.01)	320 (0.08)	160 (0.50)	-- --	-- --	-- --	-- --	-- --	-- --	160 (0.500)
Not Specified	40 (0.46)	1383 (0.35)	514 (0.37)	-- --	2 (0.001)	7 (0.005)	5 (0.004)	2 (0.001)	3 (0.002)	495 (0.358)
All Failures	87 (1.00)	3961 (1.00)	1105 (0.28)	54 (0.014)	3 (0.001)	65 (0.016)	62 (0.016)	6 (0.002)	213 (0.054)	702 (0.177)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

**TABLE 4.38. Sealant Type versus Failures(a)**

Sealant Type	Banks	Filter Applications	Filter Failed	FAILURE MODE						
				Media Rupture	Sealant Failure	Frame Failure	Gasket or Seal Failure	Filter Construction	Handling or Installation Damage	Unknown
Glass Packing	26 (0.30)	1567 (0.40)	315 (0.20)	4 (0.003)	-- (0.003)	58 (0.037)	52 (0.033)	4 (0.003)	194 (0.124)	3 (0.002)
Silicone	6 (0.07)	382 (0.10)	172 (0.45)	1 (0.003)	1 (0.003)	-- (0.003)	2 (0.005)	-- (0.003)	6 (0.016)	162 (0.424)
Polyurethane Foam	7 (0.08)	531 (0.13)	56 (0.10)	48 (0.090)	-- (0.090)	-- (0.090)	-- (0.090)	-- (0.090)	8 (0.015)	-- (0.015)
Elastomeric Adhesive	1 (0.01)	12 (0.01)	3 (0.25)	-- (0.25)	-- (0.25)	-- (0.25)	-- (0.25)	-- (0.25)	-- (0.25)	3 (0.250)
Not Glass, specific type not specific	6 (0.07)	73 (0.02)	43 (0.59)	1 (0.014)	-- (0.014)	-- (0.014)	3 (0.041)	-- (0.041)	-- (0.041)	39 (0.534)
Not Specified	41 (0.47)	1396 (0.35)	516 (0.37)	-- (0.37)	2 (0.001)	7 (0.005)	5 (0.004)	2 (0.001)	5 (0.004)	495 (0.355)
All Failures	87 (1.00)	3961 (1.00)	1105 (0.28)	54 (0.014)	3 (0.001)	65 (0.016)	62 (0.016)	6 (0.002)	213 (0.054)	702 (0.177)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

**TABLE 4.39. Seal Type versus Failures(a)**

Seal Type	Banks	Filter Applications	Filter Failed	FAILURE MODE						
				Media Rupture	Sealant Failure	Frame Failure	Gasket or Seal Failure	Filter Construction	Handling or Installation Damage	Unknown
Gasket	38 (0.44)	1194 (0.30)	422 (0.35)	51 (0.043)	1 (0.001)	-- (0.001)	40 (0.034)	4 (0.003)	129 (0.108)	197 (0.165)
Fluid	4 (0.05)	40 (0.01)	14 (0.35)	1 (0.025)	-- (0.025)	-- (0.025)	3 (0.075)	-- (0.075)	-- (0.075)	10 (0.250)
Not Specified	45 (0.52)	2727 (0.69)	669 (0.25)	2 (0.001)	2 (0.001)	65 (0.024)	19 (0.007)	2 (0.001)	84 (0.031)	495 (0.182)
All Failures	87 (1.00)	3961 (1.00)	1105 (0.28)	54 (0.014)	3 (0.001)	65 (0.016)	62 (0.016)	6 (0.002)	213 (0.054)	702 (0.177)

(a) Fractions in Banks and Filter Applications columns are columnar fractions calculated using column total as denominator. All other fractions are row fractions calculated using row entry in Filter Applications column as denominator.

Table 4.40 gives filter changeout reasons and the maximum number of failures in each failure mode which could be associated with each changeout reason. Some care is necessary in the examination and interpretation of this table because the questionnaire allowed failure modes to be associated with more than one changeout reason. As a result of multiple associations, the failure mode columnar sums exceed the all reasons row entries. Also, in the visual exam row, the total filter failures entry appears to exceed the number of filters changed out. The questionnaire data actually indicated multiple changeout reasons in one particular bank with the total number of filter failures exceeding the number of changeouts performed based on visual examination of filters alone. For this reason, row and columnar fractions are intentionally omitted from this table. The leak test failure row of this table is of most interest because it provides the most direct evidence of filter failure. Failure mode entries in this row support the observation that handling and installation damage occurred more frequently than media rupture or seal failure, and that the majority of filters failed for unknown or unreported reasons.

#### 4.4 SERVICE LIFE EXPERIENCE

Service life responses were received for 231 filter banks. Indefinite service life responses accounted for 53 of these banks. For those responses indicating definite service lives, a mean life of 3.0 years and standard deviation of 2.0 years were calculated. The distribution of these service lives is shown as a histogram in Figure 4.2. The calculated mean life, standard deviation, maximum and minimum reported lives, as well as the number of responses indicating definite and indefinite service lives are shown in Tables 4.41 through 4.54, for the same filter variables as discussed in previous sections of this report. These tables appear to show only nominal differences in mean life for filter stage application. Combinations of environments appeared to generally have shorter service lives than single environments. It was also noted that longer service life appeared to be associated with filters of unspecified component types. This may be attributed to lack of retrievable records on the filter components used in such systems, (i.e., if the filters have not been a problem or concern, only minimal documentation of their type may exist).

TABLE 4.40. Changeout Reasons versus Failures

Changeout Reason	Banks	Filter Changed	Filters Failed	FAILURE MODE						
				Media Rupture	Media to Sealant Failure	Frame Failure	Gasket or Seal Failure	Filter Construction	Handling or Installation Damage	Unknown
Leak Test Failure	67	1020	861	39	2	7	33	2	78	700
Other Evidence of Penetration	2	15	21	1	--	--	--	--	--	20
High Pressure Drop	137	4333	692	33	--	58	61	4	192	344
Radiation Buildup	15	256	38	--	--	--	--	--	--	38
Suspected Damage	9	376	1	--	--	--	--	--	--	1
Preventive Maintenance Service Life	22	871	304	--	--	--	4	--	--	300
Visual Exam	3	23	36	14	1	--	--	--	21	--
All Reasons	207	6894	1105	54	3	65	62	6	213	702

4.36

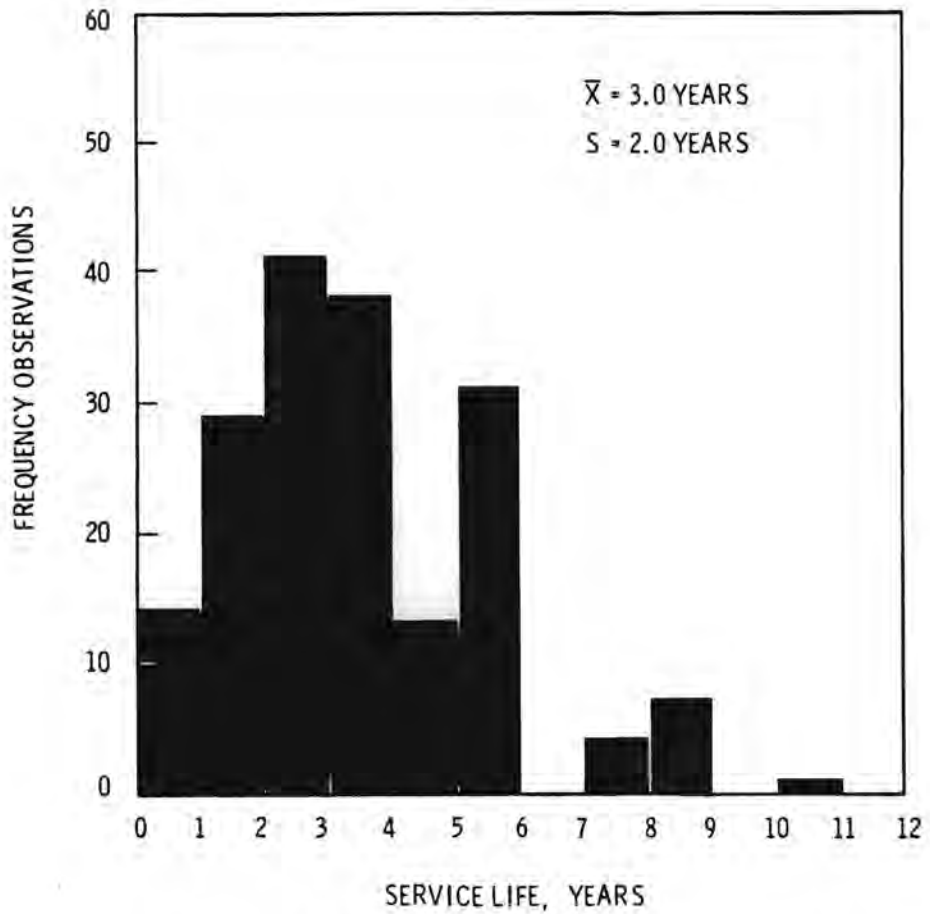


FIGURE 4.2. HEPA Filter Service Life

TABLE 4.41. Stage versus Service Life

Stage	# Filters		Years			
	Indefinite Life	Definite Life	Mean Life	Standard Deviation	Maximum Life	Minimum Life
First of Series	13	52	2.8	1.9	7.5	0.2
Intermediate	2	7	2.9	1.5	5.0	1.0
Final of Series and all single	38	119	3.1	2.0	10.0	0.2
All	53	178	3.0	2.0	10.0	0.2

TABLE 4.42. Environment Number versus Service Life

Number of Environments	# Filters		Years			
	Indefinite Life	Definite Life	Mean Life	Standard Deviation	Maximum Life	Minimum Life
One	50	108	3.3	1.9	10.0	0.2
Two	--	40	2.9	2.3	8.0	0.5
Three	2	12	2.1	1.2	4.0	1.0
Four or more	1	18	2.1	1.6	5.0	0.2
All	53	178	3.0	2.0	10.0	0.2

TABLE 4.43. Single Environment Versus Service Life

Environment	# Filters		Years			
	Indefinite Life	Definite Life	Mean Life	Standard Deviation	Maximum Life	Minimum Life
Solvent	--	1	5.0	--	5.0	5.0
High moisture	--	2	3.0	--	3.0	3.0
High dust	2	12	2.2	1.8	5.0	0.2
Grease/oil	1	1	0.2	--	0.2	0.2
High temperature	--	2	2.0	--	2.0	2.0
HF acid	1	4	2.2	2.2	5.0	0.2
Other acid	--	10	2.5	0.8	3.0	1.0
No distinguishing characteristics	46	76	3.7	1.9	10.0	0.5
All single environments	50	108	3.3	1.9	10.0	0.2

TABLE 4.44. Combinations of Two Environments versus Service Life

Environment Combination	# Filters		Years			
	Indefinite Life	Definite Life	Mean Life	Standard Deviation	Maximum Life	Minimum Life
High moisture, high dust	--	5	1.8	0.9	3.0	0.5
High moisture, grease/oil	--	2	2.0	1.4	3.0	1.0
High dust, other acid	--	31	3.4	2.4	8.0	1.0
High dust, grease/oil	--	1	0.5	--	0.5	0.5
HNO <sub>3</sub> , other acid	--	1	0.5	--	0.5	0.5
All combinations of 2 environments	--	40	2.9	2.3	8.0	0.5

TABLE 4.45. Combinations of Three Environments versus Service Life

Environment Combination	# Filters		Years			
	Indefinite Life	Definite Life	Mean Life	Standard Deviation	Maximum Life	Minimum Life
Solvent, HF, HNO <sub>3</sub>	--	1	1.0	--	1.0	1.0
Solvent, HNO <sub>3</sub> , other acid	--	5	2.8	1.3	4.0	1.0
High moisture, HNO <sub>3</sub> , other acid	2	1	3.0	--	3.0	3.0
High dust, HNO <sub>3</sub> , other acid	--	1	2.0	--	2.0	2.0
HF, HNO <sub>3</sub> , other acid	--	4	1.3	0.5	2.0	1.0
All combinations of Three environments	2	12	2.1	1.2	4.0	1.0

TABLE 4.46. Combinations of Four or More Environments versus Service Life

Environment Combination	# Filters		Years			
	Indefinite Life	Definite Life	Mean Life	Standard Deviation	Maximum Life	Minimum Life
Solvent, HF, HNO <sub>3</sub> , other acids	--	3	4.0	1.7	5.0	2.0
Solvent, high dust, HF, HNO <sub>3</sub> , other acids	1	5	2.2	0.9	3.0	0.8
Solvent, HF, HNO <sub>3</sub> other acids, no distinguishing characteristics	--	1	4.0	--	4.0	4.0
High moisture, high dust, HF, HNO <sub>3</sub> , other acids	--	2	2.0	1.4	3.0	1.0
High moisture, grease/oil, HF, HNO <sub>3</sub> , other acids	--	4	0.2	0.02	0.2	0.2
Solvent, high dust, high temp., HNO <sub>3</sub> , other acids	--	2	3.0	--	3.0	3.0
High moisture, high dust, high temp., HF, HNO <sub>3</sub> , other acids, no distinguishing characteristics	--	1	1.0	--	1.0	1.0
All combinations of four or more environments	1	18	2.1	1.6	5.0	0.2

TABLE 4.47. Number of Sources versus Service Life

Number of Sources	# Filters		Years			
	Indefinite Life	Definite Life	Mean Life	Standard Deviation	Maximum Life	Minimum Life
One	44	139	2.8	1.8	10.0	0.2
Two	6	14	3.5	1.5	5.0	1.0
Three or more	3	25	3.8	2.6	8.0	1.0
All	53	178	3.0	2.0	10.0	0.2

TABLE 4.48. Single Source versus Service Life

Source	# Filters		Years			
	Indefinite Life	Definite Life	Mean Life	Standard Deviation	Maximum Life	Minimum Life
General build- ing ventilation	11	59	3.3	1.6	8.0	1.0
Incinerator	--	1	3.0	--	3.0	3.0
Vessel vent	--	6	2.0	1.2	3.0	0.5
Laboratory hood	19	20	2.3	1.8	5.0	0.2
Process hood	3	27	2.4	1.7	7.0	0.5
Glove box	11	23	2.4	2.3	10.0	0.2
Hot cell	--	3	5.8	1.4	7.5	5.0
All single sources	44	139	2.8	1.8	10.0	0.2

TABLE 4.49. Combinations of Two Sources versus Service Life

Source Combinations	# Filters		Years			
	Indefinite Life	Definite Life	Mean Life	Standard Deviation	Maximum Life	Minimum Life
General building vent, vessel vent	--	1	3.0	--	3.0	3.0
General building vent, laboratory hood	3	3	4.3	1.2	5.0	3.0
General building vent, glove box	1	3	5.0	0.0	5.0	5.0
General building vent, hot cell	--	1	2.0	--	2.0	2.0
Laboratory hood, process hood	--	1	1.0	--	1.0	1.0
Laboratory hood, glove box	2	3	3.0	1.0	4.0	2.0
Process hood, incinerator	--	1	1.5	--	1.5	1.5
Process hood, glove box	--	1	5.0	--	5.0	5.0
All combinations of two sources	6	14	3.5	1.5	5.0	1.0

TABLE 4.50. Combinations of Three or More Sources versus Service Life

Source Combinations	# Filters		Years			
	Indefinite Life	Definite Life	Mean Life	Standard Deviation	Maximum Life	Minimum Life
General building ventilation, vessel vent, laboratory hood	--	1	4.0	--	4.0	4.0
General building ventilation, vessel vent, glove box	--	3	1.7	1.2	3.0	1.0
General building ventilation, lab hood, process hood	--	1	2.0	--	2.0	2.0
General building ventilation, process hood, glove box	--	2	3.0	--	3.0	3.0
Laboratory hood, process hood, glove box	3	15	4.5	3.0	8.0	3.0
General building ventilation, vessel vent, process hood, glove box	--	1	4.0	--	4.0	4.0
General building ventilation, vessel vent, laboratory hood, glove box	--	1	4.0	--	4.0	4.0
Dissolver offgas, laboratory hood, process hood, glove box	--	1	3.0	--	3.0	3.0
All combinations of three or more sources	3	25	3.8	2.6	8.0	1.0

TABLE 4.51. Frame Type versus Service Life

<u>Frame Type</u>	<u># Filters</u>		<u>Years</u>			
	<u>Indefinite Life</u>	<u>Definite Life</u>	<u>Mean Life</u>	<u>Standard Deviation</u>	<u>Maximum Life</u>	<u>Minimum Life</u>
Wood	23	141	3.1	2.1	10.0	0.2
Stainless steel	1	5	3.0	1.0	4.0	2.0
Chromized steel	1	21	2.2	1.2	4.0	0.5
Not specified	28	11	3.7	1.1	5.0	2.0
All	53	178	3.0	2.0	10.0	0.2

TABLE 4.52. Separator Type versus Service Life

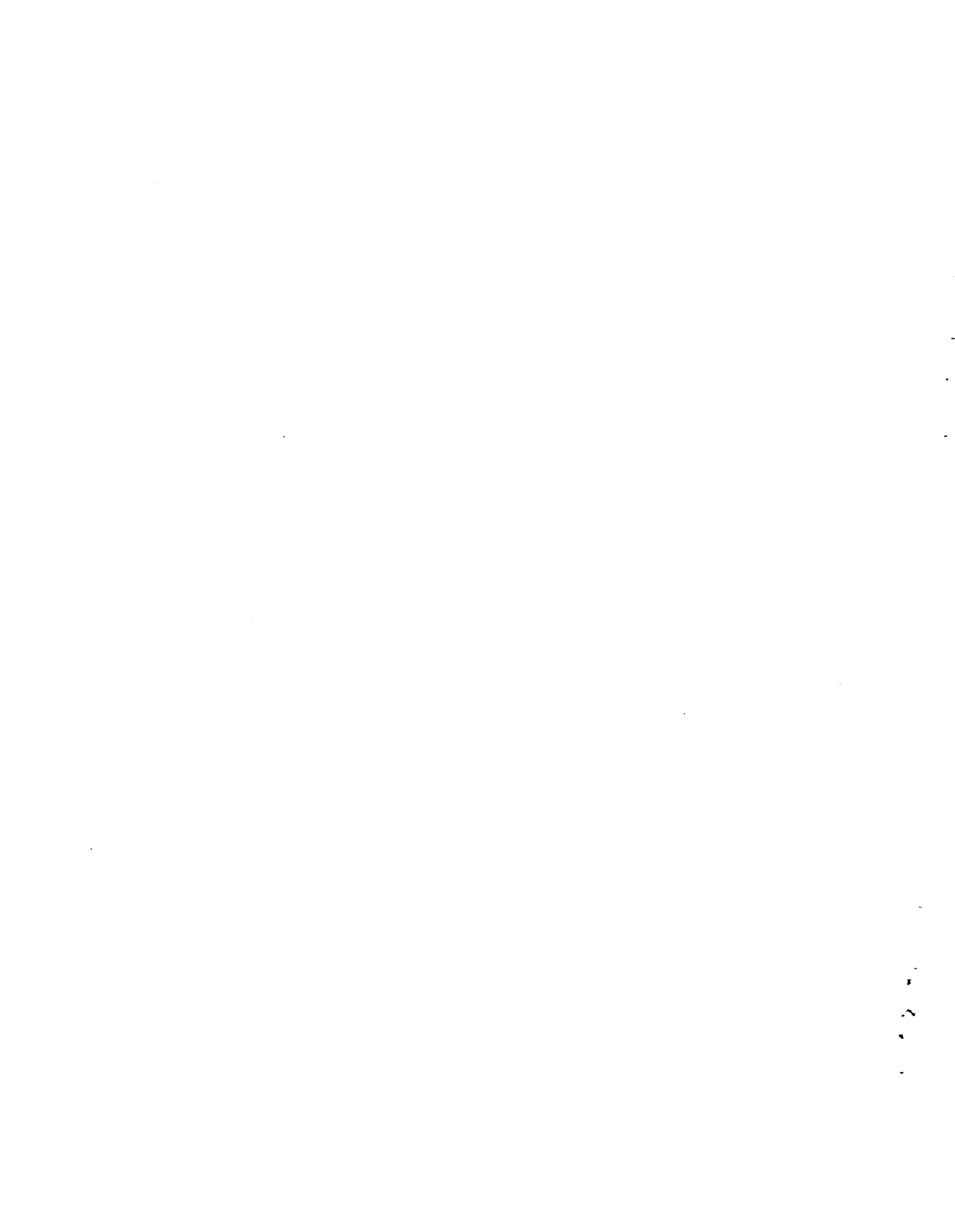
<u>Separator Type</u>	<u># Filters</u>		<u>Years</u>			
	<u>Indefinite Life</u>	<u>Definite Life</u>	<u>Mean Life</u>	<u>Standard Deviation</u>	<u>Maximum Life</u>	<u>Minimum Life</u>
Separatorless	--	17	3.9	2.0	7.5	1.0
Asbestos	4	12	3.5	2.1	8.0	2.0
Aluminum	17	95	2.7	1.9	10.0	0.2
Plastic	2	41	3.1	2.2	8.0	1.0
Other	4	7	2.1	1.0	4.0	1.0
Not specified	26	6	4.0	0.9	5.0	3.0
All types	53	178	3.0	2.0	10.0	0.2

TABLE 4.53. Sealant Type versus Service Life

Sealant Type	# Filters		Years			
	Indefinite Life	Definite Life	Mean Life	Standard Deviation	Maximum Life	Minimum Life
Glass packing	--	36	3.2	2.3	8.0	1.0
Silicone	1	13	2.2	0.9	4.0	1.0
Polyurethane foam	20	68	3.5	2.1	10.0	0.2
Elastomeric adhesive	2	8	4.6	1.9	8.0	3.0
Not glass (specific type, no specified)	1	46	2.0	1.2	5.0	0.2
Not specified	29	7	3.7	1.1	5.0	2.0
All types	53	178	3.0	2.0	10.0	0.2

TABLE 4.54. Seal Type versus Service Life

Seal Type	# Filters		Years			
	Indefinite Life	Definite Life	Mean Life	Standard Deviation	Maximum Life	Minimum Life
Gasket	23	143	3.1	2.1	10.0	0.2
Fluid	--	16	2.1	1.1	4.0	0.2
Not specified	30	19	3.3	1.0	5.0	2.0
All types	53	178	3.0	2.0	10.0	0.2



## 5.0 REFERENCES

Burchsted, C. A., et al. 1970. Design, Construction and Testing of High Efficiency Air Filtration Systems for Nuclear Applications, ORNL/NSIC-65. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

Burchsted, C. A., J. E. Kahn and A. B. Fuller. 1976. Nuclear Air Cleaning Handbook, ERDA 76-21. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

Burchsted, C. A. 1981. An Index to the 1st Through 16th AEC/ERDA/DOE Nuclear Air Cleaning Conference, DOE/TIC-11405. Oak Ridge National Laboratory. Oak Ridge, Tennessee.



APPENDIX A  
HEPA FILTER SURVEY

HEPA FILTER SURVEY

INSTRUCTIONS

The attached HEPA filter questionnaire is intended to summarize HEPA filter experience at Department of Energy sites over the last three years. The results of this effort will be used to provide direction to future DOE-sponsored development programs.

A. System Identification

1. Identify the system as coded in the DOE Effluent Discharge Information System EDIS data base.
2. Review the system description as it currently appears in EDIS. If it does not accurately reflect the source and nature of the effluent stream, attach an updated description.
3. For systems not included in EDIS, provide the requested information.
4. Indicate a contact person should further clarification be necessary (typically the individual completing the questionnaire). Provide an FTS phone number where available; otherwise, give commercial number.

B. Filter Use and Experience

The data in this section will be used to summarize experience from various filter applications. Limit responses to nuclear grade (or application) experience with HEPA filters of 8"x8", 12"x12" and 24"x24" dimensions. Combine filter stages into categories according to the following definitions:

- Primary: The first HEPA filter stage in a multiple stage HEPA filter system.
- Secondary: All HEPA filter stages between the primary and final stages.
- Final: The last HEPA filter stage before effluent discharge. Include single stage filtration systems in this category.

The time frame of interest is 1977-1979 inclusive.

1. Identify the gas stream filtered. For effluent systems combining multiple streams, subdivide Primary stage responses by gas stream. Use additional paper or copies of the questionnaire as required. Select from the following gas stream codes:

General Building Ventilation (including reactor containment)	1
Dissolver Offgas	2
Incinerator	3
Vessel Vent	4
Laboratory Hood	5
Process Hood	6
Glove Box	7

2. State total number of HEPA filters for each gas stream and stage indicated in B.1.
3. Indicate the environment to which the HEPA filter is exposed. Select codes from the following. (Use as many as applicable.) Consider the environmental modifications provided by moisture separators, roughing filters, etc. upstream of the HEPA filters.

Solvent	1
High Moisture	2
High Dust	3
Grease or Oil	4
High Temperature	5
Acid - HF	6
Acid - HNO <sub>3</sub>	7
Acid - Other	8
No distinguishing characteristics	9

4. Describe the type of filter used in the above service. Provide a four digit code in the format FRAME-SEPARATOR-SEALANT-SEAL based on structure codes given below:

<u>Frame</u>		<u>Separator</u>	
Wood	1	Separatorless	0
Stainless Steel	2	Asbestos	1
Chromized Steel	3	Aluminum	2
Other (Specify)	4	Plastic	3
<u>Media to Frame Sealant</u>		Other Material (specify)	4
Glass Packing	1	<u>Frame to Housing Seal</u>	
Silicone	2	Gasket	1
Urethane Foam	3	Fluid	2
Elastomeric Adhesive	4		

5. Indicate the number of filters changed out over the last 3 years due to the stated reasons.
6. Indicate number of filters failed over the last 3 years for the stated causes.
7. Estimate the total man-hours involved in change out of all filters included in item 5 above.
8. Based on your site experience estimate HEPA filter service life in the stated categories.

C. Problem Areas

Self-explanatory.

D. Development Needs

Self-explanatory.

E. Procurement Specifications

Multiple copies of duplicate site HEPA filter specifications are not required. It is sufficient to provide one copy of each appropriate specification and reference the specification.

F. Other Comments

Self-explanatory.

Thank you for your cooperation. Please return completed questionnaire to:

Eugene H. Carbaugh  
Pacific Northwest Laboratory  
P.O. Box 999  
300 Area/318-TR 3  
Richland, WA 99352

If questions arise in completing, please contact E. H. Carbaugh on FTS 444-0104, Comercial Phone (509) 376-0104, or in his absence, Lois Peter (509) 375-2288 (Richland FTS 444-7511).

HEPA FILTER SURVEY

A. SYSTEM IDENTIFICATION

1. System listing as coded in EDIS: \_\_\_\_\_
2. Is the EDIS description accurate? Yes \_\_\_\_\_ No \_\_\_\_\_ (If no, attach revision)
3. If not included in EDIS, please indicate the following:  
 DOE Site \_\_\_\_\_ Contractor \_\_\_\_\_  
 Area/Facility \_\_\_\_\_ Site System Identification \_\_\_\_\_  
 Brief description of system function: \_\_\_\_\_  
 \_\_\_\_\_
4. Contact for questions or further information.  
 Name \_\_\_\_\_ Phone \_\_\_\_\_

B. FILTER USE AND EXPERIENCE

Describe HEPA filter use and experience within the above system over the last three (3) years. Describe single stage filtration systems under "FINAL".

	<u>Primary</u>	<u>Secondary</u>	<u>Final</u>
1. Gas Stream Filtered	_____	_____	_____
2. Total Number of HEPA filters	_____	_____	_____
3. Exposure Environment	_____	_____	_____
4. Filter Type	_____	_____	_____
5. Number of filters changed-out due to			
Leak Test Failure	_____	_____	_____
Other Evidence of Penetration (specify)	_____	_____	_____
_____	_____	_____	_____
High ΔP	_____	_____	_____
Radiation Buildup	_____	_____	_____
Suspected Damage	_____	_____	_____
Service Life Limit	_____	_____	_____
Wet Filter	_____	_____	_____
Visual Exam	_____	_____	_____
Other (Specify)	_____	_____	_____
_____	_____	_____	_____
6. Number of failures due to			
Rupture Media	_____	_____	_____
Sealant/Adhesive Failure	_____	_____	_____
Frame Damage	_____	_____	_____
Gasket or Seal Damage	_____	_____	_____
Filter Construction	_____	_____	_____
Handling or Installation Damage	_____	_____	_____
Other (Specify)	_____	_____	_____
_____	_____	_____	_____

	<u>Primary</u>	<u>Secondary</u>	<u>Final</u>
7. Estimated total man-hours required for filters changed-out	_____	_____	_____
8. Typical filter service life	_____	_____	_____

C. PROBLEM AREAS

What are your current or foreseen problem areas with HEPA filters? (Use additional paper if necessary.)

D. DEVELOPMENT NEEDS

What improvements in HEPA filter materials or construction would you like to see? (Use additional paper if necessary.)

E. PROCUREMENT SPECIFICATIONS

Attach a copy of your most recent procurement specification for each service of filter.

F. OTHER COMMENTS

Any comments relevant to HEPA filter experience would be appreciated. (Use additional paper if necessary.)

Thank you for your cooperation. Please return completed questionnaire to:

Eugene H. Carbaugh  
Pacific Northwest Laboratory  
P. O. Box 999  
300 Area/318 TR 3  
Richland, WA 99352

DISTRIBUTION

<u>No. of Copies</u>		<u>No. of Copies</u>
<u>OFFSITE</u>		
	A. A. Churm DOE Patent Office 9800 S. Cass Avenue Argonne, IL 60439	M. E. Remley Rockwell International 8900 DeSoto Avenue Canoga Park, CA 91304
	J. P. Hamric DOE Nuclear Fuel Cycle and Waste Management Division 550 Second Street Idaho Falls, ID 83401	5 T. R. Thomas Exxon Nuclear Idaho Co. P.O. Box 800 Idaho Falls, ID 83401
	M. Widmayer DOE Nuclear Fuel Cycle and Waste Management Division 550 Second Street Idaho Falls, ID 83401	W. Thorvaldson Rockwell International Rocky Flats Plant P.O. Box 464 Golden, CO 80401
	M. Bebon DOE Brookhaven Area Office Upton, NY 11973	<u>3 DOE Richland Operations Office</u>
	E. J. Vallario Office of Operational Safety U.S. Department of Energy Washington, DC 20545	E. A. Bracken L. Musen H. E. Ransom
27	DOE Technical Information Center	<u>4 Rockwell Hanford Operations</u>
	R. A. Brown Exxon Nuclear Idaho Co., P.O. Box 800 Idaho Falls, ID 83401	J. W. Camman G. F. Boothe H. A. Lee H. P. Shaw
	J. Ortiz Los Alamos Scientific Lab P.O. Box 1663 Los Alamos, NM 87545	<u>37 Pacific Northwest Laboratory</u>
	Beverly Rawles Battelle Memorial Institute Office of Nuclear Waste Isolation 505 King Avenue Columbus, OH 43201	J. R. Berry E. H. Carbaugh (25) J. P. Corley R. R. Kinnison C. R. Richey

No. of  
Copies

J. M. Selby  
Publishing Coordination (2)  
Technical Information R0(5)

No. of  
Copies

HEHF  
R. Gilmore