Technical Note
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SAMPLING AND DATA REPORTING CONSIDERATIONS FOR AIRBORNE PARTICULATE RADIOACTIVITY

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PREFACE

The Office of Radiation Programs of the U.S. Environmental Protection Agency carries out a national program designed to evaluate population exposure to ionizing and nonionizing radiation, and to promote development of controls necessary to protect the public health and safety. This report describes the evaluation of selected air filters for use in environmental radiological air quality monitoring studies conducted by the Las Vegas Facility. Readers of this report are encouraged to inform the Office of Radiation Programs of any omissions or errors. Comments or requests for further information are also invited.

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The authors, although recognizing the assistance of others, accept full responsibility for the contents of this report.

SUMMARY

This report discusses the evaluation of selected air filters for their suitability as collection media for the radiological analyses of airborne particulate matter. Standard four-inch diameter filters were analyzed for their natural radioactivity contents. Of the filters tested, glass fiber filters had the highest radium-226 content (0.35 picocuries per filter) and Microsorban filters contained roughly one-third of this activity. Microsorban filters also have lower uranium and thorium contents than do the glass fiber filters. For the analytical methods used in this study, all filter types tested had undetectable polonium-210, lead-210, and radium-228 contents. Dust loading characteristics of selected filters were also evaluated. The results indicate that Microsorban filters have higher collection and dust retention efficiencies (ranging from 6 to 26 percent greater) than do glass fiber filters. As a result of these evaluations, Microsorban filters are being used in the routine environmental radiological air quality monitoring networks operated by the Office of Radiation Programs - Las Vegas Facility (ORP-LVF).

INTRODUCTION

High-volume air sampling systems are routinely utilized to measure the ambient airborne particulate concentrations of naturally-occurring radionuclides such as radium-226 and -228, lead-210, polonium-210, isotopic uranium and isotopic thorium. In many cases, it is necessary to distinguish the contribution of normal background concentrations of these radionuclides from quantities which may be contributed by some industrial activity. This report discusses the comparisons of selected air filters for natural radioactivity content and for airborne particulate collection properties. It also discusses the air sampling procedures used by the Office of Radiation Programs - Las Vegas Facility (ORP-LVF) to measure airborne levels of naturally-occurring particulate radioactivity.

AIR SAMPLING SYSTEM

1. SYSTEM DESCRIPTION

Air particulate sampling is conducted using a heavy-duty air sampler*, as shown in Figure 1, which may be run continuously for periods of about a year without requiring any routine maintenance. This unit uses the English units of measure and therefore, the following discussions and reported data will utilize English units. (Appendix A - Metric Conversion Table has been included for cross-referencing purposes.) This sampler has a carbon-vane pump with a 10.5 cubic feet per minute (CFM) free flow capacity. The pump is driven through a V-belt system by a 110-volt, 3/4-hp motor equipped with thermal overload protection. Each unit has a built-in vacuum gauge, and is calibrated to provide an air flow rate versus pressure drop calibration curve. A running time meter, with readout to tenths of an hour, provides the total sampling time and can be reset to zero for each new sampling period. The air volume collected is determined from the calibration curve by averaging the "on" and "off" air flow rates and multiplying this average by the total time of sample collection. A quick change filter holder is mounted at one meter above the ground surface and is secured such that the open face of the filter (four-inch diameter) is toward the ground.

The average face velocity at the filter is 1.4 miles per hour (61 cm/sec). Thus, sampling is sub-isokinetic other than under extremely low wind velocity conditions. Normally, sampling sub-isokinetically results in an excess of coarse material, versus fines, due to the inertia of these particles in the air; but, the downward orientation of the filter holder reduces this bias. The sampled air and associated particulate material is actually drawn from the air stream; hence, there is discrimination against large particles due to their inclination to follow their basic trajectory. This size discrimination should be of limited significance for normal atmospheric aerosol particle size distributions and for particle size distributions pertinent to inhalation by man. For example, the settling velocity for a 10-micrometer equivalent aerodynamic particle (settling velocity in air of an equivalent-sized particle with a density of 1 g/cm^3) is 0.3 cm/sec (Silverman, et al. 1971). This is over two orders of magnitude less than the face velocity of the air sampler.

2. DETERMINATION OF THE AIR VOLUME SAMPLED

A calibration curve showing the air flow rate (CFM) versus the pressure drop, as measured by the built-in vacuum gauge, is obtained for each air sampling unit. These curves are plotted from measurements made in the Las Vegas, Nevada facility (elevation 2000 feet) and are normalized to a temperature of 21° C (about 70° F) and a pressure of 760 mm (29.92 inches) of mercury, the standard pressure at sea level.

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* Heavy-Duty Air Sampler, Research Appliance Corporation, Allison Park, PA; or Tempest Air Sampler, Gelman Instrument Corporation, Ann Arbor, MI.

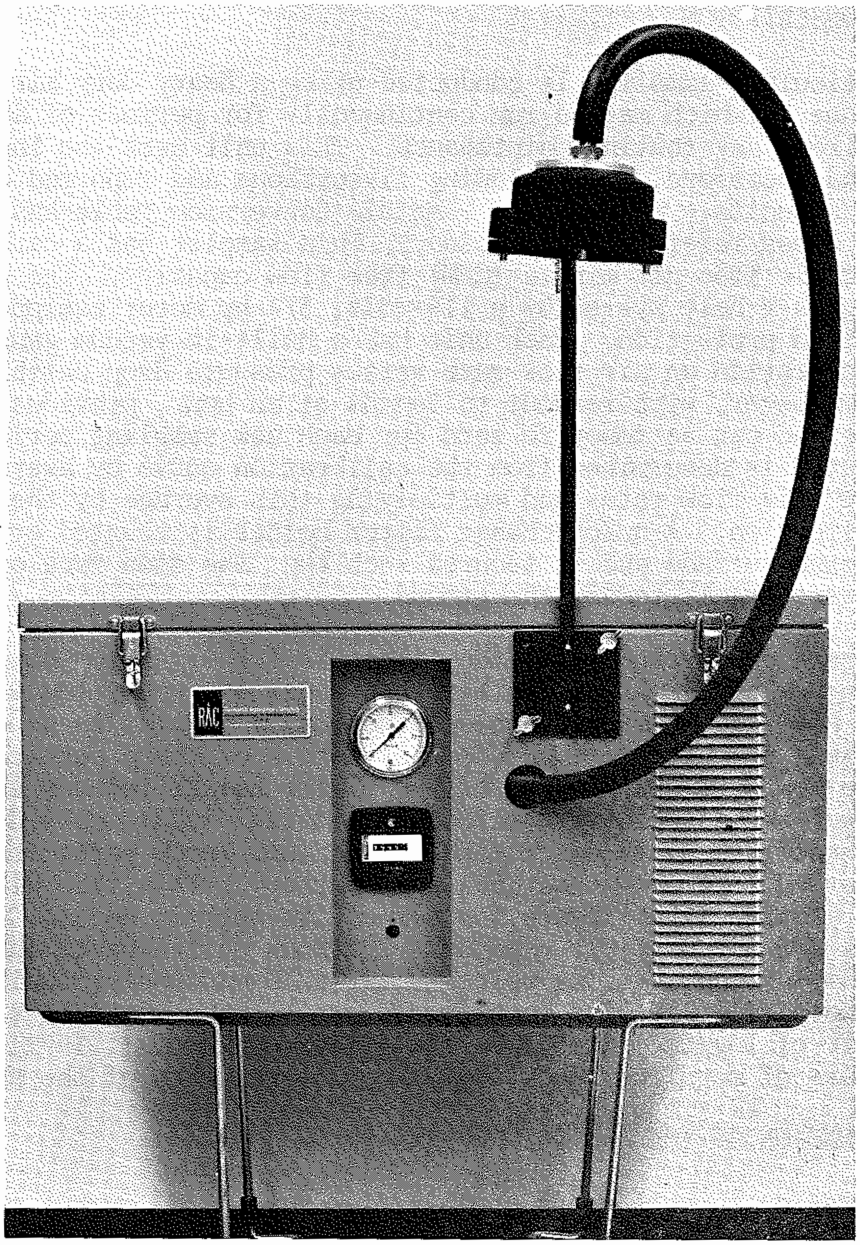

FIGURE 1. TYPICAL HIGH-VOLUME AIR SAMPLING UNIT

In order to calculate the volume of air sampled under ambient conditions at the specific air sampling site, an air density correction factor which includes the effects of air pressure, temperature, and humidity, should be considered. Such a correction factor has been derived based only on the air pressure term for each 1000-foot increment in elevation and is shown in Table 1. The influence of humidity and temperature on the air density is not considered to be significant compared to the air pressure term. For example, a fluctuation of 20° F about a normal temperature of 70° F (i.e., a range of 40° F from 50° F to 90° F) represents less than a four percent variance in the air density over this temperature range. For most ORP-LVF air sampling locations, the annual mean temperature falls within 20° F of the normal 70° F; therefore, the temperature correction term represents much less than a two percent error in the air density determinations. The use of constant air flow sampling units, which can be calibrated at the specific sampling site, would overcome this difficulty in determining the true air volume sampled.

To obtain the ambient air volume sampled, the total air volume, as calculated from the flow rate versus pressure drop calibration curve, is multiplied by the respective correction factor (Table 1) to the nearest 1000-foot increment of elevation for the specific sampling site. This air pressure correction factor (Federal Register, 1971) represents approximately a 1.9 percent change in air volume sampled per 1000-foot increment of elevation. Since most of the ORP-LVF air sampling sites are at elevations in the 4000 to 7000-foot range, this correction factor ranges from about 8 to 14 percent.

TABLE 1. AIR PRESSURE CORRECTION FACTOR PER 1000-FOOT ELEVATION INCREMENTS

Elevation (feet)	Barometric Pressure* (Inches of Mercury)	Air Pressure Correction Factor**
Sea Level (Zero feet)	29.92	1.000
1000	28.86	1.018
2000	27.82	1.037
3000	26.81	1.056
4000	25.84	1.076
5000	24.89	1.096
6000	23.98	1.117
7000	23.09	1.138
8000	22.22	1.160

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* Taken from J. H. Perry and R. H. Perry, eds, 1959, Engineering Manual, Table 4-25, McGraw-Hill Book Co.

** Air Pressure Correction Factor = $\left[\frac{\text{Standard Pressure at Sea Level}}{\text{Pressure at Site Elevation}}\right]^{\frac{1}{2}}$
(Federal Register, 1971)

TYPES OF AIR FILTERS

1. GLASS FIBER FILTER

Glass fiber filters are routinely used in air sampling networks. They are rather durable under various sampling conditions, easy to handle, inexpensive and have very good particulate collection characteristics. They are relatively non-hygroscopic, i.e., they maintain constant weight regardless of the ambient humidity. Glass fiber filters are manufactured from micro-sized filaments of pure glass. Type A filters have no special organic binders, as used in the Type E filters, and are treated to remove any trace amounts of organic fiber contaminants. Type A filters are extremely useful for trace element air pollution monitoring purposes. Both types of glass fiber filters have collection efficiencies of at least 99.7 percent for particles larger than 0.3 micrometer (μm) at a collection face velocity of 100 feet per minute (fpm). For particles as small as 0.05 μm, collection efficiencies may be as high as 98 percent (Air Sampling Instruments, 1972; Yaffe et al., 1956). Particulates are retained on the filter's surface as well as within the filter matrix; hence, the glass fiber filter is considered a "depth" filter. Type E-glass fiber filters were used in this study.

2. MICROSORBAN FILTER - (Delbag)

The Microsorban filter consists of very fine thermoplastic filaments (polystyrene) of a thickness of approximately one micrometer or less. These filaments are of hydrophobic nature, and can be charged electrostatically. Particulate collection efficiencies of almost 100 percent can be achieved for sub-micron sized dust particles. Efficiencies exceeding 99.9 percent have been measured for particles less than 0.3 μm (Air Sampling Instruments, 1972). Particle penetration of the filter media does occur; hence, Microsorban is also considered a "depth" filter. The dust storage capacity of the Microsorban filter is extremely high due to the large surface area of the matted polystyrene filaments.

3. ACROPOR (MEMBRANE) FILTER

Acropor is an acrylonitrile polyvinylchloride copolymer membrane, reinforced with nylon. It is flexible, easy to handle, and will not chip or break. The Acropor (AN-200) filter used for this study has a mean flow pore size of 0.20 μm and corresponding particulate collection efficiency greater than 99.9 percent (Air Sampling Instruments, 1972). Collection efficiencies for particles smaller than this membrane pore size are approximately the same due to the electrostatic forces resulting from the movement of air through the filter. In contrast to the "depth"-type filters, particle deposition occurs almost exclusively at the upper surface of the membrane filter.

4. CELLULOSE FIBER - PAPER FILTERS

Whatman Type #41 and #541 cellulose fiber filters were also used in this study. These filters are made of purified cellulose pulp and are relatively inexpensive, easily obtainable, and have low air flow resistance. Although there is considerable penetration of sub-micron sized particles through the cellulose paper filters, their collection efficiencies are usually considered adequate for most air sampling programs.

RADIOACTIVITY CONTENT OF AIR FILTERS

1. BLANK FILTER ANALYSES

The Gelman Type E glass fiber filters which were evaluated were standard four-inch diameter filters having an average mass with an associated two standard deviations of 0.5251 ± 0.0172 grams (measured to a tenth of a milligram accuracy). Two different sets of filters were analyzed for natural radioactivity contents. The first set consisted of five single glass fiber filters. The second set consisted of a series of five samples with each sample representing an aliquot from a composite of four filters. Individual radionuclide analysis was completed on separate aliquots of the total sample. In general, one-fourth of the total sample was analyzed for uranium content, one-fourth for thorium, one-fourth for radium, and the remainder for lead/polonium. All radiological analyses were completed at the U.S. EPA - Environmental Monitoring and Support Laboratory, Las Vegas, Nevada (EMSL-LV). Standard radiochemical procedures (Johns, 1975) were employed. Table 2 shows the individual radionuclide content and two-sigma counting error term for each analysis. Usually, counting times ranged from 30 minutes for radium-226 analysis to 1000 minutes for the actinide analyses.

Also shown in Table 2, for each group of analyses, is the average radionuclide content plus and minus the standard error of the mean at the 95 percent confidence level. A grand average of all results per radionuclide analysis, and its standard error term, is also given.

The standard error term about the mean is calculated at the 95 percent confidence level based on the "t-distribution" for the appropriate number of degrees of freedom due to the small sample sizes (usually $n < 10$). The standard error of the mean is defined as follows:

$\sigma_{\bar{X}}$ = standard error of the mean

σ = standard deviation of the results

X_i = analytical result

$\bar{X}$ = mean value = $\frac{\Sigma X_i}{n}$

n = number of sample results

df = degrees of freedom = $n-1$

t = value of the t-distribution at the 95 percent confidence level for the appropriate degrees of freedom (t values may be obtained from Appendix M, Spurr and Bonini, 1973).

TABLE 2. GLASS FIBER FILTER RADIOACTIVITY CONTENT(1)

(pCi/filter ± two-sigma counting error terms)

Radium-226		Thorium-230		Thorium-232		Uranium-234		Uranium-235(2)	
Single Filter Analysis	4-Filter Composite	Single Filter Analysis	4-Filter Composite	Single Filter Analysis	4-Filter Composite	Single Filter Analysis	4-Filter Composite	Single Filter Analysis	4-Filter Composite
0.53 ± .20	0.58 ± .15	0.19 ± .07	0.52 ± .07	0.15 ± .06	0.13 ± .04	0.10 ± .06	0.09 ± .02	0.0051 ± .0028	0.0028 ± .0009
0.39 ± .19	0.43 ± .13	0.15 ± .14	0.12 ± .04	0.11 ± .08	0.08 ± .03	0.13 ± .03	0.07 ± .02	0.0033 ± .0009	0.0023 ± .0009
0.30 ± .17	0.36 ± .12	0.17 ± .06	0.14 ± .04	0.17 ± .05	0.12 ± .05	0.14 ± .04	0.06 ± .02	0.0037 ± .0014	0.0023 ± .0009
0.24 ± .15	0.18 ± .08	0.19 ± .08	0.17 ± .05	0.17 ± .06	0.10 ± .04	0.18 ± .04	0.08 ± .02	0.0037 ± .0014	0.0070 ± .0014
0.26 ± .17	0.23 ± .09	0.18 ± .06	0.14 ± .05	0.11 ± .05	0.15 ± .05	0.06 ± .02	0.07 ± .02	0.0028 ± .0009	0.0023 ± .0009
Average (3)									
0.34 ± .15	0.36 ± .19	0.18 ± .03	0.22 ± .21	0.14 ± .04	0.12 ± .03	0.12 ± .06	0.07 ± .01	0.0037 ± .0011	0.0033 ± .0025
Grand Average (3)									
0.35 ± .09		0.20 ± .08		0.13 ± .02		0.10 ± .03		0.0035 ± .0010	

Uranium-238		Radium-228		Polonium-210		Lead-210	
Single Filter Analysis	4-Filter Composite	Single Filter Analysis	4-Filter Composite	Single Filter Analysis	4-Filter Composite	Single Filter Analysis	4-Filter Composite
0.11 ± .06	0.06 ± .02	4.78 ± 1.84	<0.84	<0.36	0.04 ± .04	<0.15	<0.28
0.07 ± .02	0.05 ± .02	<1.52	1.0 ± .95	<0.04	<0.08	0.17	-
0.08 ± .03	0.05 ± .02	<1.68	<0.84	<0.06	<0.06	<0.47	-
0.08 ± .03	0.15 ± .03	<1.68	<1.0	<0.07	-	<0.46	-
0.06 ± .02	0.05 ± .02	<1.63	<0.89	0.63 ± .29	-	<0.38	-
Average(3)							
0.08 ± .03	0.07 ± .06	<2.26	<0.91	<0.23	<0.06	<0.33	<0.28
Grand Avarage(3)							
0.08 ± .02		<1.59		<0.17		<0.32	

(1) Average four-inch diameter glass fiber filter mass ± two standard deviations of 0.5251 ± 0.0172 grams.

(2) U-235 calculated based on natural U-235 to U-238 activity ratio of 1:21.45 (or 0.0466).

(3) Average of all results with standard error about this mean based on the t-distribution at the 95 percent confidence level.

Then:

$$\sigma_{\bar{X}} = \frac{\sigma}{\sqrt{n}} = \left[\frac{\Sigma(X_i - \bar{X})^2}{n(n-1)}\right]^{1/2} \qquad \text{Equation (1)}$$

Therefore, the average and grand average are reported plus and minus the 95 percent confidence level standard error of the mean term: $(t\,\sigma_{\bar{X}})$. All results are reported in units of picocuries per four-inch diameter filter (pCi/filter). The Ra-228, Po-210, and Pb-210 contents per filter are essentially at or below the minimum detectable activity (MDA) levels for the routine analytical procedures used in this study. However, appreciable quantities of other naturally-occurring radionuclides (i.e., Ra-226 and isotopic uranium and thorium) are present in the glass fiber filter blanks. No determination of the specific source of radioactivity was made; hence, the radioactivity content reported here represents all possible sources, such as filter media, reagents, laboratory equipment, and errors introduced by analytical methods.

The results of the EMSL-LV radiochemical analyses of Microsorban filters are shown in Table 3. Fluorophotometric analysis of the natural uranium content of Microsorban filters by Argonne National Laboratory (Golchert, 1975) indicated less than 0.008 pCi/filter. Isotopic thorium analyses using alpha spectrometry indicated less than 0.00065, 0.00081, and 0.00032 pCi/filter of thorium-228, -230, and -232 respectively. These results indicate a lower level of blank analytical sensitivity for uranium and thorium (from a factor of five for uranium to 30-80 for thorium) than that achieved at the EMSL-LV laboratory (Table 3). This further indicates that individual laboratories involved in the determinations of environmental levels of natural radionuclides must exercise extreme caution to minimize analytical errors and that a quality assurance program to periodically evaluate the radioactivity content of blank filter media should be instituted.

The results of radioactivity analyses for selected radionuclides in Acropor and Whatman #541 and #41 filter media are shown in Tables 4, 5, and 6, respectively. Table 7 presents a summary of the radioactivity content of the various air filters analyzed. Glass fiber and cellulose-type filters contain the most radium-226 activity, 0.35 and about 0.27 pCi per filter, respectively. Microsorban and Acropor filters contain roughly one-third of this amount of radium-226 activity. Compared to glass fiber filters, Microsorban filters have appreciably lower contents of thorium and uranium, about one-sixth and one-fourth the activity, respectively. The concentrations of Po-210, Pb-210, and Ra-228 in the various filters were below the analytical sensitivities for the radiochemical procedures used for these analyses. In general, the analytical sensitivities for Po-210, Pb-210, and Ra-228 were at least twice the sensitivity (or MDA) for Ra-226, thorium, or uranium analyses.

2. DATA REPORTING FORMATS

The following discussions concerning the statistical treatment of the data are based on the assumption that the data are normally distributed.

TABLE 3. MICROSORBAN FILTER RADIOACTIVITY CONTENT (1)

{pCi/filter ± two sigma counting error terms}

Radium-226	Thorium-230	Thorium-232	Uranium-234	Uranium-235 (2)	Uranium-238	Radium-228	Polonium-210	Lead-210
0.18 ± .07	<0.015	<0.012	0.024 ± .015	0.003 ± .001	0.067 ± .023	0.73 ± .62	0.22 ± .09	<0.071
0.15 ± .07	<0.030	<0.027	0.016 ± .012	<0.0004	<0.009	<0.67	0.16 ± .09	<2.95
0.06 ± .05	<0.032	0.047 ± .038	<0.010	<0.0003	<0.008	<0.68	0.24 ± .09	1.21 ± .75
0.05 ± .05	<0.022	<0.016	0.015 ± .013	<0.0004	<0.009	<0.62	0.19 ± .06	<0.50
0.19 ± .08	<0.021	<0.011	0.018 ± .013	<0.0006	0.018 ± .012	<0.60	0.39 ± .08	1.75 ± .42
Grand Average (3)								
0.13 ± .08	<0.024	<0.023	0.017 ± .006	<0.0009	<0.022	<0.66	0.24 ± .11	<1.30

(1). Average four-inch diameter Microsorban filter mass ± two standard deviations of 1.0960 ± 0.1510 grams; four filter composite analyzed.
(2). U-235 calculated based on natural U-235 to U-238 activity ratio of 1:21.45 (or 0.0466).
(3). Grand average of all results with standard error about this mean based on the t-distribution at the 95 percent confidence level.

TABLE 4. ACROPOR FILTER RADIOACTIVITY CONTENT (1)
{pCi/filter ± two sigma counting error terms}

Radium-226	Radium-228	Polonium-210	Lead-210
0.08 ± .04	<0.43	0.04 ± .03	<0.54
0.16 ± .05	0.46 ± .41	<0.05	<0.09
0.06 ± .04	<0.40	<0.06	<0.34
<0.04	-	<0.05	<0.29
0.21 ± .06	<0.43	<0.04	<0.27
Grand Average (2)			
0.11 ± .09	<0.43	<0.05	<0.31

(1). Average four-inch diameter Acropor filter mass ± two standard deviations of 0.0495 ± 0.0072 grams; single filter analyzed.

(2). Grand Average of all results with two standard error terms about this mean based on the t-distribution at the 95 percent confidence level.

TABLE 5. WHATMAN #541 FILTER RADIOACTIVITY CONTENT(1)

{pCi/filter ± two sigma counting error terms}

	Radium-226	Radium-228	Polonium-210	Lead-210
Single Filter	0.40 ± .17	<2.14	0.25 ± .08	0.30 ± .18
	0.32 ± .18	2.14 ± 1.70	<0.07	<0.28
	0.18 ± .13	2.52 ± 1.95	<0.04	<0.34
	0.26 ± .15	<1.83	<0.06	<0.18
	1.01 ± .27	<1.76	<0.08	<0.23
Four Filter Composite	<0.08	<0.95	<0.18	<0.76
	0.20 ± .09	-	<0.25	<0.21
	0.42 ± .13	<1.01	<0.11	<1.32
	0.13 ± .09	<0.88	0.24 ± .11	0.21 ± .13
	0.11 ± .06	<1.01	0.16 ± .11	<0.15
Grand Average (2)	0.31 ± .19	<1.58	<0.14	<1.88

(1). Average four-inch diameter Whatman #541 filter mass ± two standard deviations of 0.6301 ± 0.0264 grams.

(2). Grand average of all results with standard error about this mean based on the t-distribution at the 95 percent confidence level.

TABLE 6. WHATMAN #41 FILTER RADIOACTIVITY CONTENT(1)

{pCi/filter ± two sigma counting error terms}

Radium-226	Radium-228	Polonium-210	Lead-210
0.15 ± .09	<0.98	-	-
0.11 ± .07	<0.61	<0.20	<1.41
0.20 ± .09	<0.80	<0.86	<1.84
0.45 ± .13	<0.92	<0.43	<0.92
0.23 ± .09	<0.86	<0.17	<1.29
Grand Average(2)			
0.23 ± .16	<0.83	<0.42	<1.37

(1). Average four-inch diameter Whatman #41 filter mass ± two standard deviations of 0.6119 ± 0.0324 grams, four filter composite analyzed.

(2). Grand Average of all results with standard error about this mean based on the t-distribution at the 95 percent confidence level.

TABLE 7. SUMMARY OF RADIOACTIVITY CONTENTS OF SELECTED AIR FILTERS (1)

(pCi/filter ± standard error about the mean based on the t-distribution at the 95 percent confidence level)

Type Of Filter	Radium-226	Radium-228	Polonium-210	Lead-210	Thorium-230	Thorium-232	Uranium-234	Uranium-235	Uranium-238
Glass Fiber	0.35 ± .09	<1.59	<0.17	<0.32	0.20 ± .08	0.13 ± .02	0.10 ± .03	0.0035 ± .0010	0.08 ± .02
Microsorban	0.13 ± .08	<0.66	0.24 ± .11	<1.30	<0.024	<0.023	0.017 ± .006	<0.0009	<0.022
Whatman #41	0.23 ± .16	<0.83	<0.42	<1.37	-	-	-	-	-
Whatman #541	0.31 ± .19	<1.58	<0.14	<1.88	-	-	-	-	-
Acropor	0.11 ± .09	<0.43	<0.05	<0.31	-	-	-	-	-

(1). Grand Average of all results per filter type, four-inch diameter filters.

a. Net Result Calculation

Since glass fiber air filters have been routinely used in ORP-LVF air sampling systems, a program has been established to adjust the measured gross radioactivity results to account for the natural radioactivity content of the blank filter. This blank filter subtraction calculation consists of subtracting the appropriate grand blank filter content (Table 2) from the gross analytical result to obtain a corrected net result per composite sampling period. The number of sample filters associated with a given composite sampling period must, therefore, be used to determine the appropriate quantity of total activity contained in the blank filters. Since continuous air samples are usually obtained, with individual filter changes about once per week, the composite sampling period is normally four weekly samples combined into one monthly period. Then, for example, the appropriate blank activity subtraction value would be four times the grand average blank content for each radionuclide of interest. No blank subtractions are made for the three radionuclides (Ra-228, Po-210, and Pb-210) which are at the analytical MDA levels.

Let G = gross analytical result

B = blank value

N = net result

Then N = G - (Number of Filters per Composite x B) Equation (2)

b. Standard Deviation of the Net Result

The standard deviation of the net result is the square root of the sum of the variances of the gross result and of the blank value.

Let σ_G = one-sigma counting error term of the gross result

σ_B = one-sigma error term of the blank value

σ_N = one standard deviation of the net result

Then $$\sigma_N = \left[\sigma_G^2 + \left(\text{NUMBERS OF FILTERS PER COMPOSITE} \times \sigma_B^2 \right) \right]^{1/2}$$ Equation (3)

c. Net Result Reporting Format

Results are reported as net result (N), with a two-sigma standard deviation ($N \pm 2\sigma_N$). The reporting units for the net results are activity per volume of air sampled (pCi/m³) and/or activity per gram of particulate matter collected (pCi/g).

Actual net result values are reported, regardless of sign (i.e., negative, positive, or zero). A negative net result indicates a statistical fluctuation of the counting data or radioactivity in the blank filter which signifies that the gross value determination lies within the uncertainty of the analytical method. In reality, there is no physical meaning to reporting negative radioactivity concentrations, but further statistical manipulations of the data require such a reporting format.

For any gross result which is equal to the two-sigma counting error term (due to sample and equipment background counts), the analytical result is reported as a less than (LT or the symbol <) value. This is also the EMSL-LV definition of the minimum detectable activity (MDA)(Bernhardt, 1976). For calculational purposes, all "less than" values are considered as real numbers with a two-sigma counting error term of equal value.

d. Volume Weighted Monthly Average Result

Data are usually reported as a monthly composited sampling period. Individual filters are composited based on sample "OFF" dates within the same calendar month. Any sampling period of less than a month's duration (e.g., weekly or daily samples) are statistically averaged, using a sampled volume weighting procedure.

Let $\overline{X}$ = volume weighted monthly average

X_i = individual net result

V_i = individual volume

n = number of samples

W_i = sampled volume weighting factor

$$W_i = \frac{nV_i}{\Sigma V_i} \qquad \text{Equation (4)}$$

Then $$\overline{X} = \frac{\Sigma W_i X_i}{n} \qquad \text{Equation (5)}$$

A sampled volume versus collection time weighting factor was chosen because of the operational variability between air sampling units. That is, two identical units may have operated for exactly the same collection period, but the volume of air sampled will probably not be the same for both units. This is due to different sampling rates caused by filter loading and typical operational variances between the units.

e. Standard Error Term of the Volume Weighted Monthly Average Result

The standard error term of the volume weighted monthly average is obtained by selecting the larger error term of either the variance between individual net results and the average, or the variance within the individual net results.

Let SD^2 between = variance calculated from the volume weighted individual net results and the average value, divided by n

SD^2 within = variance within individual net results

SE = standard error term of the volume weighted monthly average result

Where:

$$SD^2 \text{ between} = \frac{\Sigma W_i^2 (X_i - \overline{X})^2}{n(n-1)} \qquad \text{Equation (6)}$$

$$SD^2 \text{ within} = \frac{\Sigma W_i^2 \sigma_{Ni}^2}{n^2} \qquad \text{Equation (7)}$$

Then:

SE = the larger of either SD between or SD within Equation (8)

For repetitive counting of the same sample, the between error and within error are identical. The between error for an average of a number of samples includes the within error and the error from the uniqueness of the samples as well as any analytical error (Jaffey, 1960). Thus, for most cases the between error is larger than the within error.

The use of the concept of less than values, for values below the detection limit, can often result in a group of samples being reported as identical less than results. The calculated between error for such a group of identical less than values would be zero. Such a result would be the figment of the "less than" reporting technique, and not a valid error estimate. Thus, when less than values are reported, the within error should be calculated by setting the individual counting errors equal to one-half of the less than value (the less than value is the two-sigma error). Both the between and the within error terms should be calculated and compared, and the larger of the two error terms, between or within, should then be used as the standard error term of the volume weighted monthly average result.

f. The t-Distribution

Since the number of samples being averaged is usually small (i.e., $n < 20$) the "t-distribution" should be used, instead of the normal distribution, to obtain the standard error term of the monthly average at the 95 percent confidence level. Then the reporting format becomes: $\overline{X} \pm t \times SE$.

Values of t may be obtained for the appropriate degrees of freedom at the 95 percent confidence level from Appendix M, Spurr and Bonini, 1973. For example, for an average determination using five sample results, the degrees of freedom would be four and the t value would be 2.78 instead of the 1.96 value for the normal distribution at the 95 percent confidence level.

g. Grand Average

A volume weighted grand average result is calculated for selected time periods (usually an annual average) using all available individual data and volume weighting these results. The standard error of this grand average is also calculated. These calculations are preformed in the same manner as shown in Equations 5 through 8 and the appropriate t-distribution value for the 95 percent confidence level is applied to the calculated standard error term.

AIRBORNE PARTICULATE COLLECTION EVALUATIONS

1. DUST LOADING DETERMINATIONS

The dust loading of each filter type was determined by measuring the mass of each filter prior to and at the end of a sampling period. These mass measurements were made under controlled laboratory conditions, at 21° C room temperature. In order to establish the degree of hygroscopicity of each filter type, relative humidity measurements were periodically made using a sling psychrometer. Mass measurements were made at an average relative humidity of 35 percent, ranging from 15 to 55 percent. Glass fiber filters showed a relative error of 2.3 percent of the filter mass due to filter hygroscopicity. Similarily, Microsorban and Whatman #41 media showed 1.1 percent and 1.5 percent mass variations with changes in relative humidity, respectively.

Dust loading determinations were also attempted using a "dry ashing" procedure (i.e., igniting the filter media at 800° C). This method proved inadequate for the glass fiber media which leaves a silicon residue upon ashing. The Microsorban and Whatman #41 media were essentially ashless; therefore, dust loading capacities could be determined from the mass of the remaining residue if the organic and volatile components (e.g., Polonium-210) of the airborne particulates are unimportant. Dust loads are reported in units of microgram per volume of air sampled ($\mu g/ft^3$).

2. REPLICATE SAMPLING VARIABILITY

Air particulate collection effectiveness and the dust loading were evaluated using selected air filters and standard air sampling procedures. Since adequate facilities were not available to provide constant airborne particulate concentrations of known particle sizes, tests were run out-of-doors at the Las Vegas facility under ambient field conditions. These tests were conducted using the air sampling units as described above. The units were arranged so that the air sampling inlets were in very close proximity to each other in order to assure sampling of equivalent airborne particulate concentrations.

In order to establish the sampling variability of the air sampling unit, two identical units were operated side-by-side during the same time period. Glass fiber filters were employed as the particulate collection medium and the results of these tests are shown in Table 8. Assuming that each sampling unit was capable of sampling an equivalent airborne particulate concentration, the relative sampling variability between the two units ranged from zero percent to 12.64 percent, with an average of 6.79 ± 4.72 (one-sigma) percent. Using the t-distribution for six degrees of freedom at the 95 percent confidence level, the t value would be 2.447 and the error would then be 11.55 percent.

TABLE 8. REPLICATE SAMPLING VARIABILITY* - GLASS FIBER FILTERS

On Flow CFM	Off Flow CFM	Total Time Hours	Total Volume ft^3	Total Dust Load Grams	Dust Load Capacity $\mu g/ft^3$	Replicate Sampling Variability Percent
10.3	10.1	45.4	27784	0.0245	0.88	1.14
9.2	9.2	45.4	25060	0.0217	0.87	
10.4	9.9	69.8	42718	0.0552	1.29	6.20
9.2	9.1	69.7	38474	0.0464	1.21	
10.4	9.5	53.2	31920	0.0778	2.44	10.66
9.2	9.0	53.4	29156	0.0634	2.18	
9.6	8.9	47.7	26617	0.0916	3.44	8.99
9.3	9.1	47.7	26330	0.0994	3.78	
9.4	9.2	71.7	40009	0.0512	1.28	7.91
9.7	9.2	71.7	40869	0.0569	1.39	
9.2	9.1	50.4	27821	0.0442	1.59	12.64
9.7	9.4	50.5	29088	0.0530	1.82	
9.9	8.7	70.9	39562	0.1454	3.68	0
10.4	8.7	71.0	40896	0.1505	3.68	

* Replicate Sampling Variability = $\frac{\text{Maximum Dust Load - Minimum Dust Load}}{\text{Maximum Dust Load}}$

The resultant sampling variability is, therefore, 6.79 ± 11.55 percent, with a maximum value of 18.34 percent.

3. FREQUENCY OF FILTER CHANGING

The evaluation of weekly versus daily and every-other-day air filter changing was conducted using three air sampling units positioned side-by-side. Glass fiber filters were used as the particulate collection medium and the dust loading was determined for each filter. The results of these tests are shown in Table 9.

The greatest dust loading (0.2383 grams, corresponding to a concentration of 2.89 μg/ft^3) was obtained for the weekly sampling period using only one air filter. This weekly sampling period result is in excess of the expected maximum 18.34 percent replicate sampling variability from the results of the other two shorter sampling periods results (i.e., 2.38 and 2.37 μg/ft^3). Similar conclusions are obtained using the collection time weighted results (Table 9). A possible explanation is that frequent glass fiber filter changing results in the loss of particulate matter from the filter's surface due to normal handling during the filter changing procedure. For routine air sampling using glass fiber filters, sample collection periods of about one-week duration per filter appears to be adequate. It should be noted that this conclusion is based on only one trial result.

4. DUST LOADING COMPARISONS

In order to evaluate selected air filters for suitability as air particulate collection media, field tests were conducted to permit relative comparisons of the dust loading of each filter type. Three air sampling units were operated side-by-side using the same sampling periods, but each unit utilized a different filter medium. The results of these tests are shown in Table 10.

Glass fiber appears to have a dust loading capacity about twice that of Whatman #541 paper filters and the Acropor membrane filters. The dust loading capacity of glass fiber filters ranges from roughly two to ten times the values obtained using Whatman #41 paper filters.

Microsorban versus glass fiber filter comparisons are shown in Table 11. For the two tests using one-week collection periods, Microsorban filters had the greater dust loading of 1.28 versus 1.07 and 2.17 versus 1.62 μg/ft^3, a range of 16 to 25 percent greater than the glass fiber filter results.

The results from Microsorban filters changed weekly versus about every two-days show that frequent Microsorban filter changes yield greater total dust loading results. For the first series of tests, the weekly dust load was 1.28 μg/ft^3 versus the average dust load for three filter changes of 1.73 μg/ft , a 26 percent greater dust load than the weekly value. For the second series of tests, the weekly value was 2.17 μg/ft^3 versus the every two-day change cycle value of 2.31 μg/ft^3, a six percent increase. Similar conclusions are obtained using the collection time weighted dust loading results. In general, optimum dust loading was obtained for Microsorban filters with sample collection periods of about two days; but weekly filter changes also

TABLE 9. EFFECT OF FREQUENCY OF FILTER CHANGING - GLASS FIBER FILTERS

Sampling Period	On Flow CFM	Off Flow CFM	Total Time Hours	Total Volume ft^3	Total Dust Load Grams	Dust Load $\mu g/ft^3$	Weighted Dust Load* $\mu g/ft^3$
Weekly	9.2	7.4	165.6	82469	0.2383	2.89	2.89
2 days	9.7	9.2	46.6	26562	0.0478	1.80	-
3 days	9.9	8.7	70.9	39562	0.1454	3.68	-
2 days	9.7	9.6	47.9	27878	0.0305	1.09	-
7 days TOTAL	-	-	165.4	94002	0.2237	2.38	2.40
1 day	10.5	10.3	22.5	14040	0.0267	1.90	-
1 day	10.6	10.3	24.0	15120	0.0264	1.75	-
3 days	10.4	8.7	71.0	40896	0.1505	3.68	-
1 day	10.4	10.4	23.2	14477	0.0138	0.95	-
1 day	10.4	10.2	24.5	15141	0.0184	1.22	-
7 days TOTAL	-	-	165.2	99461	0.2358	2.37	2.41

* Weighted Dust Load = $\frac{\Sigma(\text{Dust Load})\ (\text{Collection Time})}{\text{Total Time}}$

TABLE 10. DUST LOADING COMPARISONS

Filter Type	On Flow CFM	Off Flow CFM	Total Time Hours	Total Volume ft^3	Total Dust Grams	Dust Load $\mu g/ft^3$
Glass Fiber	9.6	6.0	95.1	44506	0.4756	10.69
Whatman #541	9.9	3.6	95.1	38801	0.2025	5.22
Acropor	6.3	1.9	95.1	23395	0.0987	4.22
Glass Fiber	10.5	6.7	164.9	85088	0.2599	3.05
Whatman #541	9.5	3.8	165.1	66370	0.1116	1.68
Acropor	4.5	2.6	164.9	35618	0.0587	1.65
Glass Fiber	9.5	6.5	262.7	126096	0.4751	3.77
Whatman #541	9.7	3.8	261.7	106774	0.1694	1.59
Acropor	4.5	1.5	262.7	47286	0.1254	2.65
Glass Fiber	9.9	6.9	211.7	106697	0.2260	2.12
Whatman #41	8.9	8.2	211.7	109237	0.0230	0.21
Glass Fiber	9.5	6.0	601.3	281408	0.5159	1.83
Whatman #41	4.6	3.6	601.2	147895	0.1314	0.89

TABLE 11. DUST LOADING COMPARISONS - MICROSORBAN VERSUS GLASS FIBER FILTERS

Filter Type	On Flow CFM	Off Flow CFM	Total Time Hours	Total Volume ft^3	Total Dust Grams	Dust Load $\mu g/ft^3$	Weighted Dust Load* $\mu g/ft^3$
Microsorban	9.7	9.5	46.3	26669	0.0489	1.83	-
	9.6	9.3	65.6	37392	0.0404	1.08	-
	9.9	9.5	52.5	30555	0.0472	2.43	-
TOTALS	-	-	164.4	94616	0.1635	1.73	1.72
Microsorban	10.8	9.2	164.6	98760	0.1259	1.28	1.28
Glass Fiber	9.4	8.7	164.6	89872	0.0961	1.07	1.07
Microsorban	9.7	9.2	48.0	27360	0.1176	4.30	-
	9.7	9.6	64.9	37772	0.0569	1.51	-
	9.8	9.7	55.9	32869	0.0520	1.58	-
TOTALS	-	-	168.8	98001	0.2265	2.31	2.33
Microsorban	9.2	8.7	169.0	91260	0.1977	2.17	2.17
Glass Fiber	10.8	9.8	169.0	104442	0.1696	1.62	1.62

* Weighted Dust Load = $\frac{\Sigma(\text{Dust Load})\ (\text{Collection Time})}{\text{Total Time}}$

appear to be adequate for routine sample collection. Of all the air filters tested, Microsorban filters had the greatest dust loading capacity.

5. MEASUREMENT OF SAMPLED VOLUME

The technique for estimating sampled volume was described above in the "Air Sampling System" section of this report. There are several potential sources of error or inaccuracy associated with the estimation of sampled volume. These include:

1. Leakage of air around the filter and the gasket of the sample filter holder.
2. Inaccuracies in reading the vacuum gauge (the vacuum readings are translated to flow rate). The gauge can only be read to two significant figures and operators are prone to read them to only one significant figure.
3. The sampled volume is based on the average sampling rate as determined from the initial and final flow rates. This assumes a linear decrease in sampling rate with time.

The above items are difficult to quantitate, but some information was gathered concerning Item 3.

Figure 2 presents time versus flow-rate profiles indicative of those obtained for several types of filters. The plots are flow rate, in cubic feet per minute, versus sampling time. The data points (measured line) represent actual vacuum measurements and associated flow rates and, thus, the best estimate of the actual sampled volume. The dashed line represents the flow rate estimated from the initial and final flow rates and is indicative of the flow rate actually used to calculate the concentration of the various radionuclides in the sampled air. The indicated percent error is the difference between the area under the dashed line and the measured line divided by the area under the measured line. The net grams of airborne particulate collected on each filter is also indicated.

Figures 2a and 2b indicate that the normal estimate of sample volume is in error by up to 70 percent for the indicated samples using Acropor or Whatman #541 filters. These plots relate to sampling resulting in a mass loading of 0.1 to 0.2 grams of particulate matter on the filter. This is relatable to an ambient dust concentration of 50 $\mu g/m^3$ (1.4 $\mu g/ft^3$) and a sampling rate of 8 ft^3/min for one week, which gives a dust loading of 0.1 gram.

There is probably an additional error as a result of the decreased entrapment of airborne particulates due to the reduced face velocity resulting from the increased air resistance of the filter as dust is accumulated. Both the error in the estimated volume and the reduced entrapment of airborne particulates may account for some of the discrepencies in the mass loading indicated in the previous section.

ALL FIGURES:

Y = SAMPLER FLOW RATE (ft³/min)

X = SAMPLING TIME (hours)

%ERROR = % THAT THE AVERAGE VOLUME IS LESS THAN THE TRUE INTEGRATED VOLUME

g DUST = GRAMS OF DUST COLLECTED ON FILTER

FIGURE 2(a).

Jan. 24, to Feb. 4, 1975

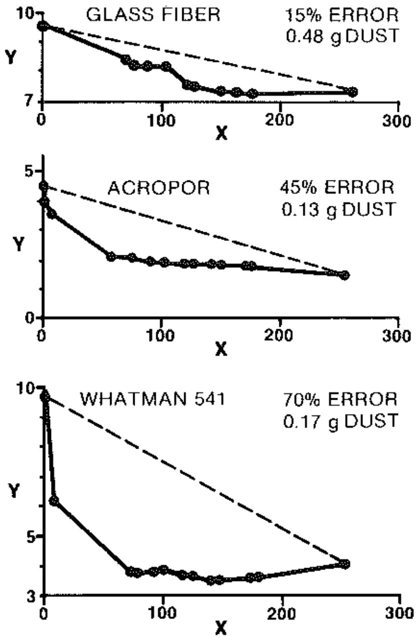


FIGURE 2(b)

Jan. 20, to Jan. 24, 1975

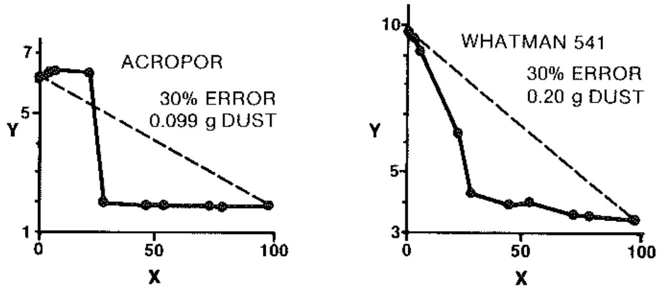
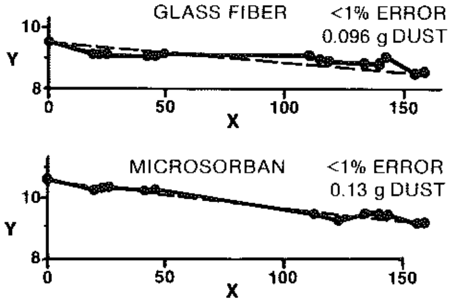


FIGURE 2(c)

April 9, to April 16, 1975



April 2, to April 9, 1975

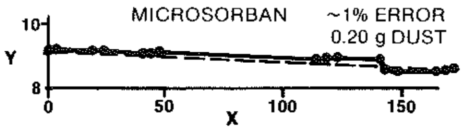


FIGURE 2. SAMPLER FLOW RATE (ft³/min) VERSUS SAMPLING TIME (hours)

The plots in Figures 2a and 2b note errors of 30 to 70 percent for Acropor and Whatman #541 for mass loadings of 0.1 to 0.2 grams. Figure 2a notes an error of only 15 percent for a mass loading of 0.48 grams on glass fiber. The plots in Figure 2c show a negligible error in the volume estimate for mass loadings of 0.1 to 0.2 grams on Microsorban or 0.1 gram on glass fiber filters.

The plots illustrated in Figure 2 are generally indicative of the flow-rate versus time profiles of the other similar samples of this study. Thus, it is concluded that glass fiber and Microsorban filters are preferable to Whatman #541 and Acropor for mass loading in the range of the stated experimental values (generally 0.1 to 0.5 gram per 4-inch diameter filter). There is the additional concern that as a result of the decreased flow rates towards the end of the sampling period, that Whatman #541 (also #41) and Acropor filters will not sample the airborne activity present at a representative sampling rate.

In summary, since Microsorban filters have minimal natural radioactivity content (Table 3), compared to glass fiber filters (Table 2), the need to perform a blank filter radioactivity content subtraction from the ambient gross results, as is the case with the glass fiber filter, is usually not necessary unless background determinations are being made. Compared to the other filter types tested, the Microsorban filter also appears to have the highest dust loading and retention capacity. As a result of these comparisons, Microsorban filters have replaced glass fiber filters for routine airborne particulate sampling conducted by ORP-LVF.

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APPENDIX A

METRIC CONVERSION TABLE

Multiply	By	To Obtain
Cubic feet (ft^3)	0.02832	Cubic meters (m^3)
Cubic feet per minute (CFM)	472	Cubic centimeters per second (cm^3/sec)
Feet (ft)	0.3048	Meters (m)
Inches (in)	25.4	Millimeters (mm)
Inches (in)	2.54	Centimeters (cm)
Inches (in)	0.0254	Meters (m)
Micrograms per cubic foot ($\mu g/ft^3$)	35.31	Micrograms per cubic meter ($\mu g/m^3$)
Temperature (degrees F - 32)	0.555	Temperature (degrees C)

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16. ABSTRACT

This report discusses the evaluation of selected air filters for their suitability as collection media for the radiological analyses of airborne particulate matter. Standard four-inch diameter filters were analyzed for their natural radioactivity contents. Of the filters tested, glass fiber filters had the highest radium-226 content (0.35 picocuries per filter) and Microsorban filters contained roughly one-third of this activity. Microsorban filters also have lower uranium and thorium contents than do the glass fiber filters. For the analytical methods used in this study, all filter types tested had undetectable polonium-210, lead-210, and radium-228 contents. Dust loading characteristics of selected filters were also evaluated. The results indicate that Microsorban filters have higher collection and dust retention efficiencies (ranging from 6 to 26 percent greater) than do glass fiber filters. As a result of these evaluations, Microsorban filters are being used in the routine environmental radiological air quality monitoring networks operated by the Office of Radiation Programs - Las Vegas Facility (ORP-LVF).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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