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SURVEY OF LIFE-CYCLE COSTS OF GLASS-PAPER HEPA FILTERS*

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Abstract

We have conducted a survey of the major users of glass-paper HEPA filters in the DOE complex to ascertain the life cycle costs of these filters. Purchase price of the filters is only a minor portion of the costs; the major expenditures are incurred during the removal and disposal of contaminated filters. Through a combination of personal interviews, site visits and completion of questionnaires, we have determined the costs associated with the use of HEPA filters in the DOE complex.

The total approximate life-cycle cost for a glass-paper HEPA filter is $3,000 for one considered low-level waste (LLW), $11,780 for transuranic (TRU) and $15,000 for high-level waste (HLW). The weighted-average cost for a standard HEPA filter in the complex is $4,753. Although the cost estimate represents an average for all sizes and types of HEPA filters used in DOE facilities, the majority of the filters are 2' x 2' x1' filters with wooden frames, deep pleated glass-fiber media, and an adhesive sealant.

I. Introduction

We have been working on a project to develop a cleanable, re-usable stainless steel HEPA filter (1). The steel filter will be more reliable than the glass-paper filter due to its higher strength. We also believe that the steel filter will be more cost-effective over its life-cycle than the glass-paper filter, due to the re-usability of the steel filter. In order to make this comparison, we needed to have information about the life-cycle costs of the glass-paper filters. Therefore, we initiated this survey and cost analysis.

Previous cost studies were not adequate for our needs. None of the work was current, nor looked specifically at the cost of HEPA filters, only at the cost of the entire air cleaning systems, including capital costs, ongoing maintenance and replacement of parts and filters. Researchers from Harvard University (2,3,4,5) conducted a multi-year study of many AEC sites and air cleaning systems. They found that the initial capital costs were approximately 20% of the cost of the systems, and that filter replacement (materials and labor) represented 65% or more of the cost of the system (4). They noted that data on

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operational costs was more difficult to obtain than data on purchase and installation costs, and that the compilation of the data represented broad averages that could have significant deviations (5). Jordan (6) made a detailed cost study of 3 different air cleaning systems, none of which contained HEPA filters. However, one comment in his report is also applicable in explaining the high handling and disposal costs of HEPA filters. He notes "the matter of requiring men to enter highly contaminated areas in protective equipment to change filter media should receive more attention. The men generally earn hazard pay and must work at a slower rate."

II. Filter Usage

We gathered data on filters processed through the three DOE filter test and certification stations (Hanford, Oak Ridge and Rocky Flats) for the period 1987-90. We created a database from this information, which allowed us to identify the number of filters tested in each fiscal year, major users, mix of filter sizes in use, and mix of manufacturers. That data is shown in Appendix A (Figure 1 and Tables 1-3).

Highlights of that data:

- Average annual filters tested/used - 11,478
- Largest user - Rocky Flats - 3,476 annually or 30%
- Most common capacity/size - 1000 cfm, 24"x24"x12" - 64%
- Most common vendor - Flanders - 74%

III. Cost of Glass-Paper Filters

The typical stages or costs in the life cycle of a glass-paper HEPA filter are as follows:

1. purchase, receipt and certification
2. filter change-out (remove used filter, install new filter)
3. in-place leak testing of new filter
4. pre-packaging assay of used filter
5. filter packaging/size reduction
6. post-packaging assay
7. shipping and handling
8. final disposal
9. administrative overhead

Generally, the costs related to HEPA filters are not tracked separately; they are included in various departments or waste disposal groups along with all other types of waste handled. To gather specific and detailed information on these different stages, we sent questionnaires, made site visits and had telephone conversations with various personnel at different user locations. We were primarily interested in the top four DOE filter users (Rocky Flats, Savannah River, Oak Ridge and Hanford), as they comprised 73% of all filters used in the DOE complex.

We were able to obtain data about the number of personnel or man-hours involved in each life cycle stage fairly easily. Labor rates, overhead rates and other costs were more difficult. Based on the cost data we were able to obtain, we have used $60 per hour as an average, fully loaded labor rate, and applied that to the time data for the various stages.

We will discuss each of these stages in the following sections. The various costs and calculations are summarized in Appendix B, Tables 1-2, and the text will be referencing those figures. In generating the figures for Table 2, we have assumed that all other locations not surveyed will have similar costs as those of Hanford, which has multiple single filter sites. We have also assumed that the LLW/TRU mix is approximately the same as the overall mix of the top 4 users, or 80%:20%.

Purchase, Receipt and Certification

We have estimated that the cost of purchasing, receiving and certifying a HEPA filter to be approximately $450 per filter. This includes:

-purchase cost from the vendor,
-purchasing overhead
-shipping charges (to a certification station and to the user location)
-transportation labor and overhead
-receiving labor and overhead
-storage costs
-quality assurance costs.

We received detailed information on this process from the Hanford Plant, and during visits and conversations, found the handling at the other plants to be very similar. We therefore used one cost as representative of all locations. Any variances from plant to plant would be minimal.

Filter Change-Out

The process of removing the old contaminated filter and installing a new filter is the most labor-intensive stage of the life-cycle. We received estimates ranging from 210 to 360 man-hours for changing large banks of filters (18-30 filters), and from 16 to 40 man-hours to change small locations (1-2 filters). A brief description of the various locations follows.

Rocky Flats typically utilizes 4 to 10 people (technicians inside and outside the plenum, supervisors, health & safety technicians, waste coordinators) at various stages of the process, and changes a bank of 30 filters in about 210 man-hours. Approximately 50% of the time is related to setting up and taking down the various tools, instruments and safety equipment used in the operation; this set up and take-down process is very similar whether 1 filter or 30 filters are being changed. Also, they make no allowances for whether the filters are LLW or TRU; their process is the same. 210 man-hours times $60 per hour divided by 30 filters equals a cost of $420 per filter to change.

Savannah River basically follows the same process; their time estimate was approximately 360 man-hours, as they use 9 people for a week. However, as they are typically changing a bank of only 18 filters, the set-up time is spread over a smaller number of filters, and when combined with the higher number of overall hours, the per unit cost to change the filters is much higher than Rocky Flats. 360 man-hours times $60 per hour divided by 18 filters equals a cost of $1200 per filter to change. They have both LLW and TRU filters, but the change-out process is the same.

The large majority of the filter locations at Oak Ridge are 1-filter sites. They can change a filter with 4 people in 4 hours; again, the bulk of the time is spent in set up and take-down of the safety equipment. 16 man-hours times $60 per hour equals $960 per filter. Oak Ridge has only LLW filters.

Hanford is similar to Oak Ridge in that the majority of the sites contain only 1 filter. However, they estimate that they have more TRU (60%) sites than LLW (40%), and they estimate that it takes them 25% less time to change LLW filters than TRU filters. They take approximately 27 man-hours on a TRU filter, and approximately 20 hours on an LLW filter. Twenty-seven man-hours times $60 per hour equals $1,620, and with some materials costs added (bag for used filters), the total cost is $1,650 per filter. A LLW filter would cost $1,250 at 75% of the time and with the same bag costs.

An important point to note here is that the set-up and take-down time makes up a large part of the total process, and that it is more or less the same whether there is one filter being changed or 30 filters. The marginal amount of time needed to change additional filters once set-up is complete is very small. Therefore, those locations with filter sites where multiple filters can be changed for one set-up and take-down process will have lower per-filter costs, as this "fixed" cost can be spread over more filters.

<u>In Place Leak Testing</u>

In-place leak testing is similar to the change-out situation, in that there is significant set-up and take-down time whether there is one filter to be tested or many. Again, the more filters tested, the more the "fixed" set-up/take-down costs are spread, and the lower the cost per filter.

Rocky Flats uses 3-5 people for approximately 44 man-hours, and tests a bank of 30 filters. This works out to a cost of approximately $90 per filter for testing. They utilize the same procedure for LLW or TRU filters.

The data from Savannah River showed that they have a budget of approximately $400K per year, and they annually test approximately 2,000 filters. This works out to a cost of $200 per filter. They have 3 people and one truck assigned full-time to test filters throughout the plant, and utilize the same procedure for LLW or TRU filters.

Oak Ridge utilizes 3 people for 2 hours to test a filter. 6 hours times $60 per hour equals $360 per filter. They only have LLW filters.

Hanford uses 6 people for approximately 25 man-hours to test TRU filters. This works out to a total of $1,500, and is applicable to only 1 filter, which makes up the majority of their filter sites. Again, the costs are decreased for LLW filters to approximately $1,125 per filter.

Pre-Packaging Assay

Rocky Flats utilizes 8 people in their assay department (supervisor, handling technicians, health safety technicians and clerical staff), and processes approximately 30-40 filters in an 8-hour shift. This works out to a cost of $100-130 per filter. We have used the more conservative lower cost for purposes of this analysis. They use a LOSAC system (LOw Specific Activity Counter) to separate LLW from TRU filters, using 100 nanocuries of plutonium per gram of matrix material as the separation threshold. The counters operate by measuring gamma rays emitted from 55 gallon drums through a sodium iodide detector. The gamma emissions are converted to numeric data through a digital analyzer, and evaluated by the software in the counter. The software compensates for density of material, subtracts background radiation, and generates assay values. The assay department conducts assays on many other items in addition to HEPA filters. Other plants seemed to use the same process as Rocky Flats, so we have utilized this cost as representative for all locations. Even significant variances in costs would have little or no impact on the overall cost, as this is a small part of the total.

Filter Packaging/Size Reduction

Rocky Flats is the only location of the top four users that performs any size reduction of the filters. They crush LLW filters only, and the size reduction process allows them to reduce their overall cost. They utilize 17 people, and in a typical 8 hour shift (115 total man-hours), can crush 24 filters for storage in one box. The size reduction cost works out to approximately $300 per filter. The filters are put into a special box which costs $960, which gives the filter packaging cost of $40 ($960 divided by 24 filters). TRU filters are simply put into a special TRUPACT box, with a minimal amount of labor. The box costs approximately $1,140, and total labor time is one hour, giving a total packaging cost for TRU filters of $1,200.

Savannah River puts 8 LLW filters into a B-25 box, which costs $400. This makes the per filter packaging cost $50. They put TRU filters into the same box as Rocky Flats; thus the $1,200 cost.

Oak Ridge puts 8 LLW filters into a metal box that costs approximately $800, giving a cost of $100 per filter.

Hanford quoted a cost of $325 for the box to store LLW wastes, and $1,150 for the box to store TRU waste. They also quoted an "average" of 5 man-hours per box, or $300 at $60 per hour. This may be a combined average of labor on TRU and LLW boxes, but we were unable to clarify. These figures provide the totals of $625 for LLW and $1,450 for TRU filters.

Post-Packaging Assay

Rocky Flats used the same procedure to assay the packaged filters as they used to assay the unpackaged filters. They spent less time on the LLW filters after packaging, and the same on TRU filters after packaging. Other plants followed a similar process, and we have used the one set of costs as representative of this stage.

Shipping and Handling

All locations estimated the time needed to prepare a packaged filter for shipment at 2-4 man-hours, which includes palletizing, completing shipping paperwork, loading onto appropriate transportation, etc. They also noted that slightly more time was spent on TRU shipments than LLW. The $150 and $200 figures are averages of those estimates. Hanford has also included a one-time temporary storage charge that they incur before shipment to a final disposal site. Costs also include any transportation charges, which would only be a few dollars per filter.

Final Disposal

Depending on whether the filter is classified as low level waste (LLW), transuranic waste (TRU) or high level waste (HLW), the filter will eventually be sent to the Nevada Test Site (NTS), the Waste Isolation Pilot Plant (WIPP) or the Yucca Mountain burial site, respectively.

NTS charges $10 per cubic foot, and the measurement is based on the outside dimensions of the item being stored.

WIPP has a cost per cubic foot of approximately $900. The operating budget for WIPP for the planned 25-year life of the facility is $4.5 billion, and the capital budget for the facility is $1 billion. The storage capacity will be 6.2 million cubic feet. $5.5 billion divided by 6.2 million cubic feet is $887 per cubic feet; we rounded to $900 for purposes of the disposal calculations.

Rocky Flats sends 24 crushed LLW filters in a 4'x4'x7' (112 cubic feet) to NTS. At $1,120 per box, divided by 24 filters, the final disposal cost is approximately $50 per filter. They send 13 TRU filters in the same box to WIPP.

112 cu. ft. times $900 per cubic ft, divided by 13 filters, equals a per filter cost of $7,750.

Savannah River stores their LLW filters on site; they estimate the burial cost to be $25 per cubic foot. The B-25 boxes are approximately 45 cubic feet, and hold 8 filters. This works out to a cost of approximately $140 per filter. TRU filters are in TRUPACT boxes, and are being held for eventual shipment to WIPP. Cost of storage at WIPP will be approximately $6,200 per box, as each box is 6.88 cubic feet, at $900 per cubic foot.

Oak Ridge sends their LLW filters to be destroyed by a private vendor. They are charged $2 per pound, and estimate that the used filters weigh 50 lbs. on the average. They also use approximately 2 hours tracking time. $100 for the filter and $100 for labor gives the $200 disposal cost.

Hanford has an on-site burial ground for LLW filters; they estimate the cost per cubic foot of the burial ground to be approximately $30. The filters in boxes are about 5 cubic ft., giving a total cost for LLW of $150. TRU filters are sent to WIPP, and will have the same cost as Savannah River of $6,200.

Administrative Overhead

In all discussions with various personnel at the different plants, they noted that there were always "administrative paperwork costs" or "tracking costs" related to handling of the filters. There were also supplies consumed, equipment costs, time in handling of filters between stages, etc. that related to filters, but also to all other waste items processed through the plants. They could not quantify in hourly terms or dollars a direct amount, but estimates ranged from 5% to 20%. We have added this category, and used a slightly higher amount for TRU filters than LLW filters.

High Level Waste

There seemed to be very few instances of filters that qualified as high-level waste. Hanford noted some, but had no estimates of time or costs, as those filters received very special treatment and were infrequently handled. An educated guess by them put the cost at approximately $15,000-20,000. We have used the low end of the estimate to be conservative. We also estimate that there are less than 1% of the filters in use that are HLW; we therefore used 100 annually in our calculation of the average cost of a filter in the complex. The total cost average would only be affected by only 3% even if we were 100% wrong in our estimate on these filters, so these figures should be adequate for this analysis.

IV. Summary

We conducted a survey of the major users of glass-paper HEPA filters in the DOE complex to ascertain the life cycle costs of these filters. Purchase price of the filters is only a minor portion of the costs; the major expenditures are incurred during the removal and disposal of contaminated filters. Through a combination of personal interviews, site visits and completion of questionnaires, we determined the costs associated with the use of HEPA filters in the DOE complex.

Utilizing information from the 4 DOE filter test stations, we created a database of information and found the number of HEPA filters used annually by location, sizes of HEPA filters most commonly used and major vendors. This allowed us to focus our investigations.

We identified 9 different stages in the life-cycle of the HEPA filter, and determined the various material and labor costs for each stage. From that information, we calculated total costs per filter for the 4 largest HEPA filter users in the DOE complex. We then used the cost per plant figures to calculate a weighted average cost (by type of waste) for HEPA filters across the DOE complex.

The total approximate life-cycle cost for a standard (2'x2'x1') glass-paper HEPA filter is $3,000 for one considered low-level waste (LLW), $11,780 for transuranic (TRU) and $15,000 for high-level waste (HLW). The weighted-average cost for a standard HEPA filter in the complex is $4,753.

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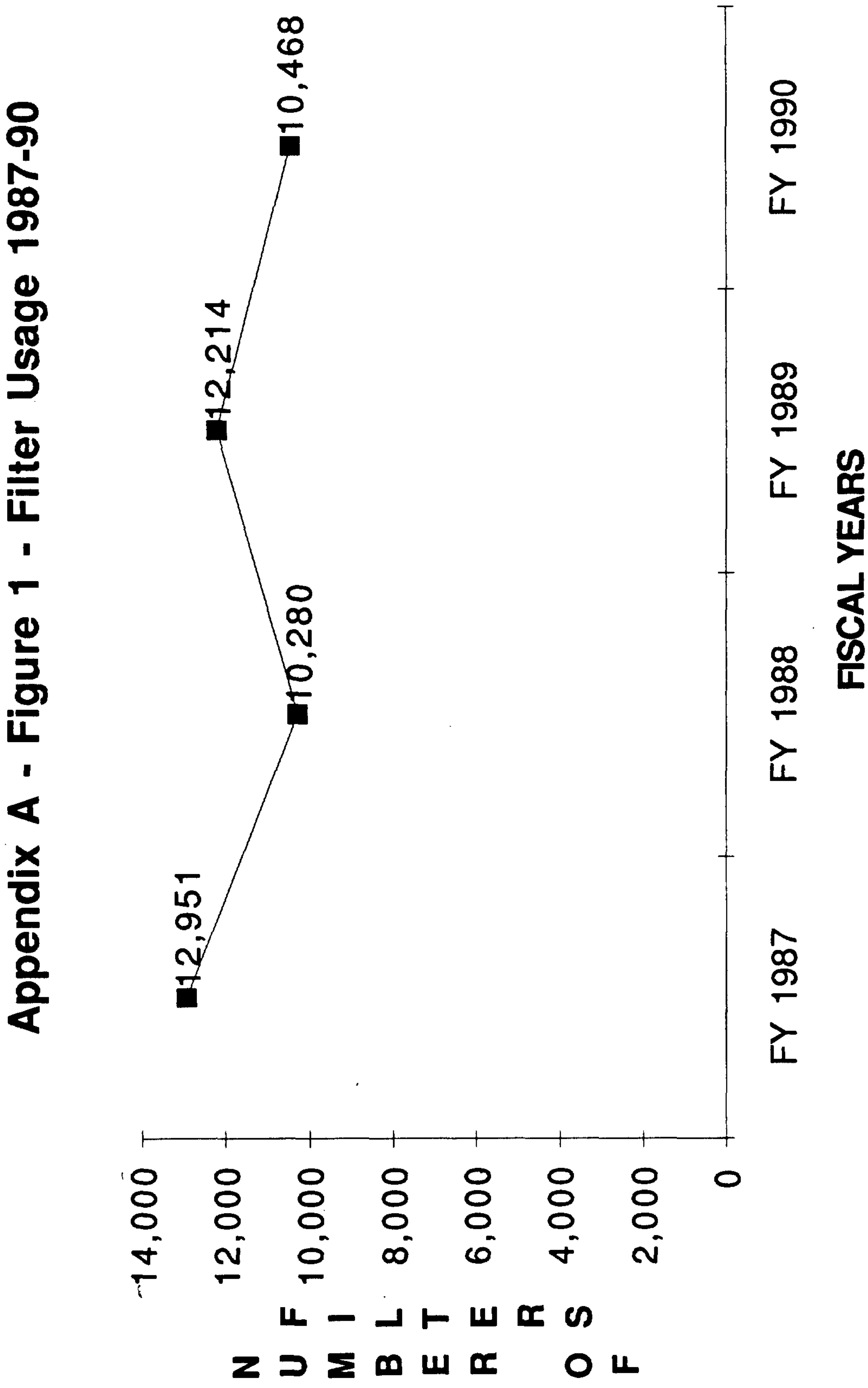

Appendix A - Figure 1 - Filter Usage 1987-90
NUMBER OF FILTERS
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
12,951
10,280
12,214
10,468
FY 1987
FY 1988
FY 1989
FY 1990
FISCAL YEARS

Appendix A - Table 1
Major Filter Users
Fiscal Years 1987 - 1990

USER	# FILTERS	% OF TOTAL	CUM % OF TOT
ROCKY FLATS PLANT	13,902	30%	30%
SAVANNAH RIVER PLANT	8,175	18%	48%
OAK RIDGE NATIONAL LAB/Y-12 PLANT	7,092	15%	64%
HANFORD RESERVATION	4,549	10%	73%
LOS ALAMOS NATIONAL LAB	3,010	7%	80%
IDAHO NATIONAL ENGINEERING LAB	2,795	6%	86%
ARGONNE NATIONAL LAB	1,529	3%	89%
LAWRENCE LIVERMORE NATIONAL LAB	1,409	3%	92%
43 USERS @ < 500 FILTERS USED	3,452	8%	100%
TOTAL	**45,913**	**100%**	
ANNUAL AVERAGE	**11,478**		

Appendix A - Table 2
Ranked by Filter Size
Fiscal Years 1987-90

CAPACITY	SIZE	# FILTERS	% OF TOTAL
1000 CFM	24"X24"X12"	29,273	63.76%
50 CFM	8"X8"X6"	6,196	13.50%
1250 CFM	24"X24"X12"	2,698	5.88%
125 CFM	12"X12"X6"	2,358	5.14%
25 CFM	8"X8"X3"	2,217	4.83%
500 CFM	24"X24"X6"	1,177	2.56%
1500 CFM	24"X24"X12"	585	1.27%
2000 CFM (MINI-PLEAT)	24"X24"X12"	28	0.06%
OTHER FILTER SIZES		1,381	3.01%
	TOTAL	45,913	100.00%

Appendix A - Table 3
Ranked by Manufacturer
Fiscal Years 1987-90

MANUFACTURER	# FILTERS	% OF TOTAL
FLANDERS	33,790	73.60%
CAMBRIDGE	7,090	15.44%
AMERICAN AIR FILTER	3,623	7.89%
21 MANUFACTURERS <550 FILTERS	1,410	3.07%
TOTAL	45,913	100.00%

Appendix B - Table 1
Cost Breakdown by Plant

PLANT	ROCKY FLATS		SAVANNAH RIVER		OAK RIDGE		HANFORD	
WASTE TYPE	LLW	TRU	LLW	TRU	LLW	TRU	LLW	TRU
PURCH, RECEIPT & CERT	450	450	450	450	450	n/a	450	450
FILTER CHANGE-OUT	420	420	1,200	1,200	960	n/a	1,250	1,650
IN-PLACE TESTING	90	90	200	200	360	n/a	1,125	1,500
PRELIMINARY ASSAY	100	100	100	100	100	n/a	100	100
FILTER PACKAGING	40	1,200	50	1,200	100	n/a	625	1,450
SIZE REDUCTION	300	0	0	0	0	n/a	0	0
FINAL ASSAY	70	100	70	100	70	n/a	70	100
SHIPPING/HANDLING	150	200	150	200	150	n/a	150	420
FINAL DISPOSAL	50	7,750	140	6,200	200	n/a	150	6,200
ADMIN OVERHEAD	400	500	400	500	400	n/a	400	500
TOTAL COST	**2,070**	**10,810**	**2,760**	**10,150**	**2,790**	**0**	**4,320**	**12,370**

Appendix B - Table 2
Average Life-Cycle Cost Calculations

FILTER USAGE MIX

	LLW	TRU	TOTAL
ROCKY FLATS	2,933	517	3,450
SAVANNAH RIVER	1,863	207	2,070
OAK RIDGE	1,725	0	1,725
HANFORD	345	805	1,150
ALL OTHER LOCATIONS	2,362	621	2,983
HLW FILTERS (ALL LOCATIONS)			100
	9,228	2,150	11,478

TOTAL COST BY PLANT

	LLW $	TRU $	TOTAL
ROCKY FLATS	6,070,275	5,588,770	11,659,045
SAVANNAH RIVER	5,141,880	2,101,050	7,242,930
OAK RIDGE	4,812,750	0	4,812,750
HANFORD	1,490,400	9,957,850	11,448,250
ALL OTHER LOCATIONS	10,203,840	7,681,770	17,885,610
HLW FILTERS (EST. $15K EA.)			1,500,000
	27,719,145	25,329,440	54,548,585
AVG LIFE-CYCLE COST/FILTER	3,004	11,781	**4,753**

CONCEPTS FOR PASSIVE HEAT REMOVAL AND FILTRATION SYSTEMS UNDER CORE MELTDOWN CONDITIONS

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Abstract

The objective of the new containment concept being developed by KfK is the complete passive enclosure of a power reactor after a core meltdown accident by means of a solid containment structure and passive removal of the decay heat. This is to be accomplished by cooling the containment walls with ambient air, with thermoconvection as the driving force.

The concept of the containment will be described. Data will be given of the heat removal and the requirements for filtration of the exhaust air, which is contaminated due to the leak rate assumed for the inner containment. The concept for the filter system will be described. Various solutions for reduction of the large volumetric flow to be filtered will be discussed.

I. Introduction

The potential occurrence of a core meltdown accident which so far has not been considered to be a design basis accident has become the most significant argument against nuclear energy in the public after the Chernobyl accident. This is true in particular in the Federal Republic of Germany where contamination of agricultural products has caused considerable damage and it may be recommended still today to refrain from consuming mushrooms and game.

With a view to further reducing the probability of occurrence of a core meltdown and to limit its consequences, discussions are being held about to improving emergency cooling, installing additional components such as coolers, core catchers, and providing further engineering measures in the reactor system which concern inter alia the reduction of reactor power and power density, respectively, in the reactor core. Independent of these discussions, considerations are being made on the ways and means of limiting the consequences of a core meltdown on the surrounding area of an NPP by improving the reactor containment.

Work carried out by members of the KfK staff is aimed at giving an answer to the question of the loads to which a reactor containment is exposed in a core meltdown accident, and in which way these loads can be accommodated by design measures.

Besides containment loading due to temperature and pressure resulting from the evolution of decay heat in the core melt, major impacts originate in the reaction of the melt with water and concrete, the explosion of the large amounts of hydrogen generated during such reaction in the oxygen bearing atmosphere of the containment and the steam explosion, e.g. as a result of slumping of the molten core into the lower reactor pressure vessel head and by high pressure failure of the reactor pressure vessel. The investigations carried out so far suggest that the loads to be assumed to act on the containment can be controlled by design measures so that its integrity is maintained (1, 2).

II. The Passive Heat Removal Concept

II.1 Decay Heat Removal by the Ambient Air

It is one of the essential goals of work in progress to improve of the containment system to develop a concept for passive removal of the decay heat and reaction heat from the containment. As the containments of light water reactors of German design have been built from steel, it has been examined whether the amounts of heat involved can actually be removed in a passive mode through the containment wall. The necessity of filtering in conformity with the valid rules the exhaust air from the space, which lies between the inner steel containment and liner, respectively, and the external concrete containment, proved to be a restriction on such a concept. The containment system conforming to the standard design in Germany is shown in Fig. 1. The space between the pressure accommodating steel containment and the surrounding concrete reactor building might be contaminated by leaks in the steel containment at penetrations and locks as well as by components in the annulus, and it is therefore vented by the emergency stand by filters installed to remove airborne particulates and iodine.

According to an advanced containment system presently studied a pressure accommodating inner steel liner and an external reinforced concrete containment are provided - the latter designed to largely diminish the high pressure loading acting on the liner via suitable connections to the liner. It has appeared from preliminary calculations that the decay heat of a 3600 MW_{th} reactor can be removed in a passive mode to the ambient air over the external side of the steel liner so that an intolerable pressure buildup in the interior can be avoided. Figure 2 shows the principle of passive air cooling of the containment. The heat is transferred from the melt to the inner wall of the steel liner by the steam condensing on the inner wall; the condensate flows back to the melt where it is evaporated again. Due to the thermal conductivity of steel the heat is carried through the steel wall onto the external side of the steel liner where it is directly discharged to the air stream passing by. The fins arranged in the annulus between the steel liner and the concrete containment constitute vertical stacks with open top and bottom ends. Besides, a considerable portion of the heat generated in the steel liner is given off by heat radiation to the side walls (fins) and the rear wall of the stacks (reinforced concrete) and from there to the convective air flow.

II.2 Unfiltered Cooling Air and Leaking Air

The following boundary conditions were assumed in the calculations based on estimates:

Reactor power 1300 $MW_{el.}$, max. decay heat to be removed by natural air convection 8 MW, diameter of steel liner 60 m, wall thickness 38 mm, outer containment made of reinforced concrete with 2 m wall thickness, annulus between concrete containment and steel liner 80 cm, partitioned by fins running longitudinal at 50 cm distance from each other, height of the stacks formed by these fins 40 m.

The power of the decay heat source was supposed to be 8 MW in all subsequent considerations, a value calculated by making use of the heat capacity of the concrete and steel components which are heated in the interior of the steel liner. With a mean air velocity in the stacks of 2.8 m/s, an inlet temperature of the ambient air of 30 °C and an outlet temperature of 50 °C, a temperature of 148 °C, corresponding to 4.5 bar steam pressure, is established within the steel liner. The reinforced concrete of the containment enclosing the annulus towards the outside is heated to 83 °C.

II.3 Filtered Cooling Air and Leaking Air

When the exhaust air from the stacks is filtered by the standard HEPA filters with a total open face area of 300 m^2, a differential pressure across the stacks and filters of about 39 Pa is obtained, with the rest of conditions unchanged, which corresponds to an air velocity of 1.05 m/s in the stacks at 87 °C outlet temperature of air, 164 °C inner temperature of the steel liner corresponding to 6.8 bar pressure of steam and a temperature of the concrete containment of 105 °C on the annulus side.

The throughput of ambient air is 474,000 m^3/h. The relation

$$\Delta p=0.08v+0.012v^2,$$

v = mean linear gas velocity at the HEPA filter open face area (m/s)

Δp = differential pressure across the HEPA filter (kPa)

determined as the mean value for non-loaded HEPA filters in the experiment, was assumed to describe the dependency of the differential pressure on the air velocity (3). Figure 3 shows the differential pressure occurring across the non-loaded filter as a function of the open face area of all HEPA filters taken together. The total open face area needed is very large in case the differential pressure is to remain low so that a high throughput of the coolant air can be maintained.

Figure 4 is a plot of the temperature in the liner atmosphere, the pressure of the steam depending on it, and the temperature on the inner side of the concrete containment, versus the open face area of the total number of HEPA filters installed. Fixing an open face area of 125 m^2 would give the following values: differential pressure for filters and stacks 61 Pa, air velocity in the stacks 68 cm/s, air outlet temperature 124 °C, inner temperature of steel liner 180 °C, steam pressure 9.9 bar, concrete temperature on the annulus side 125 °C, throughput of ambient air 306,000 m^3/h. These values are considered to constitute the upper limit of temperature in the steel liner.

It is evident from the computations that due to coupling of the flow resistance with the throughput and, as a consequence, with the temperature in the steel liner, and of the concrete of the containment, a satisfactory solution cannot be found with filters whose flow resistances correspond to that of the standard HEPA filters. Moreover, it should be possible to remove also gaseous radioiodine.

II.4 Possible Solutions

Four ways should be examined which might lead to a solution:

(a) Development of a new filter material with a flow resistance corresponding to approximately half that of the current HEPA filter medium.

(b) Intensifying the stack draft by connection to the main stack of the nuclear power plant whose diameter should be increased, if needed (Fig. 5).

(c) Dividing the exhaust air from the annulus into a non-filtered portion (cooling air) and a filtered portion which does not noticeably contribute to cooling (Figs. 6 and 7).

(d) Dispensing with passive cooling of the steel liner by external air, applying instead internal passive cooling with water of the melt (Fig. 8).

ad (a) This solution is presently being studied. The use of loosely packed fiber media without any bonding material gives better values relative to those obtained with the usual HEPA filter media. The possibilities should be examined of removing radioiodine in addition without integrating further structural material in the filter. Eligible base materials for trapping the particulates are e.g. fine steel fiber fleeces with high porosities.

ad (b) This solution allows a higher flow resistance of the filter. Together with a filter material whose flow resistance is reduced, it offers the best solution which allows the requirements to be met with respect to cooling, filtration and environmental impact, thanks to the great altitude of emission. First computations based on the input data mentioned on p. 3 have yielded the following values:

Stack height producing an additional effect 140 m, stack inner diameter 5 m, open face area of all HEPA filters taken together 50 m^2, differential pressure across filters and stacks 320 Pa, differential pressure across filters 259 Pa, air velocity in the cooling stacks 0.95 m/s, air outlet temperature 94 °C, inner temperature of steel liner 167 °C, steam pressure 7.3 bar, concrete temperature on the annulus side 108 °C, throughput of external air 429,000 m^3/h.

With the rest of conditions unchanged and an open face area of as little as 30 m^2, corresponding to a differential pressure across the filter and stacks of 402 Pa, 362 Pa of that value occurring across the filters, an inner temperature of the steel liner of 176 °C and a pressure of the steam of 9.0 bar were calculated. The throughput of ambient air is 334,000 m^3/h.

ad (c) Two versions are feasible:

1. Filtering the leaking air from the entire outside surface of the containment. (Fig. 6)

2. Filtering the leaking air solely of the bottom part of the containment. (Fig. 7)
   This separation of the filtered air from most of the annulus implies that all penetrations, locks, etc. running through the steel liner as well as all external, activity bearing plant components are arranged in the bottom part of the annulus and that only the exhaust air from that part is filtered.

   The relatively small volume of leaking air can be introduced in both versions into the main stack of the reactor block and kept at a slight negative pressure due to the stack draft. This makes less difficult the task of designing a passive exhaust air filter.

   It seems feasible in this way to reduce the volume of exhaust air to be filtered by factors up to approx. 10, provided that approval is obtained from the licensing authority to discharge unfiltered cooling air which has been passed solely over the undisturbed surface of the steel liner.

ad (d) The decay heat is removed from the core catcher with the sump water and given off in a passive mode to the ambient air via large cooling basins. It is doubtful whether the core catcher can be sufficiently flooded with sump water. The volume of air to be filtered would be on the order of 1000 m^3/h.

III. Summary

It is evident from the calculations that the decay heat of a 1300 $MW_{el.}$ reactor can be removed in a passive mode after a core meltdown accident by cooling of the steel containment with ambient air.

The throughput of air exclusively generated by thermoconvection is greatly reduced by flow resistances. By introduction of the cooling and leak air streams into an exhaust air stack of a height as already built today, the admissible differential pressure across the filter can be raised by about one order of magnitude and hence the filter size can be reduced accordingly. The design of exhaust air filters for cooling and leak air filtering must be such that differential pressures of a few 100 Pa can be accommodated. Besides airborne particulates, also gaseous radioiodine should be removed on the filters. For this to be achieved, new filter media will have to be developed which cause a much lower flow resistance than the usual HEPA filter media. Should this not be feasible, the exhaust air from the containment must be divided into an unfiltered cooling air portion and a filtered leaking air portion in order to be able to choose reasonable dimensions for the open face area of the filter. Otherwise, the decay heat would have to be removed on different paths, e.g. by passive water cooling.

IV. References

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Annex

Boundary Conditions for Calculation of the Thermohydraulics in Heat Removal to Air by Natural Convection

Decay heat power to be removed	8 MW
Diameter of steel containment	60 m
Wall thickness of steel containment	38 mm
Effective cylindrical height of individual stacks	40 m
Azimuthal width of individual stack	50 cm
Radial depth of individual stack	80 cm
Width of fins between stacks	10 cm
Number of stacks on the perimeter	314
Emission ratio of stack walls, achieved by suitable treatment	0.9
Absolute roughness of stack walls	1 mm
Useful height of main stack	140 m
Mean diameter of main stack	5 m
Length of connection line from air outlet at the containment up to main stack	50 m
Diameter of connection line	5 m
Inlet temperature of the cooling air	30 °C

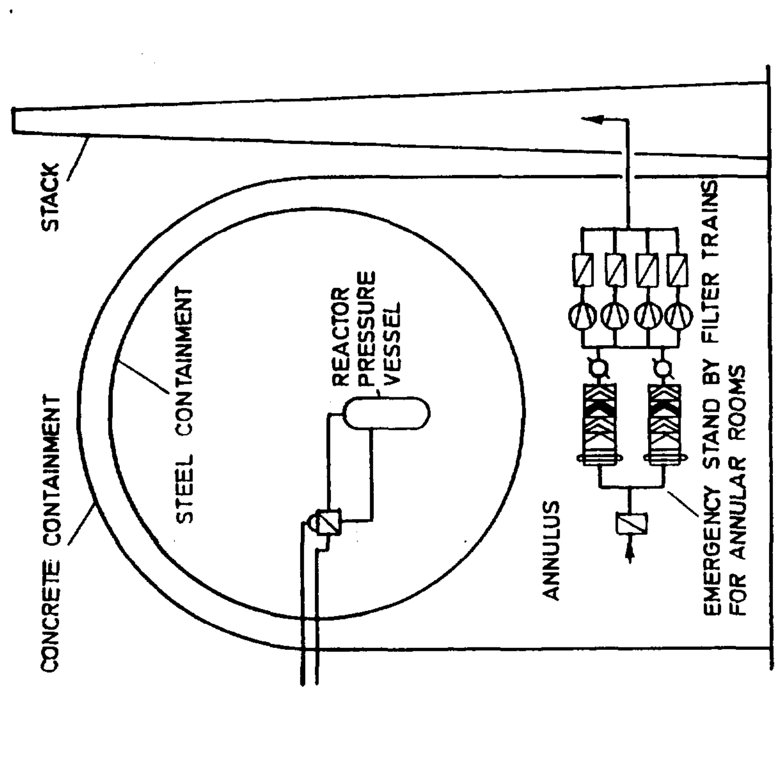

FIG. 1

FILTERING OF ANNULUS EXHAUST AIR

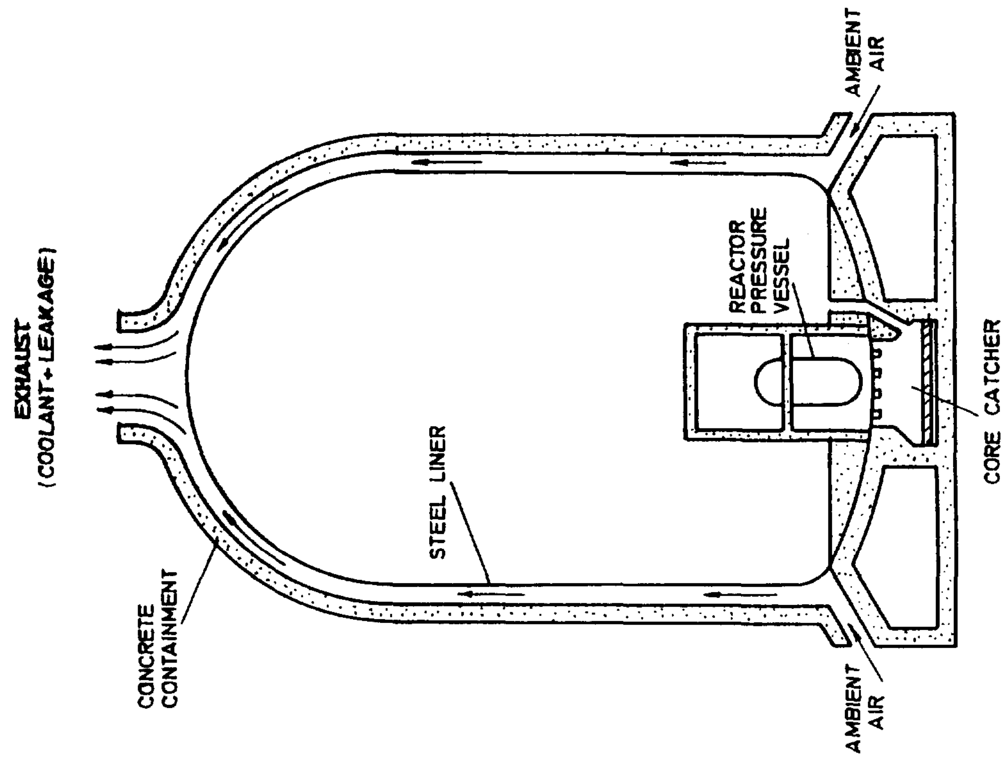

FIG. 2

CONCEPT OF PASSIVE DECAY HEAT REMOVAL

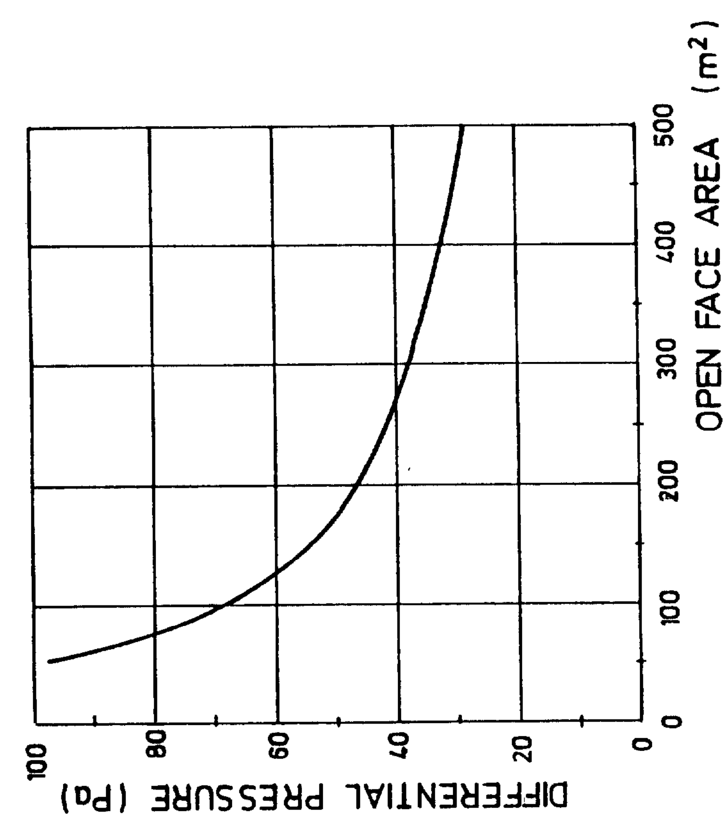

FIG. 3

CONTAINMENT 2000, HEPA - FILTER DIFFERENTIAL PRESSURE AS A FUNCTION OF THE OPEN FACE AREA

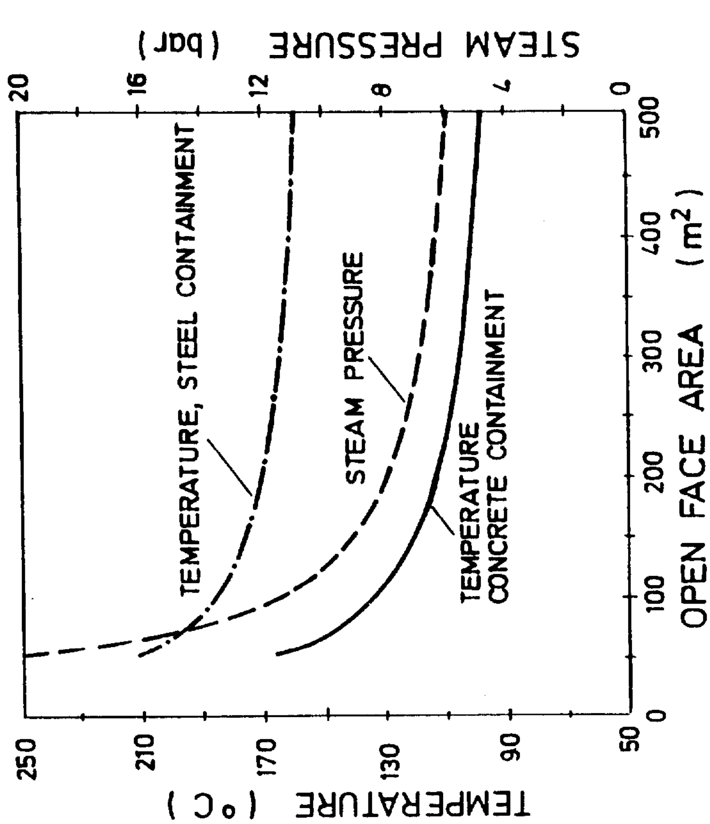

FIG. 4

CONTAINMENT 2000, TEMPERATURE AND PRESSURE AS A FUNCTION OF THE HEPA - FILTER OPEN FACE AREA

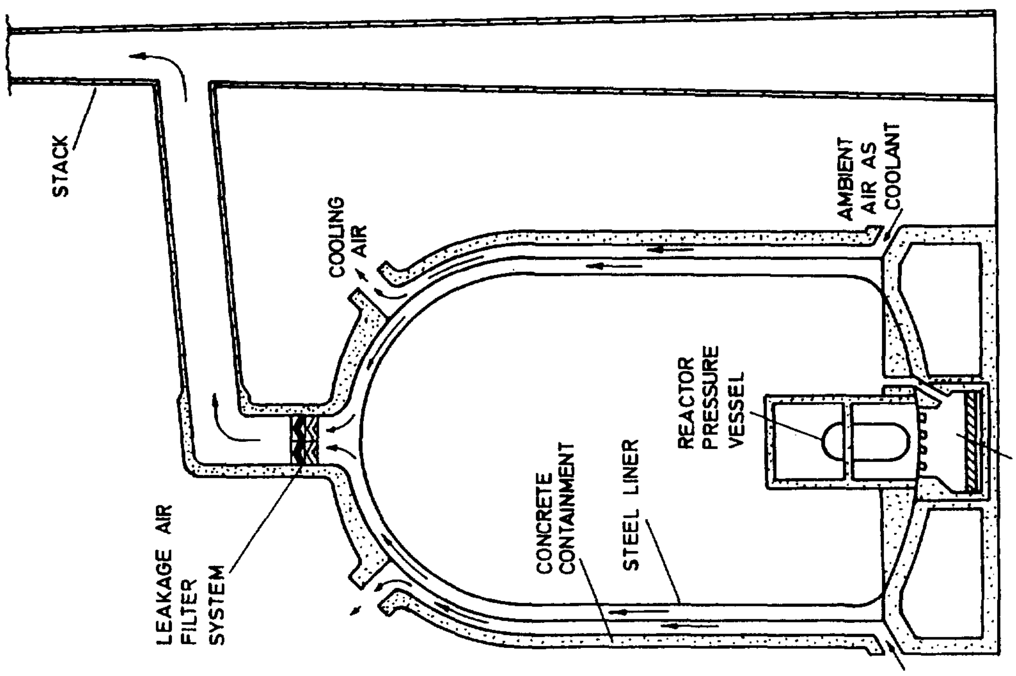

FIG. 6

CONTAINMENT 2000
LEAKAGE AIR FILTERED
COOLANT AIR UNFILTERED

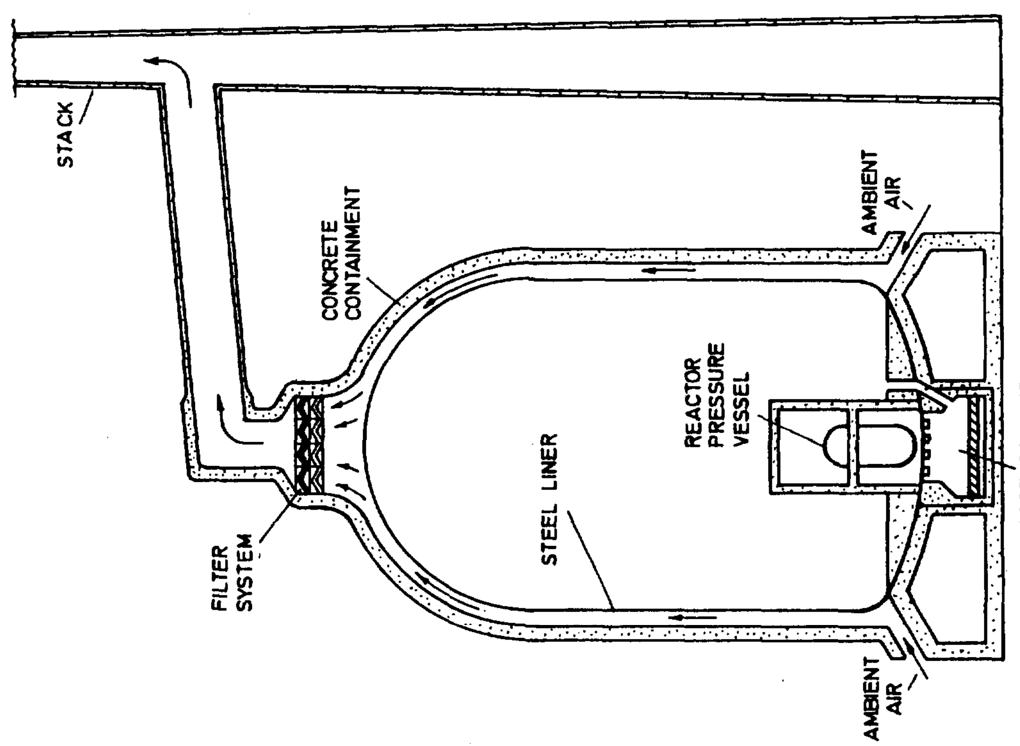

FIG. 5

CONTAINMENT 2000
COOLANT AND LEAKAGE FILTERED

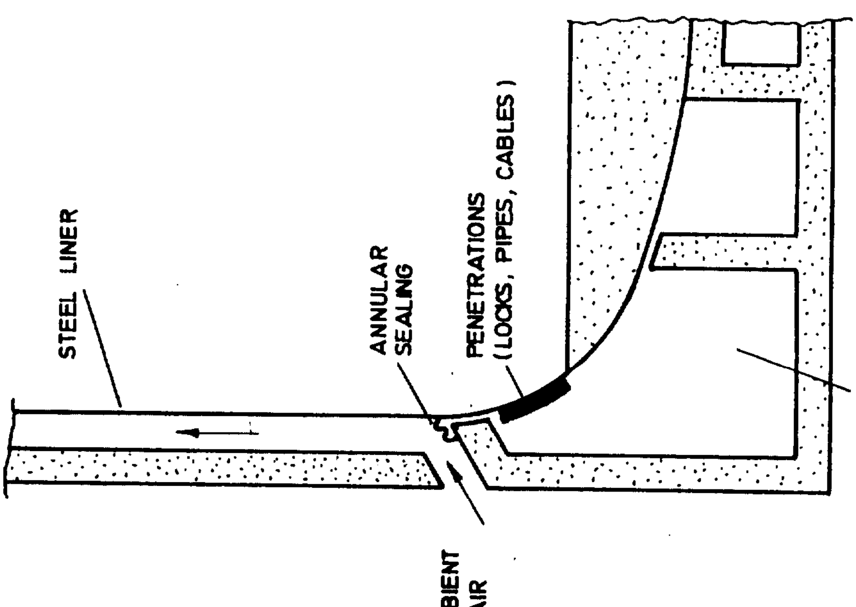

FIG. 7

CONTAINMENT 2000
FILTERED CONTAINMENT AREA FOR PENETRATIONS

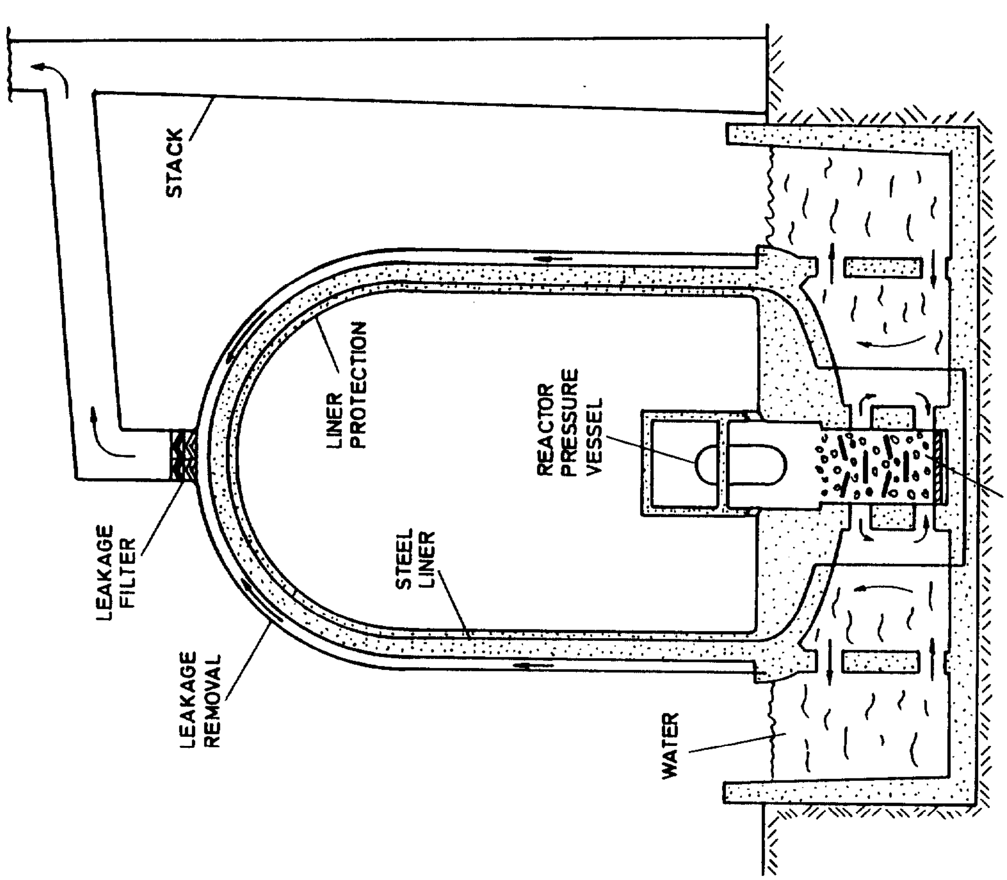

FIG. 8

CONTAINMENT
MOLTEN CORE WATER COOLED

DISCUSSION

KUMAR: Seems to be a nice concept, but if the containment structure is about 200 meters tall, the stack will have to be much, much higher for natural flow. There is no fan, is there?

WILHELM: No, no fans. The containment itself is 40 meters high. We calculated that the stack needed to be 180 meters. That means, 140 meters stack height in addition to the 40 meters of containment to produce the needed suction.

KUMAR: In that case, do we have to worry about tornado protection? Do you have to design for that?

WILHELM: Yes, we have to design the containment to withstand airplane impacts and any other external or internal events. The concrete containment will be built so that it can withstand any impact from the outside. Between the concrete containment and the inner steel containment there will be connections so the concrete containment can gain strength from the steel containment which can withstand very high pressure. At the moment, we are thinking about short pressure peaks of 35 or more bar from a hydrogen or a steam explosion. Tornados are not design basis for stacks in Germany. Maximum wind speed considered in stack design is 45.6 m/s for a height above 100 (DIN 1055).

BERGMAN: Since the differential pressure is the key impediment to this concept, would you care to share some thoughts on the directions you would take to design such a filtration system?

WILHELM: I think there is only one way. One has to lower the packing density of the filters. We have a new development in which we use the same weight per unit area but with lower packing density of the fibers. One comes up practically with the same removal efficiency.

DEVELOPMENT OF A PERSONAL COMPUTER CODE FOR FIRE PROTECTION ANALYSIS OF DOE FACILITY AIR-CLEANING SYSTEMS

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Abstract

The United States Department of Energy (DOE) has sponsored development of a computer code to aid analysts performing fire hazards analyses for DOE facilities. The code selected for this application was the FIRAC code developed by the Los Alamos National Laboratory for the Nuclear Regulatory Commission. The original code has been modified by the Westinghouse-Hanford Company. The FIRAC code simulates fire accidents in nuclear facilities and predicts effects of a hypothetical fire within a compartment and its effect throughout the rest of the facility, particularly the air-cleaning systems.

The FIRAC code was designed to run on Cray supercomputers. The input format is difficult to use. For this code to be useful to the DOE fire protection community, it had to be converted to run on an IBM PC and couple with a menu-driven pre-processor that would make preparation of the input easy to use for fire protection engineers. In addition, a graphical display of the analysis results was required.

In this paper we will describe the pre-processor, the PC version of FIRAC, and the post-processor graphics package. In the presentation, a demonstration of how to set up a problem and use the code will be made.

Introduction

The United States Department of Energy (DOE) has sponsored development and conversion of an existing fire modeling computer code into a fire hazard analysis tool that can be used throughout the DOE nuclear complex. The base code used in this effort is the FIRAC code developed by the Los Alamos National Laboratory for the United States Nuclear Regulatory Commission. The primary objective of the DOE effort was to convert the computer program to run on the IBM PC and to develope a pre- and post-processor for the code. The pre-processor had to be very easily used by the practicing fire protection engineer. Similarly, the post-processor had to include output results in graphical form rather in numerical form for easy and quick interpretation.

A description of the features of the FIRAC computer program and its fire compartment module, FIRIN, will be given. Application of the program to a real facility will be described. Demonstration of how to set up a problem using the pre- and post-processor will be made in the presentation.

Background

The FIRAC computer code allows an entire facility to be modeled in a systems analysis fashion. That is, the interconnection of all the facility rooms, corridors, and heat, ventilating, and air conditioning (HVAC) systems is taken into account. The interdependency of these elements and the feedback effect on the fire are the strengths of the model. FIRAC features the following capabilities.

- A lumped-parameter formulation allows the zones of a facility to be modeled in either coarse or fine detail.
- All HVAC components, such as blowers, dampers, ducts, glove-boxes, and filters are modeled.
- A fire compartment model called FIRIN is included.
- The inlet and outlet flow, temperature, and pressure from the fire are strongly coupled.
- The heat transfer from duct walls is taken into account.
- Blower out-running or back-flow is modeled.
- Smoke, gas, and radioactive species transport are modeled, including gravity settling, turbulent deposition, bend deposition, and filter depletion.
- Filter models that include particulate plugging and variable efficiency are included.
- Transient air pressure, density, temperature, and flow are calculated throughout the facility.
- Transient aerosol concentration, mass flow, mass fraction, deposition, and entrainment are calculated for all locations.

The fire compartment module used in FIRAC is called FIRIN and was developed by Battelle Northwest Laboratories. The strength of this compartment model is its ability to simulate radioactive contaminated burning of materials with the associated radioactive aerosol release. The primary features of the FIRIN fire compartment model are

- burning of radioactive solids and liquids,
- oxygen depletion,
- fire growth approximated by a burning-order concept,

- fire growth approximated by an ignition energy concept with autoignition of combustibles at risk (Factory Mutual data),
- Factory Mutual burning rate database,
- flaming combustion and limited smoldering combustions,
- burning rates as a function of available oxygen,
- wall and equipment heat absorption,
- water vapor formation,
- flame radiation as a function of material burned,
- aerosol depletion mechanisms that include gravity settling,
- brownian diffusion, diffusiophoresis, and thermophoresis.

There are several limitations associated with the FIRAC code and the FIRIN fire compartment module. The FIRAC code is limited by the fact that spatial variations can only be handled in an approximate way; for example, a length of duct can be subdivided into discreet lumps or control volumes to obtain spatial resolution. In addition, bidirectional flow in ductwork is not allowed with the lumped-parameter formulation of the FIRAC code. The FIRIN module is limited in the sense that it is a zone model; that is, it models the burning process by assuming that there is a hot and cold layer. The hot layer moves as a function of time and the appropriate inlet/outlet fluxes are calculated accordingly. Spatial variation in the vertical direction is handled well by the zone model, but horizontal effects are only approximated.

The FIRAC code has been applied to several facilities. The Lawrence Livermore National Laboratory (LLNL) fire test cell and special fire experiments performed by Factory Mutual for Sandia National Laboratories have been analyzed. The code has been used to simulate fire scenarios in several nuclear plants. One example is the plutonium processing facility at Los Alamos. In this analysis the effect of a fire in one part of the plant on final exhaust high-efficiency particulate filters in another area of the plant was determined. A second example was an application to the West Valley, New York storage facility. A third example is a current study applying the code to the DOE Waste Isolation Pilot Plant at Carlsbad, New Mexico. A fourth example is an analysis of a hydrogen burn in one of the waste tanks at the Hanford site near Richland, Washington.

PC FIRAC Version

The PC version of the FIRAC computer code runs relatively fast when compared to running time on the CRAY Y-MP. A moderately sized problem takes 10 min on the Cray and would require 100 min on the IBM PC.

It is difficult to describe the pre- and post-processor graphical packages for the PC version of FIRAC. It is much easier to demonstrate their capabilities. However, we have included four figures to show the IBM PC display screens. Figure 1 is a blank screen that is ready for construction of the FIRAC facility model. Figure 2 shows a model of the fire test cell at LLNL. The model was constructed using the icons on the left-hand side of the screen. The fire room is shown with a flame icon. Using the menu displayed in Fig. 1, the fire room can be selected with the shift f3 key, or if the user has a mouse, he can click on the fire room icon in the model. When the fire room is selected, another screen appears for the FIRIN module input with its icons and menus. Figure 3 is an example of a blank screen with the menus listed below. Again clicking on the appropriate area or using the keyboard allows other menus to be selected for input entry. During presentation of the paper, we will include a short demonstration of the process.

The pre-processor automatically creates the input file for running the FIRAC PC code and also prepares a document listing all of the parameters that were used for input. After FIRAC has run the problem, it provides an output file for the post-processor. Activation of the post-processor gives another menu that allows the user to select a variety of graphical or tabular displays. Figure 4 is one example of the kind of information one can access from the post-processor. In this figure all of the thermal effects in the fire compartment are grouped together to provide a composite of all the important fire scenario parameters. Any one of these plots can be displayed individually on a full screen for more resolution.

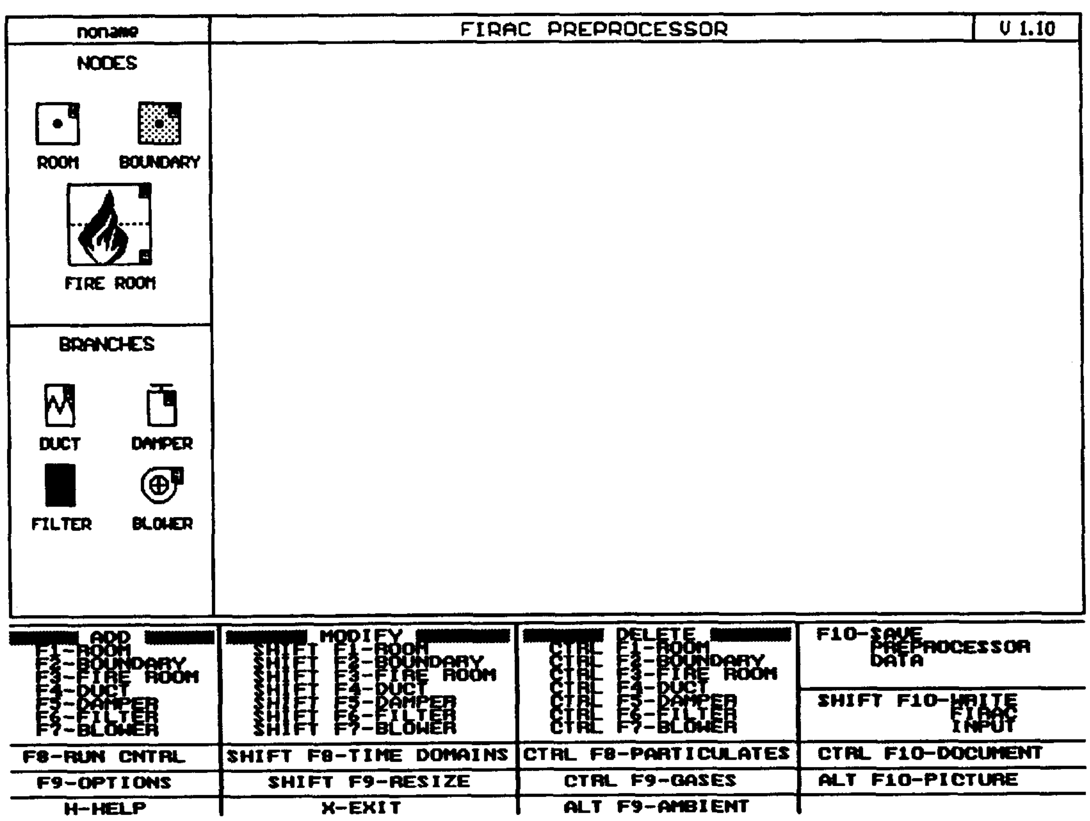

Figure 1. FIRAC pre-processor screen.

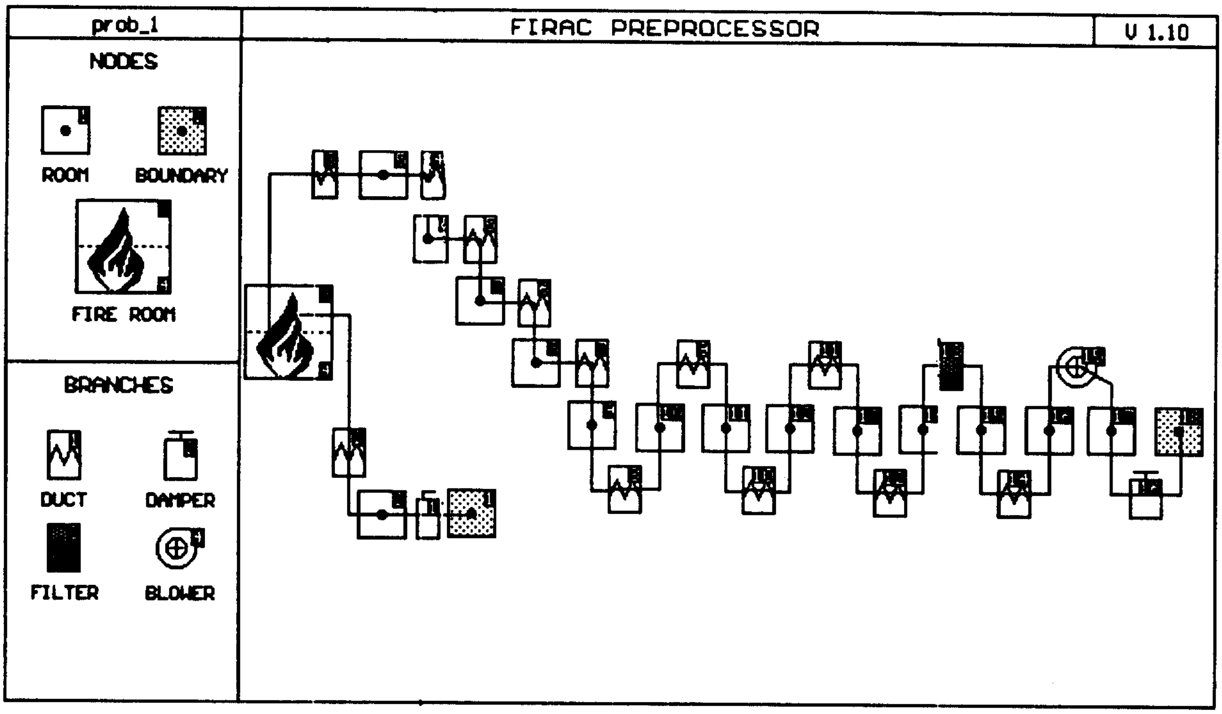

Figure 2. FIRAC pre-processor sample problem.

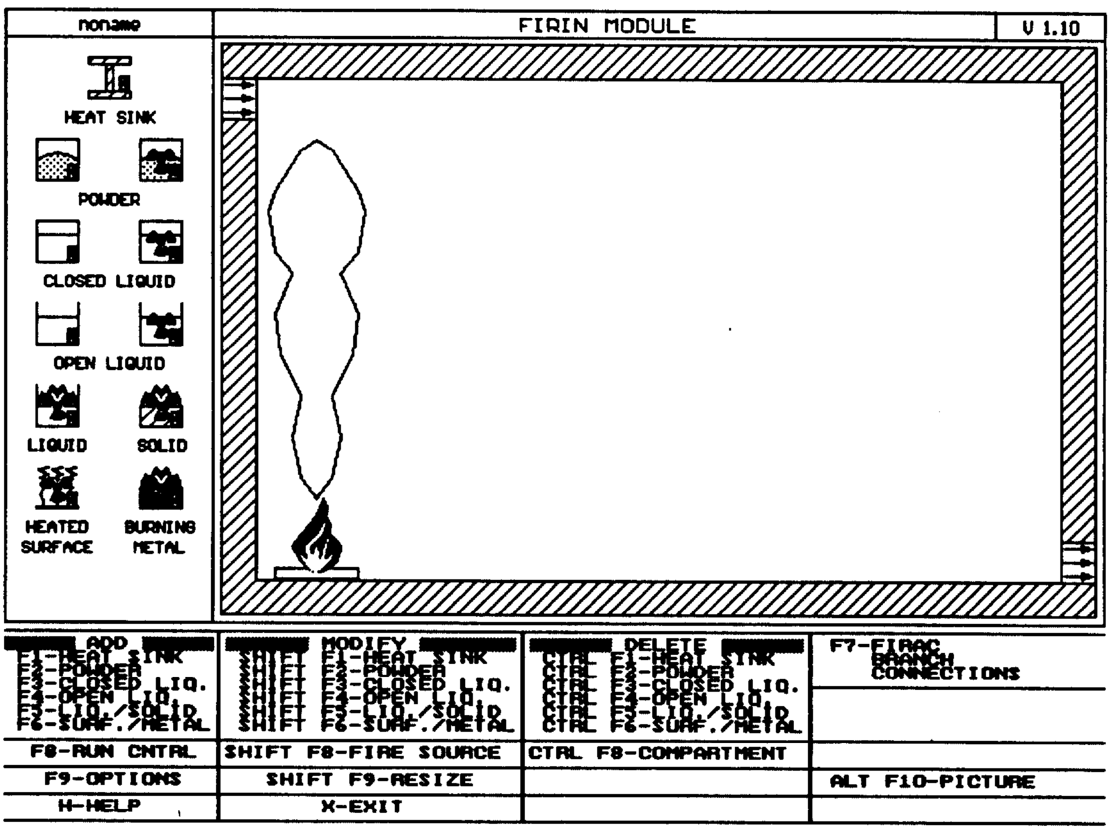

Figure 3. FIRIN module screen.

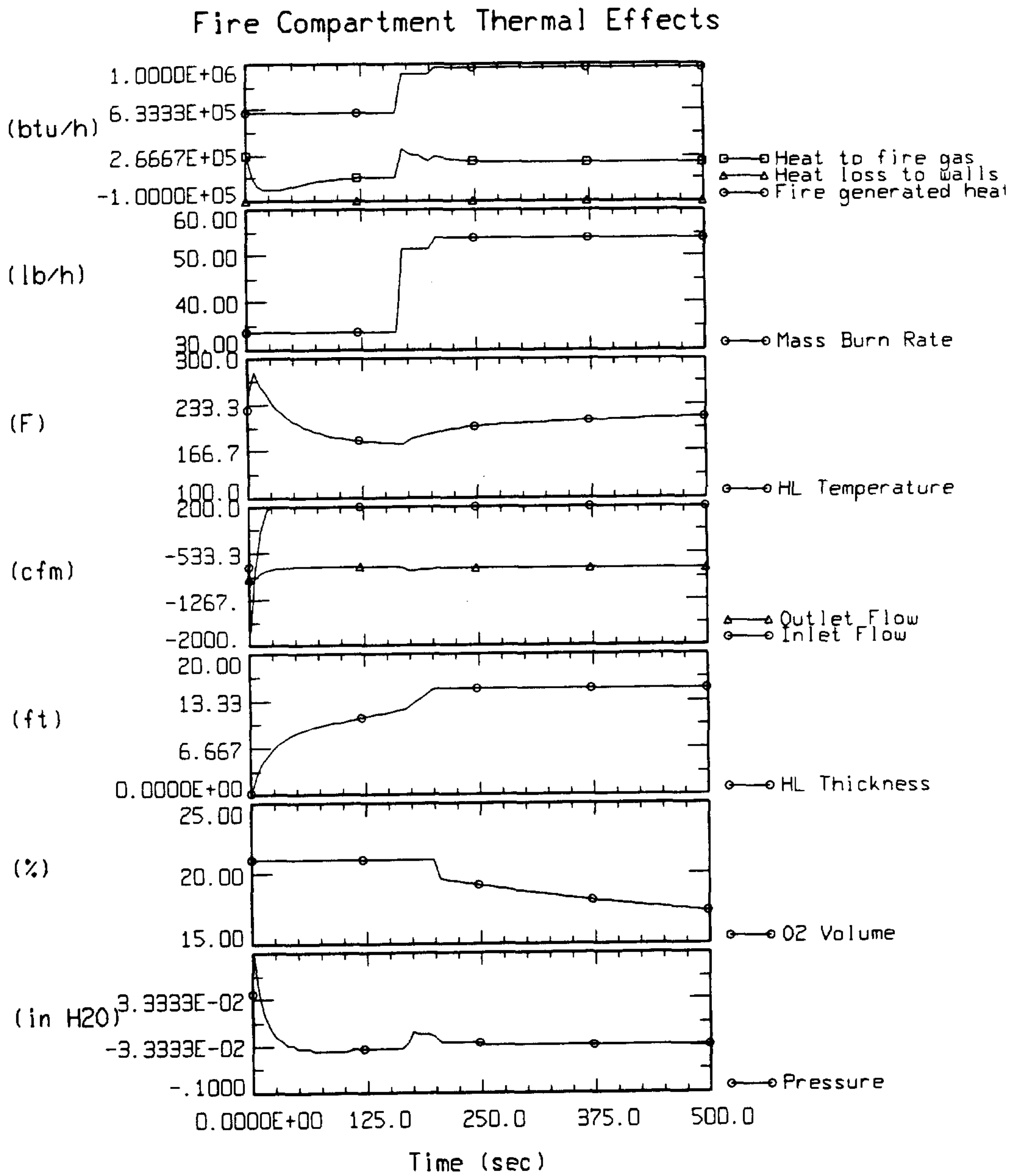

Figure 4. Fire compartment thermal effects.

Summary

Conversion of a fire modeling research tool (FIRAC) into a practical, user-friendly, PC-based tool for the fire protection engineer has been described. A description of the attributes and limitations of the FIRAC code and its fire compartment module, FIRIN, and several applications of the code were discussed. We believe that this tool can now be used by fire protection engineers to perform fire hazard analyses as necessary.

DISCUSSION

TSAL: I would like to ask you about your items. I do not see fittings. We now have more than 200 fittings, of different kinds. What happens if I need to use transitions, junctions, not just dampers?

GREGORY: With the fact that you can specify K-values, you can input K-values which could represent various fittings, or bends, or what have you.

TSAL: But there are variable K-values. In the tables there are variable functions of flow but you don't know the flow until you calculate it in your program.

GREGORY: That is right. The best we can do right now is try to get a steady-state value and go with that. The only one that varies right now with time is the filter, because it will become plugged as particles enter it.

EFFICIENCY TEST FOR ULTRA HIGH EFFICIENCY METAL AIR FILTERS

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Abstract

Pall has qualified a DOP penetration test for single stage filters to ULPA and higher efficiencies. This test is specifically designed for simplicity, speed, and to use instrumentation presently on-site at U.S. D.O.E. Filter Test Facilities. It employs a standard DOP penetrometer as aerosol generator and a laser spectrophotometric particle counter as detector, thus providing diameter dependent efficiency data.

Reliable data have been collected at penetrations to as low as E-8.

A summary of qualification testing performed by Pall's Scientific and Laboratory Services Department (SLS) is provided herein; and examples of metal filter efficiency data.

Introduction

Environmental protection is the prime objective in design and testing of nuclear off-gas and building exhaust systems. Toward this end, systems are often constructed with two or more stages of HEPA filter in series.

Multiplicity serves safety expectations by redundancy; further providing additional effluent cleanliness. In the U.S. and elsewhere, mandates for nuclear facilities calling for multistage HEPA containment also require in-place filter efficiency test. Well established methodology accepted by U.S. Department of Energy facilities employs DOP smoke as controlled contaminant for filter challenge. Smoke dispersion and detection geometries can vary by system configuration.

Sensitivity limitations of conventional light scattering detectors dictate in-place multistage HEPA testing be performed one stage at a time. Multistage testing is further complicated by problems of representative sampling and adequate smoke dispersion when these are done between stages.

By strict definition, maximum penetration of 0.3μ DOP smoke for two filters in series, each HEPA rated at 99.97% efficiency, is 9E-8. In application, removal efficiency of the train is often accepted as ≥99.999%. Single stage filters validated as providing removal efficiency at this value are known by the designation ULPA (1).

Pall has undertaken to provide an ULPA rated filter at ≤2"H_2O in stainless steel medium and welded construction to Battelle Northwest Laboratories for evaluation in radioactive waste vitrifier off-gas service. The filter will provide efficiency equivalent to two stages of HEPA in series, conforming to 1000-fold DOP reduction at 0.1μ in the first stage, 100-fold reduction in the second (99.999% filter efficiency).

Data concerning Pall metal filter technology in additional Nuclear Air Cleaning applications are presented at this Conference by other workers (2,3,4).

As result of test method qualification, and SLS tests of a variety of cartridge constructions, Pall has assembled a full-size filter comprising an assembly of 14 cartridges for laboratory evaluation preceding Battelle's pilot application. It is expected that filters of this type can be employed successfully to eliminate redundant HEPA stages and upgrade safety.

The potential value of alternative detection equipment, such as laser spectrophotometers in DOP aerosol measurement, has been recognized by DOE Filter Test Facilities (5). To encourage acceptance of single stage filters at multiple HEPA efficiencies, Pall has constructed and qualified a penetration test employing methods closely similar to those in current use. It shares the laser detection method employed by HFATS (5), diverging from HFATS by relying upon conventional hot DOP aerosol generating equipment.

Data measured to qualify this method, to define a recommended range of use, and in its initial application are presented herein.

Test Methods

Key to measuring particle penetrations for ultra-high efficiency filters is to combine high detection sensitivity with high particle density in a controlled aerosol.

We set about to measure particle count as a function of diameter and of time in DOP smoke generated by an Air Techniques Incorporated (ATI) model Q127 penetrometer. This instrument is rated to 3CFM by its manufacturer. The smoke generator was used in accordance with standard settings. Aerosol particle size distribution was measured using a Particle Measurement Systems Las-X counter. A similar combination has been used with single stage HEPA filters in evaluating hot aerosol contaminants as alternatives to DOP (6).

We began prepared for the possibility that ultimately we would be required to increase particle density beyond that standard settings produce. We constructed the initial test loop to evaluate dilution ratio required to ensure non-saturation of the Las-X counter, as depicted in Figure 1. Diluters were TSI, Model 3302. Where two diluters were used sequentially, the first was modified by duplication of its cleanup filters as a second stage in series.

Particle count as a function of dilution is given in Graph 1 for the 0.20-0.25μ bin, chosen for reference. At 10000 fold dilution, several thousand counts per minute were typically registered in the bins close to 0.3μ. Background was typically of the order of 1 count per minute. It was concluded to proceed, at dilution ratios ≥2000, provided stability of particle count obtained.

Particle count stability was monitored as a function of diameter over a period of several days. Representative particle count as a function of diameter is given in Graph 2. Comparison with Graph 3 shows typical reproducibility after overnight Q127 cooldown and restart of the hot DOP aerosol generator the next day.

After screening Pall candidate stainless steel filter media in flat sheet, a higher flow rate system was required for evaluating pleated filter elements. For this purpose, an ATI Q76 DOP penetrometer was employed as aerosol generator in conjunction with a PMS Las-X spectrophotometer, as depicted schematically in Figure 2. The aerosol was similarly qualified for population and stability.

Typical particle count as a function of diameter between 0.1 and 0.3μ is given in Graph 3. To compare particle size distribution with that of aerosol from the Q127, a plot in the manner of Graph 2 is given for Q76 data as Graph 4. At standard settings, aerosol population in bins between 0.1 and 0.3μ was consistently about an order of magnitude lower using the Q76 generator.

The Q76's particle size distribution was modified in some aerosol qualification trials by non-standard instrumental settings suggested by the manufacturer. During these, using a 0.20-0.25 bin as reference, it was observed that a change in population as recorded by the Las-X counter was registered by the Q76 penetrometer detection circuit in identical proportion.

It was concluded that aerosol population was adequate for the present filter studies at standard instrumental settings, and these were subsequently employed.

A housing to test individual pleated filter elements at 22CFM was constructed to fit within an existing chuck.

Sampling performance of a non-isokinetic probe within the chuck was compared filter-absent with that of a downstream isokinetic probe in the effluent duct (Figure 2), placed 8 duct diameters from the chuck exit. Counts registered in size ranges of interest were expected to be the same (particle pathway dominated by Brownian motion), and their correlation is shown in Graph 5. Measured equivalence of these counts was taken as a further indicator of instrumental reproducibility and non-interference of test stand construction.

DOP efficiency for a series of cylindrical element candidate constructions was then tested and, subsequently, a 14 element assembly (below).

Results and Discussion

The filter for Battelle will provide efficiency equivalent to two stages of HEPA in series, conforming to 1000-fold DOP reduction at 0.1um in the first stage, 100-fold reduction in the second (99.999% overall). Design of the full scale 14 element system is shown schematically in Figure 3.

Test results for a single Pall cartridge of design selected for full scale application are given in Table 1.

Elements of this type were assembled and shipped to Pall's 300CFM test facility for DOP test. Elements were sealed to tube sheet via gaskets; installed at factory under torque specification, six threaded studs per module (7 modules). A photograph of the assembly is reproduced as Figure 4.

DOP test results are given as Table 2. Production unit will have elements welded to tube sheet for highest seal integrity. (Tube sheet assembly with welded elements to ship in its own cradle apart from housing.)

At this writing gasketed seal to tube sheet is being confirmed in preparation for a DOP test:Backwash:repeat DOP test sequence for third party witness.

Conclusions

1. DOP efficiency test has been designed capable of demonstrating ULPA and finer efficiencies. Based upon in-house testing, source aerosol density and background count considerations, it is concluded that diameter dependent penetrations to as low as E-8 are reliably measured.

2. The DOP penetration test described herein is expected to be implemented readily by U.S. D.O.E. Filter Test Facilities should they choose to do so. Such Facilities in possession of DOP smoke generators normally part of existing DOP penetrometers, and also in possession of a laser counter and diluter(s) (e.g. as is part of an HFATS unit) are already quite well equipped.

3. The test herein described is expected to facilitate in-place test of single stage ULPA filters, pending evaluation of aerosol density produced by field smoke generators. This method is also expected potentially to simplify in-place test of multiple stage HEPA installations.

4. In most cases, duration of test is comparable with that of conventional hot DOP penetrometer test.

5. Pall has successfully demonstrated ULPA filter efficiency to beyond proof-of-concept in single stage all-welded stainless steel filters at <2"H_2O pressure drop.

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6. H.R. Carlon, U.S. Army CRDEC, personal communication.

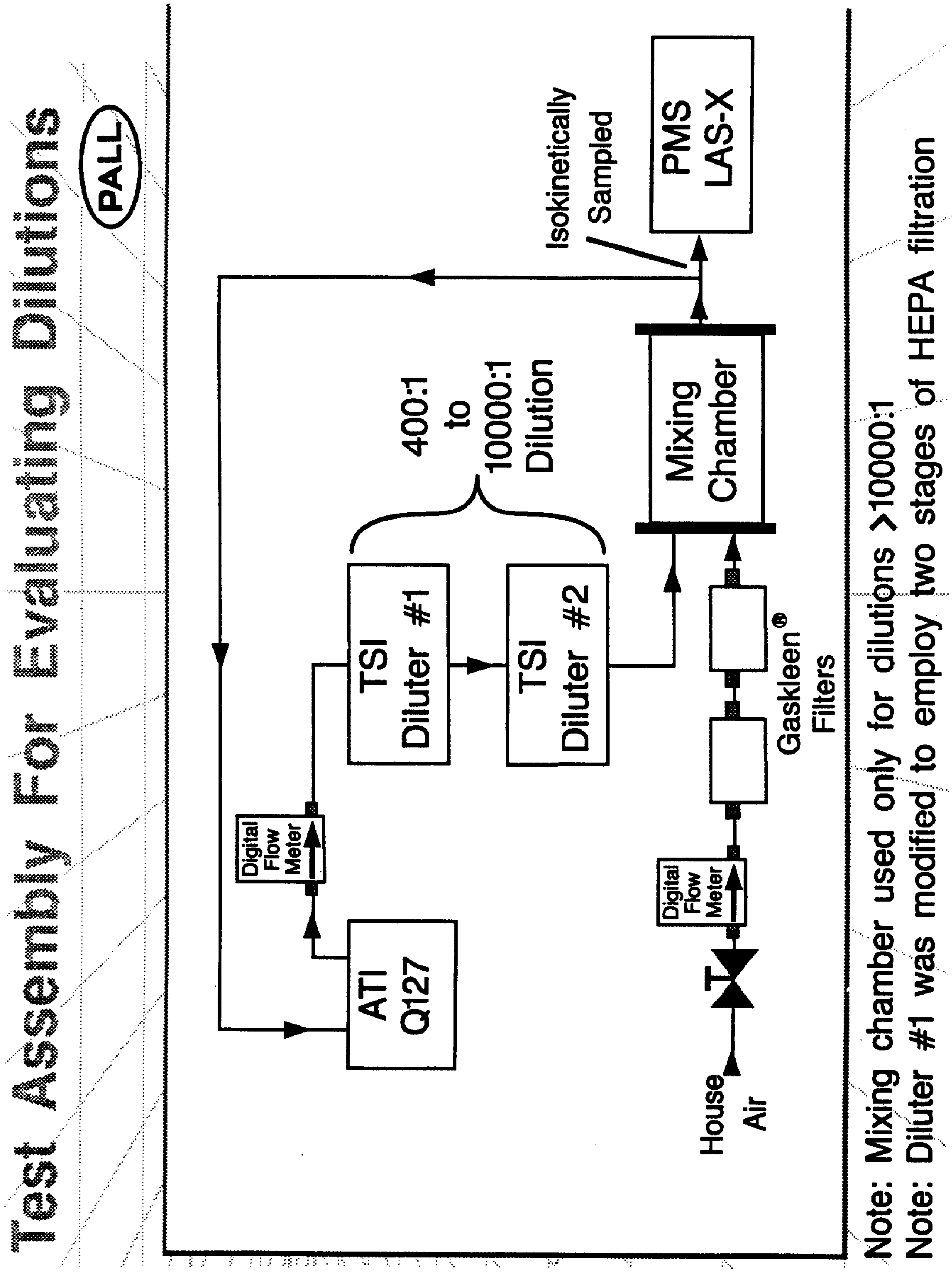

Test Assembly For Evaluating Dilutions
PALL
Isokinetically Sampled
PMS LAS-X
400:1 to 10000:1 Dilution
Mixing Chamber
TSI Diluter #1
TSI Diluter #2
Digital Flow Meter
ATI Q127
Gaskleen® Filters
Digital Flow Meter
House Air
Note: Mixing chamber used only for dilutions >10000:1
Note: Diluter #1 was modified to employ two stages of HEPA filtration

Figure 1

Filter Assembly DOP Test Loop

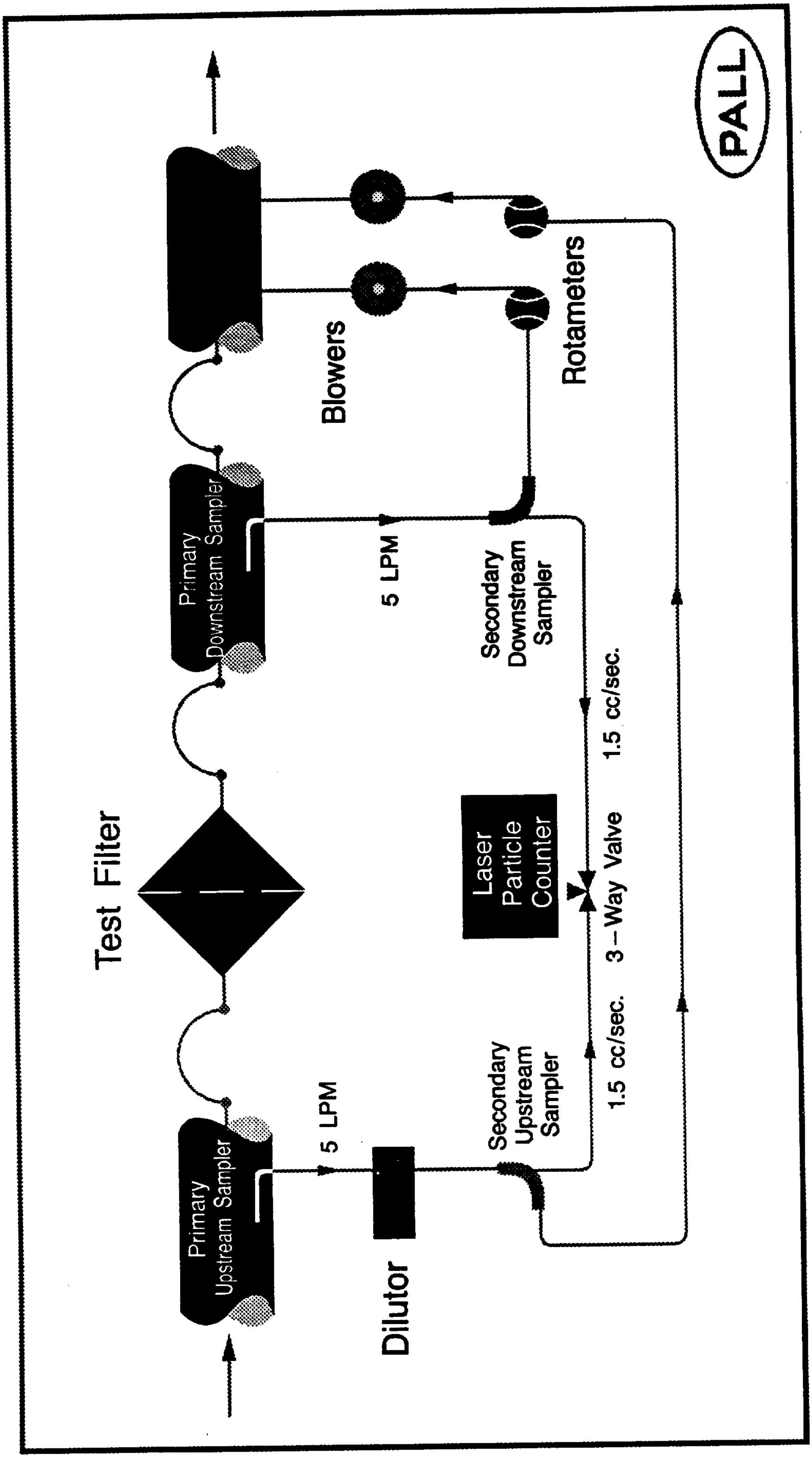


Figure 2

Melter Off-Gas Filtration System

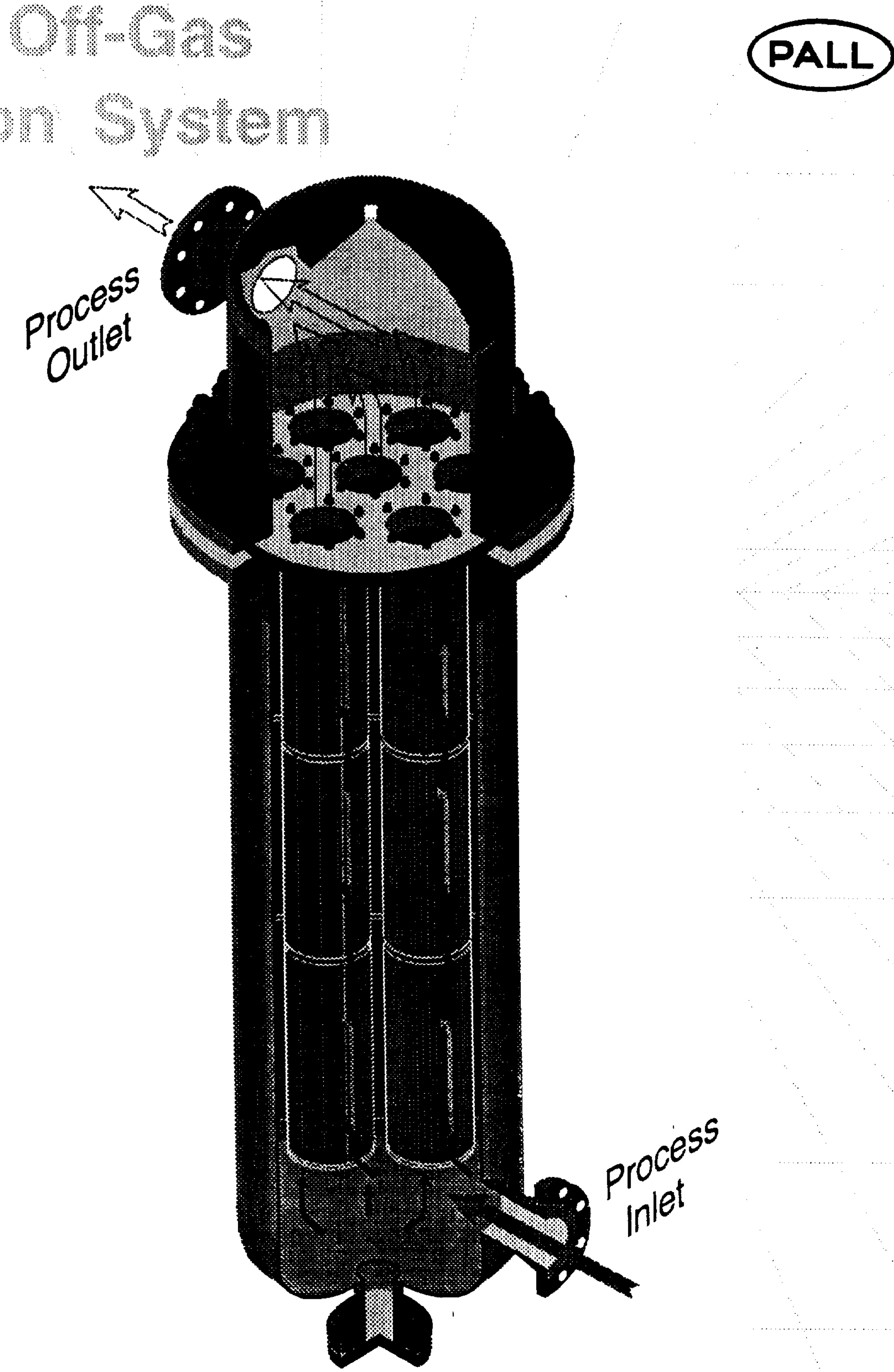
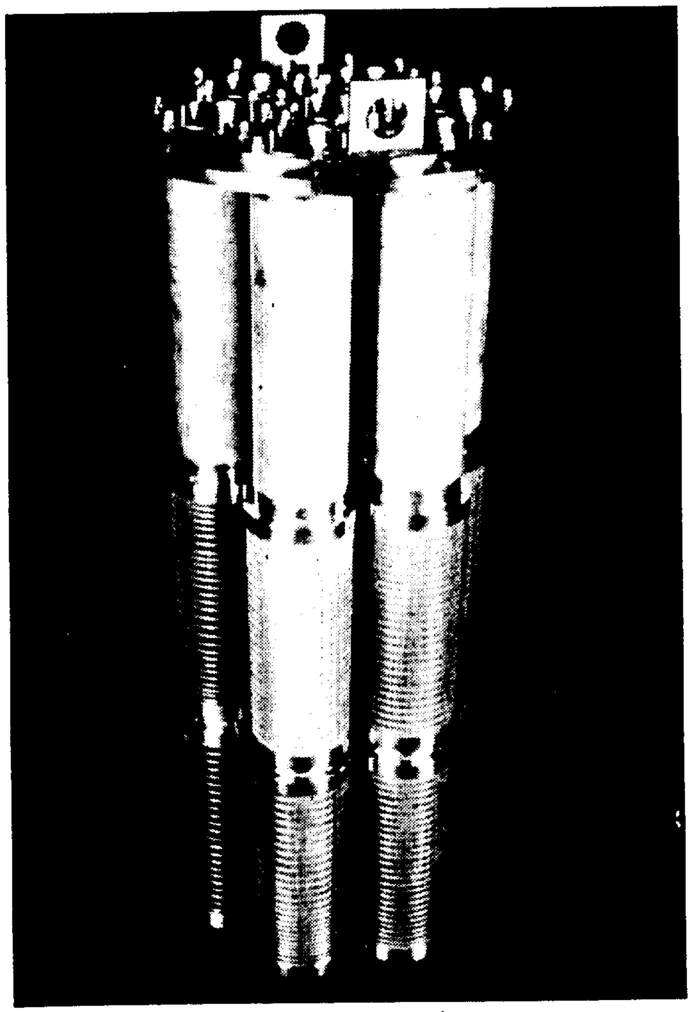


Figure 3

95″ OAL
20″ Diameter Housing
Total Filter Area 230 ft^2

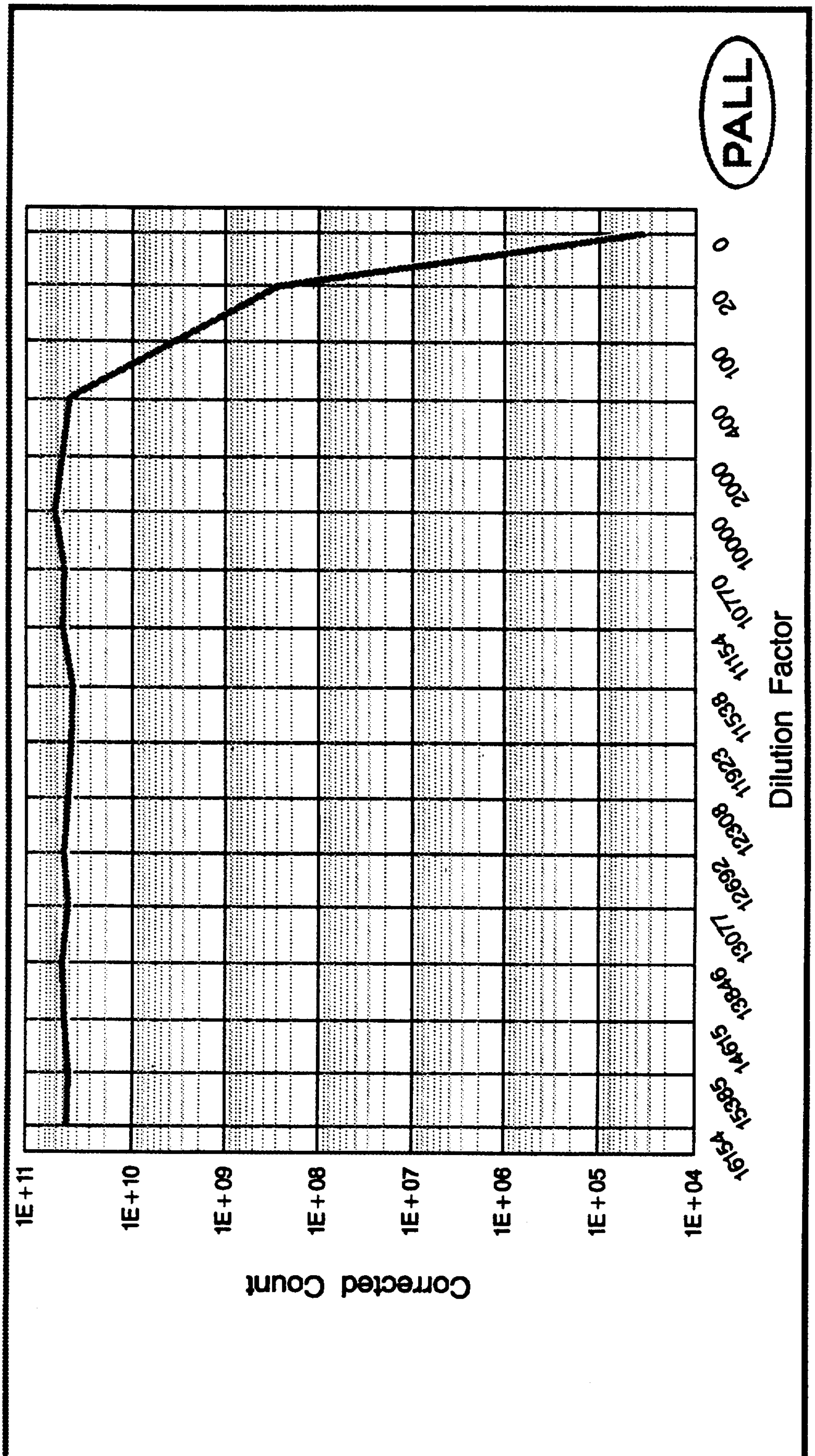
Pall Ultramet™ Multi-Cartridge Assembly



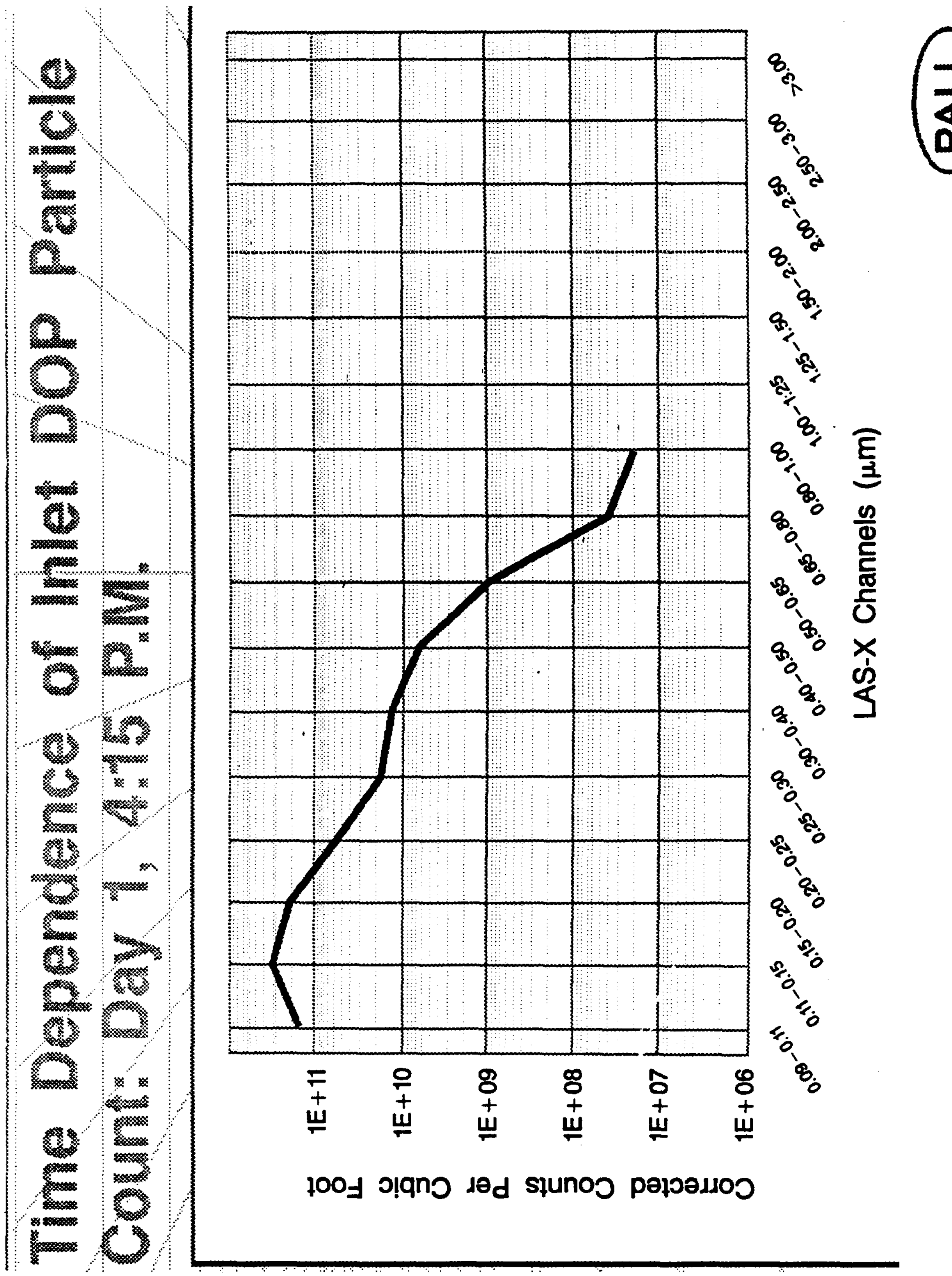
Absolute Performance℠

Figure 4

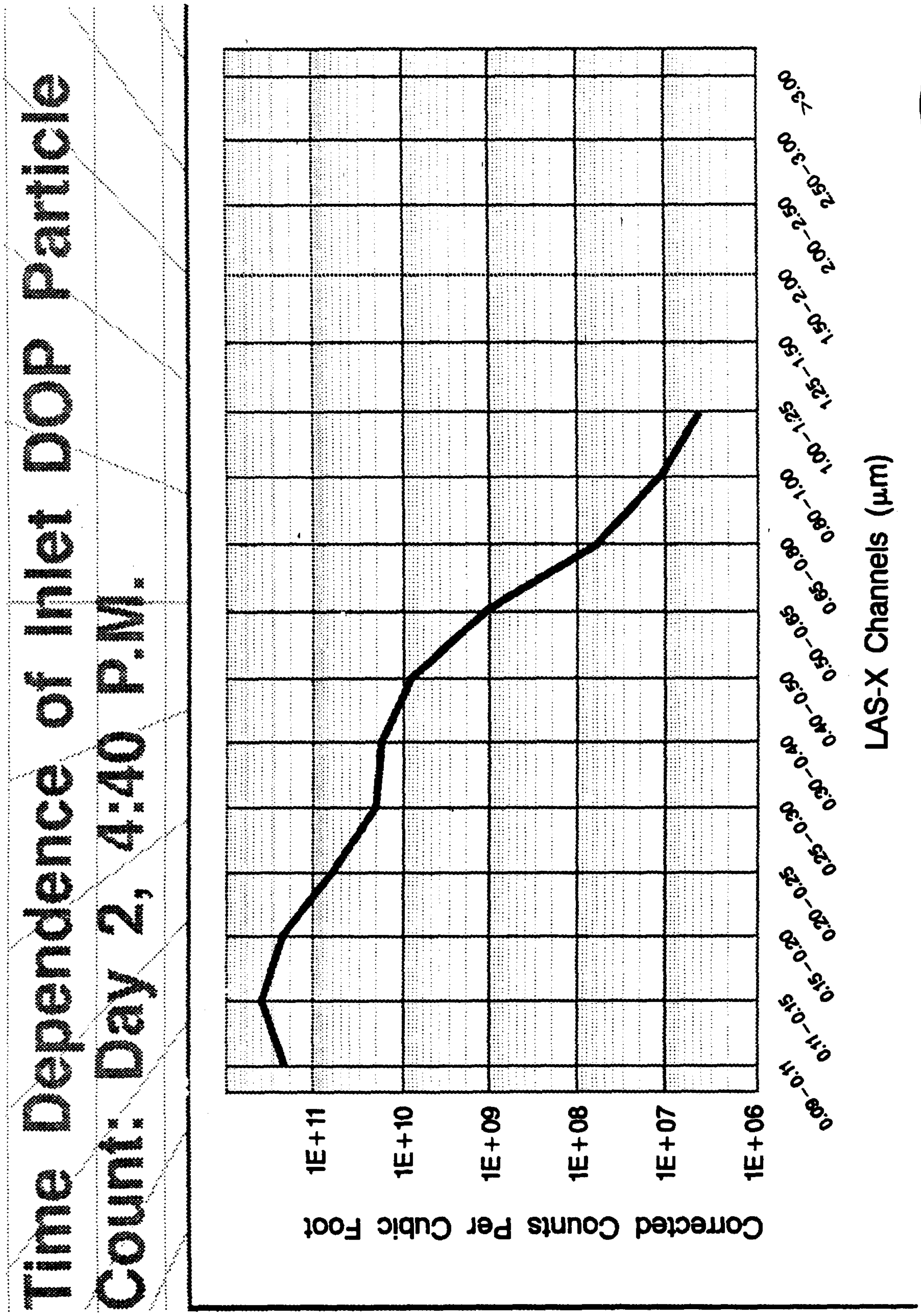
DOP Counts as a Function of Dilution LAS – X Counter, 0.20 – 0.25μm



Graph 1


Time Dependence of Inlet DOP Particle Count: Day 1, 4:15 P.M.
Corrected Counts Per Cubic Foot
1E+11
1E+10
1E+09
1E+08
1E+07
1E+06
0.09-0.11
0.11-0.15
0.15-0.20
0.20-0.25
0.25-0.30
0.30-0.40
0.40-0.50
0.50-0.65
0.65-0.80
0.80-1.00
1.00-1.25
1.25-1.50
1.50-2.00
2.00-2.50
2.50-3.00
>3.00
LAS-X Channels (µm)

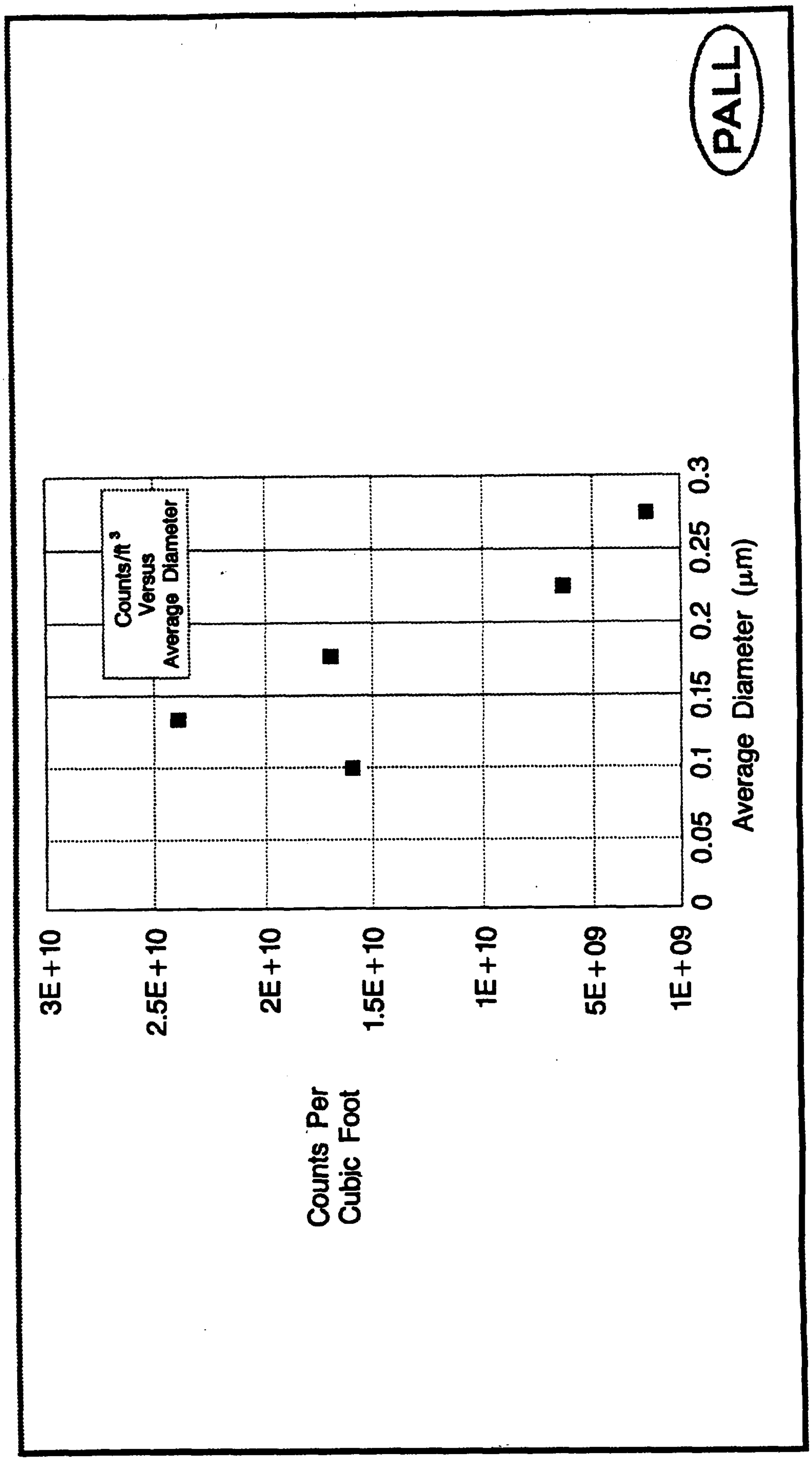
Graph 2


Time Dependence of Inlet DOP Particle
Count: Day 2, 4:40 P.M.
Corrected Counts Per Cubic Foot
1E+11
1E+10
1E+09
1E+08
1E+07
1E+06
0.09-0.11
0.11-0.15
0.15-0.20
0.20-0.25
0.25-0.30
0.30-0.40
0.40-0.50
0.50-0.65
0.65-0.80
0.80-1.00
1.00-1.25
1.25-1.50
1.50-2.00
2.00-2.50
2.50-3.00
>3.00
LAS-X Channels (µm)

PALL

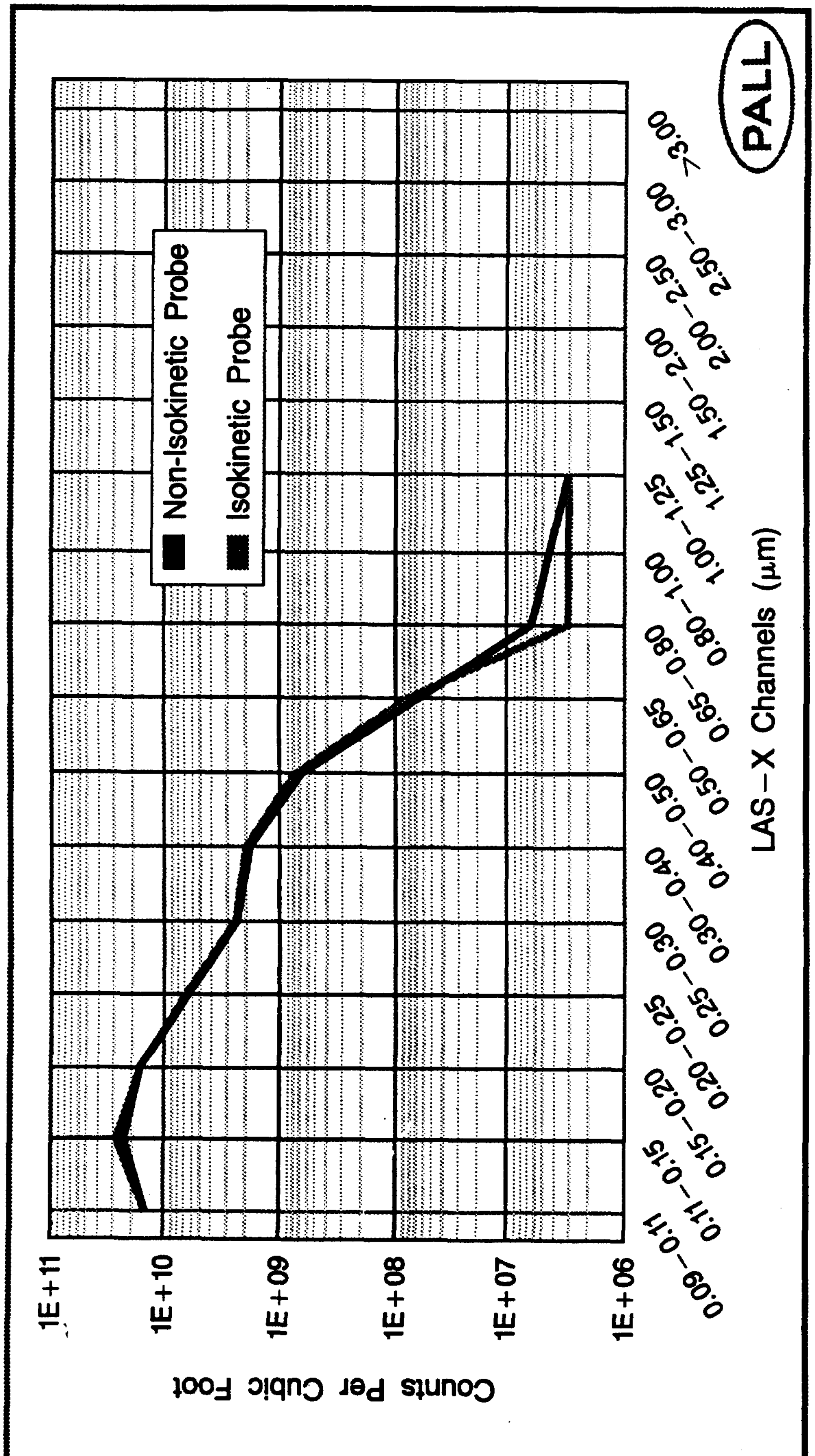
Graph 3

Dilution Corrected DOP Aerosol
ATI Q76 Operated Under Standard Settings at 22 SCFM



Graph 4

Filter Inlet Counts, Q76, 22 SCFM



Graph 5

Table 1
REPRESENTATIVE DOP PENETRATION PALL FILTER ASSEMBLY AT 300CFM.

Test	Diameter Range, um					
	0.09-0.11	0.11-0.15	0.15-0.20	0.20-0.25	0.25-0.30	0.30-0.40
1	2.0E-5	2.2E-5	2.7E-5	2.8E-5	2.6E-5	2.5E-5
2	2.1E-5	2.4E-5	2.9E-5	3.0E-5	2.9E-5	2.7E-5

Pressure drop across assembly and tube sheet was 1.7" H_2O.

Table 2
REPRESENTATIVE DOP PENETRATION PALL ELEMENT, 22CFM

Test	Diameter Range, um					
	0.09-0.11	0.11-0.15	0.15-0.20	0.20-0.25	0.25-0.30	0.30-0.40
1	4.9E-6	5.3E-6	5.9E-6	6.3E-6	6.2E-6	6.0E-6
2	4.4E-6	4.9E-6	5.6E-6	6.0E-6	6.0E-6	5.9E-6

Pressure drop across housing containing test element was 1.6" H_2O.

DISCUSSION

BERGMAN: The data on the efficiency results that you showed has a flat response as a function of particle size. That indicates to me that you have a significant leak and the true efficiency should be dramatically higher than what you reported.

WEBER: I want to thank you for making that comment. I think you are right. As a matter of fact, as I may have mentioned, the difference is that it was not welded construction at this point as it will be for field operation. It was a gasketed construction at the tube sheet. One of our tasks now is to go back and retorque to make sure that it is at the correct torque specification for that particular test. In the case of the single element, however, I beg to differ, I think there is a loose end somewhere. I have noticed in your work that frequently the difference in penetration between the most penetrating particle size and 0.3 micrometers is a factor of 2 or 3, whereas, we have a factor of 50% in some cases. However, for the single module, I didn't have a chance to test different flow rates. I found that a factor of two in velocity would make a factor of 10 difference in efficiency. In cases where I have detected leaks in the past, I have noticed that you have a flat response and I think that is a dead giveaway. The single element test results were just as flat, however, showing an extremely sharp flex dependence. So I agree with you, but I also think there is a loose end which bears investigating.

REYNOLDS: With your testing experience with metal media, what recommendations would you suggest to do an in-place test, and will the results be comparable to an in-place test for a glass filter?

WEBER: When you are testing a multistage HEPA filter, you must get in between the two stages to be able to do it with a standard penetromometer. In this case, there is only one stage at a time giving efficiency, enabling you to eliminate redundancy in the system. For single stage HEPA efficiency tests, the only thing needed is to take filter geometry into account. For tests of filters containing more than one stage, a laser detector may be needed for required sensitivity - but this may be usable with existing field aerosol generating equipment. I think it will be interesting to qualify these generators as to suitability for testing the higher efficiency filters. My recommendations are to investigate existing equipment with field DOP generators, and I would simply say, lets go out to a site, maybe one of the filter test facilities, and do a test there using portable equipment and a laser detector to get the higher sensitivity that is needed. In other words, use a portable DOP generator, a hot DOP generator, and a laser detector.

REYNOLDS: Could you successfully run an in-place test using the TDA5A?

WEBER: Well, we would like to use the flowtometer. Unless there is one that I don't know about that is sensitive enough to look in the 10^{-5} penetration range to verify two-stage HEPA. You know that in a regulatory sense, some of them give you 1,000 full decontamination factor for the first stage, 100 full for the second, which is 10^{-5}. In some case they could demand 0.03% squared, or 9 x 10^{-8}. I think there might be penetromometers sensitive enough for 10^{-5}, but I doubt 10^{-8}. There, I would recommend a laser detector.

REYNOLDS: My reason for the question is, I am in the process of doing exactly what I am asking you. I want to make sure I am getting reliable results to do that type testing in-place.

WEBER: I will be happy to discuss your test in some detail with you later because it is very interesting.

FIRST: I get the impression from your brief description (which is probably somewhat unfair to you) that you are going on the assumption that the minimum filterable size for your filter will be the same as for the conventional glass paper filter. I think that would be a remarkable coincidence because of the differences in structure, fiber size, etc. It seems to me that it is important to explore the matter more thoroughly, although you have some preliminary data. The other point is that you seem to be comparing two different things. When you do the flowtometer test, you are getting your measurement in terms of a light scattering function whereas when you do it with a laser particle counter you are obviously getting a particle number. The relationship between these two is not necessarily one-to-one. Therefore, when you talk about efficiency with the laser spectrometer and compare the numbers with the photometer, I think you have to be a little cautious.

WEBER: I think both points are very well taken and I am not convinced that, in fact, it isn't the structural differences in this particular filter which make the distribution curve on penetration so flat relative to even other stainless steel filters that have been tested. We have considered the point and I think it is an excellent point for future work. We have identified a theoretical researcher in the field, who, in fact, does calculations of most penetrating particle size in fibers and I think that is a good direction to go. As to penetromometer vs laser, I recognize that too. What we look for here is a test that is familiar, rather than to reinvent the wheel. We borrowed hot DOP, and we borrowed the HFATS detector. I think you are absolutely right. It is important not to try to correlate the readings of the two overly closely.

A REVIEW OF LICENSEE EVENT REPORTS

RELATING TO NUCLEAR AIR TREATMENT SYSTEMS AND HEATING, VENTILATING, AIR CONDITIONING SYSTEMS

FILED DURING THE PERIOD 1988-1991

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Abstract

This paper reviews Licensee Event Reports relating to nuclear air treatment systems and heating, ventilating and air conditioning systems (NATS/HVAC) from 1988 through 1991 filed by operators of U.S. nuclear power plants. It is a continuation of papers presented at past Air Cleaning Conferences by Dr. D. W. Moeller and associates[1234] and John W. Jacox[5].

NUREG/CR-2000 "Licensee Event Report (LER) Compilation"[6] was the basis for this paper. LER abstracts from 1988-1991 were reviewed and those related to NATS/HVAC were categorized and tabulated. The categories were then divided into root (primary) and secondary causes. A total of 10,687 LER's were filed during 1988-1991. Out of this total, 1730 (16.2%) were NATS/HVAC related. Of these, 59.9% were filed by PWR's, 40.0% by BWR's and 0.1% by HTGR operators. Although the total number of LER's filed per year since 1988 have gradually declined, many problem areas of the NATS/HVAC systems remain the same.

This paper is intended to provide information to the nuclear power industry which can be utilized as a basis to review problem areas. It also indicates that several areas continue to require attention.

Introduction

The monthly publication, NUREG/CR-2000, a compilation of LER abstracts from 1988 through 1991, was the basis for this paper. Each NATS/HVAC related LER was first divided into specific categories then divided into root (primary) and secondary causes. They were then further divided into Pressurized Water Reactor (PWR) and Boiling Water Reactor (BWR) related LER's.

In most cases the LER abstract was sufficient to categorize each LER. If there were no specific statements identifying the root cause, the cause was determined by the authors. Some difficulty arose in determining secondary causes. Since each LER was written with a different focus based on the root cause, determining these secondary causes for NATS/HVAC related LER's was at times difficult. As an example, some cases involving isolation valves and area monitors which may have lead the system to activate, but no activation occurred were not included. If activation occurred as a result of these items, it was included in the tabulation.

The results are presented in Tables 1 and 2. Table 1, "Tabulation of LER's by Root and Secondary Causes," lists sixteen categories and gives a breakdown of the number of root and secondary causes for each category for 1988-91. Table 2, "NATS & HVAC Related LER's Filed By Date and Reactor Type (PWR/BWR)," includes the dates between 1984-1991; and, Table 3, "Secondary Causes Categorized by Root Causes," summarizes secondary causes compared to root causes for 1988-91.

Discussion

A total of 1730 NATS/HVAC related LER's were filed by commercial nuclear power plants from 1988-1991. As illustrated in Table 2 "NATS & HVAC Related LER's By Date and Reactor Type (PWR/BWR)," 59.9% of the LER's filed were PWR related, 40.0% were BWR related and 0.1% HTGR related. It should be noted that of the total generating capacity of our domestic nuclear program, 66.7% is generated from PWR's and 33.3% from BWR's.

Table 1, "Tabulation of LER's By Root and Secondary Causes," indicates there are five categories that contain the majority (73%) of root causes. Personnel Error resulted in 29.5%, followed by Design or Installation Error and Procedure Related with 12.1% each. LER's related to Electrical Components were 9.9% and those related to Radiation Monitors were 9.4%.

The majority of secondary causes (81.9%) were divided among three categories: Radiation Monitors, 52.4%, Electrical Components, 17.1% and Mechanical Components, 12.4%.

Root Causes

The largest number of root causes were personnel error. Over 40% of these errors resulted in Engineered Safety Feature (ESF) actuations. The majority occurred while installing an electrical jumper, checking relays or calibrating radiation monitors. Other areas include misread samples and exceeded time intervals for vent of area sampling or testing. In most of these LER's, personnel error was declared the root cause; however, the procedure or component design was often at fault. This indicates that the number one root cause is closely related to the number two secondary cause, procedure and design or installation errors.

The second largest number of root causes were procedural problems. Nearly 40% of these resulted in ESF actuations. A common problem was improper surveillance testing of NATS components and radiation monitors. In some cases, the required surveillance time interval was exceeded or a test was not performed at all.

Problems associated with design and installation errors fell largely under single failure criteria concern for control room emergency ventilation, containment ventilation and standby gas treatment systems. When a system or component did not meet the single failure criteria, it often led to an unanalyzed condition which led to an LER being filed. Fire damper design and improper installation continue to be an item of concern. There were also cases of damper inoperability, failure to close in flow conditions, and, in one case, a damper was not even installed. Failure positions continue to be a problem of isolation dampers. There were several cases of damper failure "as-is" positions that were not evaluated, or dampers were failing to the wrong position.

Problems related to electrical component failure were the following: relays, breakers, fuses, inverters, loose/bad connections and faulty circuits. About 75% of these resulted in ESF actuations. In comparison, nearly all radiation monitor failures related to components resulted in ESF actuations. These included loss of power, bad power supply, fuses, loose/bad connections, circuit boards, tubes and detectors. As has been reported in earlier papers, one of the largest single causes is from electrical noise, spikes and radio frequency interference.

Secondary Causes

Two of the three most frequent secondary causes were the same as two of the top root causes: one being the radiation monitor and the other electrical component failures. As in the case of root causes, radiation monitor problems revolved around electrical component failures including, relay, loose/bad connector, power supply and circuit errors. The close relation between electrical component failure, electronic noise and spikes to radiation monitors account, in part, for the high number of radiation monitor secondary failures. Personnel error and procedure inadequacies again were a major part of these monitor failures. In the case of electrical components, the failures also paralleled the relay, breaker, fuse, and circuitry problems found in root causes. Various mechanical component failures made up the third largest category.

Comments and Summary

A number of observations can be made from this review. Out of the total number of LER's filed, almost half resulted in an inadvertent ESF actuation. The categories largely contributing to these actuations were Personnel Error, Procedural Error, Electrical Components, Radiation Monitors, and Design and Installation Errors. It should be noted that these categories make up the majority of Root Causes in this review and also in the previous review presented by John W. Jacox[5]. This indicates that the same problems continue to occur. The percent distribution of some categories between the previous review and this review are similar. Some distribution differences occur due to the subjective aspect of this paper in selecting and including LER's that may have been vague and possibly foster varied interpretations.

A pronounced lack of NATS related LER's derived from adsorber, HEPA, and airflow problems discovered during surveillance testing were noted by the authors. Only two LER's were the result of adsorbers failing the in-place surveillance test (99.0% or 99.95% required leak tightness in most cases); and no LER's were filed as a result of the HEPAs failing the in-place surveillance test. Through experience, the authors have found that the major problem encountered during in-place surveillance testing is that of air flows. Oftentimes the flow is out of specification ($\pm 10\%$ of design, normally) by being too high or too low, however, these do not appear in LER's.

To conclude, problem areas of NATS/HVAC systems of the past remain the common issues that trouble the industry today. A closer evaluation of these problems continue to require attention by power plant operators. It should be evident that in the future a more detailed review of initial design and installation and surveillance procedures would greatly reduce the number of NATS/HVAC related LER's filed. Perhaps the codification of requirements by the ASME AG-1 Code will assist in this effort.

TABLE 1

TABULATION OF LER'S BY ROOT AND SECONDARY CAUSES

	Category	Root Cause	Cause %	Secondary Cause	Cause %
I.	Adsorbers	7	0.4	9	1.2
II.	Design or Installation Errors	209	12.1	11	1.5
III.	Electrical Components	172	9.9	123	17.1
IV.	HEPA Filters	3	0.2	2	0.3
V.	Test or Technical Specification Violations	8	0.5	---	---
VI.	Mechanical Components	86	5.0	89	12.4
VII.	Personnel Error	511	29.5	15	2.1
VIII.	Procedure Related	209	12.1	17	2.4
IX.	Radiation Monitor	162	9.4	377	52.4
X.	Toxic Gas Monitor	80	4.6	45	6.2
XI.	Weather Related	21	1.2	---	---
XII.	Electrical Noise and Spikes	132	7.6	4	0.5
XIII.	Fire Protection	14	0.8	28	3.9
XIV.	Radiation Levels	6	0.3	---	---
XV.	Unknown	36	2.1	---	---
XVI.	Other	74	4.3	---	---

TABLE 2

NATS & HVAC RELATED

LER'S FILED BY DATE AND REACTOR TYPE (PWR/BWR)

Year	Reactor Type		Total/Year
	PWR (%)	BWR (%)	
1984*	1 (50)	1 (50)	2
1985*	0 (0)	1 (100)	1
1986*	8 (66.7)	4 (33.3)	12
1987*	26 (53.1)	23 (46.9)	49
1988	309 (56.8)	235 (43.2)	544
1989	250 (58.7)	176 (41.3)	426
1990**	283 (66.3)	144 (33.7)	427
1991**	159 (59.6)	108 (40.5)	267
Totals	1036 (59.9)	692 (40.0)	1728

* Not filed until 1988. This also includes any revised versions during this time period.

** 1-HTGR brings Total/Year to 1730

	% of Total
PWR	59.9
BWR	40.0
HTGR	0.1

TABLE 3
SECONDARY CAUSES CATEGORIZED BY ROOT CAUSES

Root Cause	Secondary Cause										
	Radiation Monitor	Electrical Components	Mechanical Components	Toxic Gas Monitor	Fire Protection	Procedure Related	Personnel Error	Design or Installation Errors	Adsorbers	Electrical Noise and Spikes	HEPA Filters
Personnel Error	134	50	24	15	12	14	--	2	3	1	1
Design or Installation Errors	38	12	20	9	7	1	4	--	--	--	--
Procedure Related	32	9	15	2	5	1	9	3	3	--	1
Electrical Components	41	--	6	3	1	--	1	1	--	--	--
Radiation Monitor	--	39	4	1		--	--	4	--	--	--
Electrical Noise and Spikes	119	--	--	5	--	--	1	1	--	--	--
Mechanical Components	2	1	--	1	3	1	--	--	--	--	--
Toxic Gas Monitor	—	—	—	—	—	—	—	—	—	2	--
Other	4	7	12	--	--	--	--	--	1	--	--
Unknown	3	5	6	--	--	--	--	--	--	--	--
Weather Related	4	--	1	9	--	--	--	--	--	1	--
Fire Protection	--	--	1	--	--	--	--	--	2	--	--
Totals	377	123	89	45	28	17	15	11	9	4	2

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DISCUSSION

KOVACH: First of all, it is a good sign that we see very few root causes associated with adsorbers and HEPA filters. I think our air cleaning components are behaving much better then I think we sometimes make them out to be. At the same time, I wonder what sort of feedback we get from this type of presentation that we have had for a number of years. To people such as those in the radiation monitoring and manufacturing industries as well as to people who never attend this Conference. I think we are dealing here with the air cleaning technology part of it and I think either ISNATT or CONAGT or some other group could pass the information on to people who are much more closely involved with these problems that tend to shut down the entire system. We could utilize these organizations to assure that there is some improvement in the operation of the overall system.

JACOX: I think that is an excellent suggestion and one that would be particularly appropriate for ISNATT to do. I probably should have mentioned that there are only two or three adsorber related LERs and no HEPA related LERs, a much better record than I reported two years ago. Then, there were quite a few adsorber problems, although it may be considered a fire control problem rather than an adsorber problem when you get water on the carbon from a false fire alarm. As a member of ISNATT, I suggest that we use it for effective feedback because we are "preaching to the choir" here. That is an excellent suggestion.

PATLOVANY: Up until last January I was a member of Power Plant A. I have been in their safety engineering group for three years. One of the things that we did was to look at the licensee event reports and perform a root cause analysis to provide input into this kind of a table. One of the things that I noticed was that a lot of the personnel error judgments had a lot to do with licensing department language being different than root cause analysis language. A lot of times you couldn't resolve the differences between the two. Going to a deeper level, you could find a lot of these 500+ personnel error events really had design related and procedure related causes. This is what I found from my personal experience. I understand why there are so many personnel errors. In I&C maintenance, personnel errors accounted for the largest number for that period of time I was in there. Although I&C technicians seem to have the lead in personnel errors, a lot of it has to do with lack of design and testability from the start. That you are in there with a jumper or alligator clip has a lot to do with the initial design of the equipment as to its testability.

JACOX: I appreciate the comments and I agree completely. When I was writing the paper four years ago, I wrestled with the idea that you could almost make a case that everything is a personnel error in the sense that people do everything. If something has to be tested, it must be made testable, particularly when designing the electrical and the toxic gas alarms which were such a problem in the last seven analyses. In the air treatment area, CONAGT goes to extreme lengths to insist in the standards and codes that things be testable. Obviously, that doesn't happen in the electrical area and this would be an area where feedback, as Lou Kovach mentioned, should be emphasized to send this important information to the right people.

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10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)
This document contains the papers and the associated discussions of the 22nd DOE/NRC Nuclear Air Cleaning Conference. Major topics are: (1) advanced reactors, (2) reprocessing, (3) filter testing, (4) waste management, (5) instruments and sampling, (6) reactor accidents, (7) filters and filter performance, (8) adsorber testing and performance, (9) carbon testing, and (10) ventilation systems.

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