

OTIC FILE COPY

4

CR 89.004

# NCEL

Contract Report

January 1989  
An Investigation Conducted by  
Acurex Corporation, Mountain View, CA  
Sponsored By Naval Facilities  
Engineering Command

AD-A206 926

## NAVY PAINT BOOTH CONVERSION FEASIBILITY STUDY

**ABSTRACT** This study is an evaluation of the hazardous waste minimization benefits which may be achieved in converting Naval shipyard and Naval aviation depot paint booth emission control systems from wet to dry operation. In addition, a cost/benefit analysis of converting several types of paint spray booths is presented.

DTIC  
ELECTE  
S 29 MAR 1989 D  
E

NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME, CALIFORNIA 93043

Approved for public release; distrubution is unlimited.

89 3 28 074

**APPROXIMATE CONVERSION FACTORS**

**Approximate Conversions to Metric Measures**

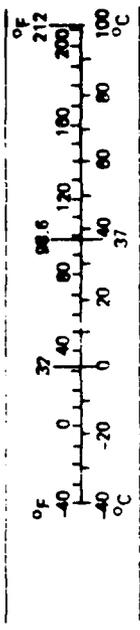
Symbol	When You Know	Multiply by	To Find	Symbol
		<b>LENGTH</b>		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		<b>AREA</b>		
in <sup>2</sup>	square inches	6.5	square centimeters	cm <sup>2</sup>
ft <sup>2</sup>	square feet	0.09	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yards	0.8	square meters	m <sup>2</sup>
mi <sup>2</sup>	square miles	2.6	square kilometers	km <sup>2</sup>
	acres	0.4	hectares	ha
		<b>MASS (weight)</b>		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons	0.9	tonnes	t
	(2,000 lb)			
		<b>VOLUME</b>		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft <sup>3</sup>	cubic feet	0.03	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.76	cubic meters	m <sup>3</sup>
		<b>TEMPERATURE (exact)</b>		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

**Approximate Conversions from Metric Measures**

Symbol	When You Know	Multiply by	To Find	Symbol
		<b>LENGTH</b>		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
km	kilometers	1.1	yards	yd
		0.6	miles	mi
		<b>AREA</b>		
cm <sup>2</sup>	square centimeters	0.16	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	1.2	square yards	yd <sup>2</sup>
km <sup>2</sup>	square kilometers	0.4	square miles	mi <sup>2</sup>
ha	hectares (10,000 m <sup>2</sup> )	2.5	acres	
		<b>MASS (weight)</b>		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		<b>VOLUME</b>		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
		1.06	quarts	qt
		0.26	gallons	gal
m <sup>3</sup>	cubic meters	35	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.3	cubic yards	yd <sup>3</sup>
		<b>TEMPERATURE (exact)</b>		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



\* 1 in. = 2.54 (exact). For other exact conversions and more detailed tables, see NBS Monograph 286, Units of Weights and Measures, Price \$7.25, SD Catalog No. C13.10.286.



Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1 REPORT NUMBER CR 89.004	2 GOVT ACCESSION NO	3 RECIPIENT'S CATALOG NUMBER
4 TITLE (and Subtitle) Navy Paint Booth Conversion Feasibility Study		5 TYPE OF REPORT & PERIOD COVERED Final Feb 1988 - Oct 1988
		6 PERFORMING ORG REPORT NUMBER
7 AUTHOR(s) Jacqueline Ayer Anthony S. McElligott		8 CONTRACT OR GRANT NUMBER(s) N62583/88 M X776
9 PERFORMING ORGANIZATION NAME AND ADDRESS Acurex Corporation PO Box 7044 Mountain View, CA 94039-7044		10 PROGRAM ELEMENT PROJECT, TASK AREA & WORK UNIT NUMBERS <del>74-086</del>
11 CONTROLLING OFFICE NAME AND ADDRESS Naval Civil Engineering Laboratory Port Hueneme, CA 93043-5003		12 REPORT DATE January 1989
		13 NUMBER OF PAGES 92
14 MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Naval Facilities Engineering Command 200 Stovall Street Alexandria, VA 22332-2300		15 SECURITY CLASS (of this report) Unclassified
		15a DECLASSIFICATION DOWNGRADING SCHEDULE
16 DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution is unlimited.		
17 DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18 SUPPLEMENTARY NOTES		
19 KEY WORDS (Continue on reverse side if necessary and identify by block number) hazardous waste, air pollution control, painting, paint spray booth, paint sludge, paint overspray, wastewater, particulate filters, wet scrubbers		
20 ABSTRACT (Continue on reverse side if necessary and identify by block number) This study is an evaluation of the hazardous waste minimization benefits which may be achieved in converting Naval shipyard and Naval aviation depot paint booth emission control systems from wet to dry operation. In addition, a cost/benefit analysis of converting several types of paint spray booths is presented.		

DD FORM 1473 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

FOREWORD

This work was sponsored by the Naval Facilities Engineering Command and the Naval Civil Engineering Laboratory as part of a program to minimize the hazardous waste generated by paint spray booths operated by the Navy. The air pollution control (APC) devices typically installed in Navy spray booths, being predominantly of the wet scrubber (water-wall) configuration, are responsible for the production of large amounts of noxious wastewater and gelatinous paint sludge, both forming during the removal of paint overspray aerosol from exhausted booth ventilation air. The work described herein demonstrates the feasibility of changing out such APC equipment with dry filter systems. The project emphasis was on determining the relative: (1) performance of the APCs for aerosol control (VOCs are not significantly removed by either configuration), (2) avoidance of hazardous waste formation, and (3) cost effectiveness.

The results of this work point clearly to benefits from the wet to dry APC change-over in terms of all three of the above criteria. Because of the excellent, if limited number of, case histories of successful dry APC system applications found in Industry and some DOD paint spraying facilities, follow-on work will transition immediately into the preparation of engineering guidelines that will facilitate, at the activity level, wet to dry system conversions. This construction guide-document will thus help promote in a timely manner Navy's 1992 goal of reducing by at least 50% the hazardous waste it now generates.

If any additional or updated information is desired concerning this area of work, please contact:

Mr. Richard M. Roberts, Code L74B  
 Project Leader  
 Hazardous Waste Minimization  
 Naval Civil Engineering Laboratory  
 Port Hueneme, CA 93043-5003

Telephone:  
 Commercial: (805)982-5085  
 Autovon: 360-5085



Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input checked="" type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

## TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
1	INTRODUCTION .....	1-1
2	TECHNICAL APPROACH .....	2-1
3	PAINT BOOTH CHARACTERISTICS .....	3-1
	3.1 PARTICULATE EMISSION CONTROL SYSTEMS .....	3-1
	3.1.1 Water Curtain Systems .....	3-2
	3.1.2 Dry Filter Systems .....	3-5
	3.2 PAINT SPRAY BOOTH VENTILATION SYSTEMS .....	3-7
	3.2.1 Crossdraft Ventilation Systems .....	3-7
	3.2.2 Downdraft Ventilation Systems .....	3-9
4	WASTES GENERATED BY WATER CURTAIN AND DRY FILTER PARTICULATE EMISSION CONTROL SYSTEMS .....	4-1
	4.1 WASTES GENERATED BY DRY FILTER SYSTEMS .....	4-1
	4.2 WASTES GENERATED BY WATER CURTAIN SYSTEMS .....	4-2
5	PAINT BOOTH CONVERSION OPTIONS AND ISSUES .....	5-1
	5.1 DESIGN CONSIDERATIONS FOR CONVERTING A CROSSDRAFT BOOTH .....	5-1
	5.2 DESIGN CONSIDERATIONS FOR CONVERTING A DOWNDRAFT BOOTH .....	5-3
	5.3 THE IMPACT OF OPERATING PROCEDURES ON CONVERSION OPTIONS .....	5-4
	5.4 OTHER CONVERSION ISSUES .....	5-4
	5.4.1 Building Fire and Safety Codes .....	5-5
	5.4.2 Air Pollution Control Statutes .....	5-5
	5.4.3 Waste Disposal Requirements .....	5-5
6	NSY AND NADEP PAINTING FACILITIES .....	6-1
	6.1 SURVEY OBJECTIVE .....	6-1
	6.2 NADEP AND NSY PAINT BOOTH CHARACTERISTICS .....	6-3
	6.2.1 Sump Maintenance and Wastewater Treatment Practices .....	6-3
	6.2.2 Sludge Generation Rates .....	6-5
	6.2.3 Operating Conditions and Operational Quality of Water Curtain Booths .....	6-6

TABLE OF CONTENTS (CONCLUDED)

<u>Section</u>		<u>Page</u>
7	COST/BENEFIT ANALYSIS .....	7-1
	7.1 COST BENEFIT ANALYSIS ASSUMPTIONS AND JUSTIFICATIONS .....	7-1
	7.2 COST/BENEFIT ANALYSES TECHNIQUES .....	7-3
	7.2.1 Issues and Assumptions Made in Performing the Type I Economic Analyses for Paint Booth Scenarios 1, 2, and 3 .....	7-3
	7.2.2 Issues and Assumptions Made in Performing the Type II Economic Analyses for Paint Booth Scenario 4 .....	7-6
	7.3 PAINT BOOTH CONVERSION COST/BENEFIT ANALYSIS .....	7-6
8	FACILITIES COST-EFFECTIVELY CONVERTED .....	8-1
9	CONCLUSIONS .....	9-1
	REFERENCES .....	R-1
	APPENDIX A -- CHARACTERISTICS OF TYPICAL DRY FILTER SYSTEMS .....	A-1

SECTION 1  
INTRODUCTION

The Navy is currently exploring the possibility of reducing the quantities of hazardous waste generated in many industrial processes. Seventeen processes have been identified as targets for waste minimization efforts in the "Naval Civil Engineering Laboratory (NCEL) Hazardous Waste Minimization Initial Report." One hazardous waste source selected for study is the particulate emission control system (PECS) currently used on nearly every Navy paint spray booth. This system utilizes a water curtain to remove paint overspray particulate from the booth exhaust. The large volumes of wastewater generated by this process contain significant quantities of paint particulate, solvents, and in some cases, flocculating and coagulating agents. The wastewater must be treated to remove the hazardous constituents before it may be discharged, and the paint sludge waste which is generated must be disposed of as hazardous waste.

The waste minimization option that the Navy is exploring is the replacement of water curtain PECSs with dry filter systems at Navy Ship Yard (NSY) and Naval Aviation Depot (NADEP) painting facilities. The primary objective of this study is to determine the effectiveness of PECS conversion in achieving the Navy's hazardous waste minimization goals. In addition, the cost-effectiveness and feasibility of converting NSY and NADEP paint booths is explored. The emphasis, however, is on the hazardous waste minimization benefits which may be realized through paint booth PECS conversion.

SECTION 2  
TECHNICAL APPROACH

The hazardous waste minimization evaluation and cost/benefit analysis was carried out in three phases:

- Phase I was the collection and evaluation of filter and paint booth manufacturer data.
- Phase II was a survey of several NSY and NADEP painting facilities to determine types and quantities of booths used in these activities.
- Phase III was an engineering evaluation of the hazardous wastes generated by NSY and NADEP PECSs, and PECS installation and operating costs.

In order to develop a realistic cost/benefit analysis of converting paint booths from wet to dry operation, it was necessary to gather information pertaining to the types and applicability of wet and dry PECSs. These data were gathered from previous Acurex paint booth studies, and several paint booth and filter manufacturers. The results of this effort are presented in Section 3 and Appendix A. The detail of the information presented in these sections is necessary in order to fully understand the assumptions made in the cost/benefit analysis presented in Section 7.

A survey of representative NSY and NADEP activities was performed to gather specific painting facility information such as paint booth types,

sizes, duty cycles, and hazardous waste generation rates. This information was required to ascertain the waste minimization benefits that may be realized by paint booth PECS conversions at NSY and NADEP activities. The information was also used to help make more realistic assumptions in the cost/benefit analysis.

The data gathered during the Phase I and Phase II efforts were evaluated and used to develop a hazardous waste minimization and cost/benefit analysis in Phase III.

## SECTION 3

### PAINT BOOTH CHARACTERISTICS

To determine the costs involved in converting a PECS from wet to dry operation, the characteristics of the paint booth to be converted must be determined. Two parameters which characterize all paint spray booths are the PECS and the ventilation system. The two types of PECSs used in industrial applications are water curtain and dry filter particulate scrubbers. The ventilation systems in all NSY and NADEP painting facilities are either crossdraft or downdraft. PECS will be presented in greater detail in Section 3.1, and ventilation systems are discussed in Section 3.2.

#### 3.1 PARTICULATE EMISSION CONTROL SYSTEMS

There are two methods of controlling particulate emissions from paint spray booths; the particulate laden air passes through either a water curtain or a dry filter. If operated properly, both systems can have very high particulate removal efficiencies.

Before beginning a discussion of PECSs, a distinction must be made between particulate and VOC emission control. Neither water curtain nor dry filter emission control systems may be considered to control VOC emissions because neither are capable of consistently removing solvent vapors from an air stream. For obvious reasons, dry filter systems cannot be used for VOC emission control. In the case of water curtain systems, many paint solvents are not miscible with water, thus they easily pass through a water curtain.

Those few paint solvents that are collected by the water curtain generally have low solubilities, thus only small quantities actually remain trapped in the collection sump. Because neither system is capable of controlling VOC emissions from the paint spray booth, they both require the same degree of VOC air pollution control.

Results from a recent study performed at McClellan AFB indicate that solvent concentrations measured in water curtain sump water can reach a state of equilibrium in one day or less (Reference 1). In the case of sumps that are drained approximately once per month, this implies that over 95 percent of the solvent vapors passing through the water curtain are not collected. This same study indicated that sump water solvent concentrations can decrease over time, due to re-entrainment of volatile solvents by air passing through the water curtain.

### 3.1.1 Water Curtain Systems

There are many types of water curtain systems in common use, however two typical systems are illustrated in Figure 3-1 (Reference 2). Water curtain systems are generally comprised of a large collection sump, water pumps, and a series of one or more baffles. Water is pumped up from the collection sump and over the baffles to produce one or more water curtains, depending on the number of baffles. The air is scrubbed by the water curtain and ducted to the atmosphere. The water from the curtain falls down into the collection sump, from which it again is pumped up over the baffles. The sump water is constantly cycled in this manner until the sump is drained, and the sludge collected in the bottom is shoveled out and disposed of as hazardous waste.

The water flowrate through the curtain system depends on the size of the system and the type of water curtain employed. Spray type systems require

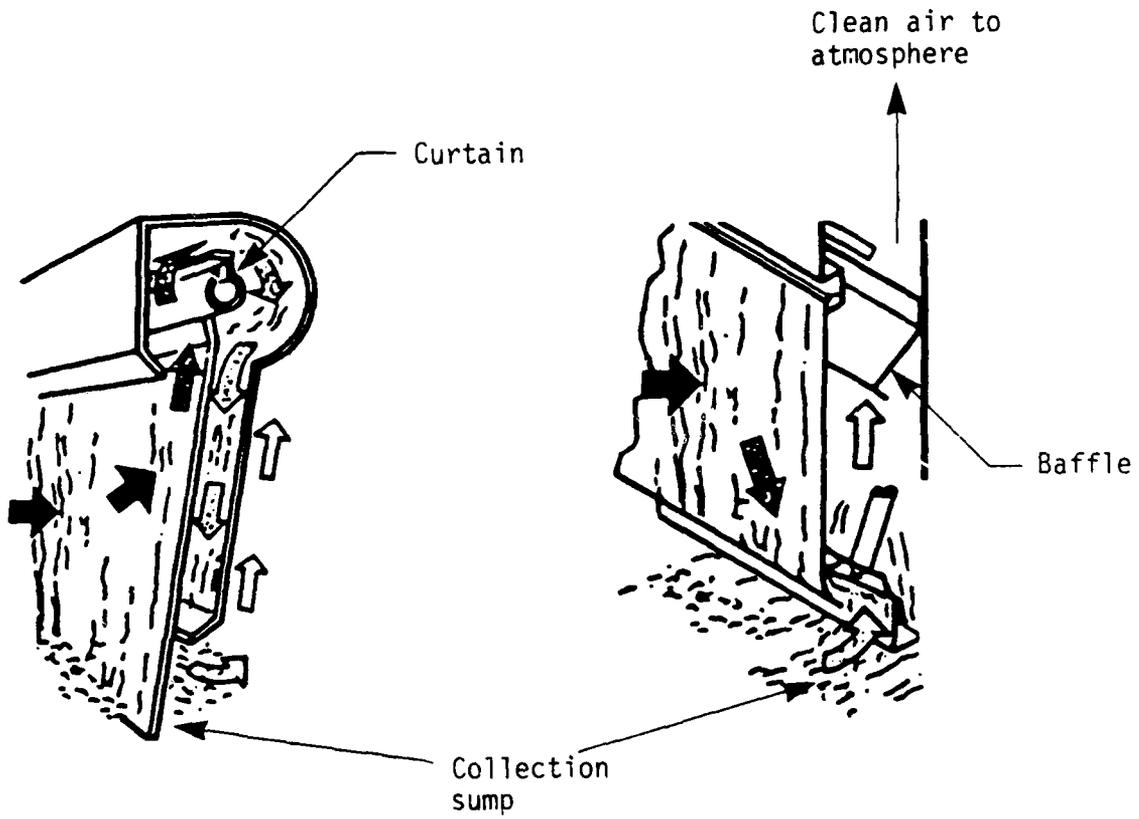


Figure 3-1. Two Typical Water Curtain PECCS

different flowrates than sheet type systems. Because the flowrate is system dependent, no generalized value can be assigned.

The particulate removed by the water curtain collects in a sump located under the water curtain. Most of the solvents removed by the water curtain are either volatile or semivolatile, and are not miscible with water. Therefore, most are re-entrained by the ventilation air, and emitted to the atmosphere.

The only significant maintenance required of a typical water curtain system is periodic sump drainage and cleaning. For this reason, water curtain systems are better suited to booths with heavy duty cycles (two or more shifts per day). Other minor maintenance requirements are: topping off the sumps to replace water lost due to evaporation and, if necessary, adding flocculating and coagulating agents to the sump water. These chemicals cause paint particulate collected in the sump to agglomerate and either sink or rise to the sump surface. The floating paint scum is easily skimmed off. In systems where the paint sludge collects on the bottom of the sump, significant downtime is experienced due to sump cleanout. In these cases, the sludge must often be dug out of the sump before it is drummed and shipped to a treatment, storage, and disposal facility (TSDF) as hazardous waste.

The primary advantage of water curtain systems is that, in some cases, the associated maintenance requirements are fairly low compared to dry systems; some manufacturers claim that their sump systems require draining and cleaning less than once per year. This is not always the case, however. The results of a phone survey of several NADEP and NSY activities indicate that many paint booth operators drain their sumps as often as once or twice a month. Unfortunately, frequent sump drainage results in considerable downtime.

There are a number of disadvantages associated with water curtain PECSs. The primary disadvantage is that the sludge and wastewater collected in the sump is designated a hazardous waste because it contains both paint solvents and toxic metals such as chrome and lead (some of the paints used at NSY and NADEP facilities contain these metals). The costs associated with the proper disposal of the hazardous sludge and/or water is quite high.

Another disadvantage of water curtain systems is that, if not made of durable materials, the sumps and associated ductwork will quickly rust. A number of manufacturers contacted maintain that their booths last anywhere from 10 to 20 years (References 3 and 4). This is true if high-quality equipment and materials are used in the water curtain system. However, two NSY and NADEP paint booth operators interviewed during the phone survey indicated that some booths were heavily rusted after only 6 years. Repair costs for rusted systems are quite high, because the duct work, fans, baffles, and sumps require replacement. In addition, the replacement equipment may have to be custom-made.

### 3.1.2 Dry Filter Systems

There are many types of dry filter PECSs available on the market; some differ only slightly from one manufacturer to another. However, all dry filter systems operate on the same principle: particulate-laden air drawn into the filter is forced to rapidly change directions as it flows around the filter media. The particulate, having more inertia than the surrounding air, impacts on the filter media and is removed from the air flow. Dry filter systems operate in much the same way as mist eliminators.

There are a number of advantages of dry filter PECSs over water curtain systems. The primary advantage is that the associated waste disposal costs are low compared to the waste disposal costs associated with water curtain

systems. A detailed description of wastes generated by dry filter systems is given in Section 4. Another advantage is that, if properly maintained, the booth structure should never require rebuilding or replacement. Unlike water curtain systems, which tend to rust, dry filter systems do not deteriorate with age. In addition, the installation costs of dry filter systems are much lower than water curtain systems.

The principal disadvantage of dry filter systems is that, if not properly selected based on the painting operation and paint usage rate, the downtime associated with filter replacement may be unacceptably high. For example, inexpensive cartridge filter systems which require frequent manual replacement (once every few days of use) are best suited to small booths used infrequently, because these systems are inexpensive and the downtime due to filter replacement does not affect paint booth operation. Filter systems that are more rapidly changed out are more applicable in booths that are constantly used, because the associated downtime for filter replacement is very low. However, the associated capital and installation costs for the more rapidly changed filter systems may be higher than for cartridge filter systems.

The characteristics of dry filters that affect performance are particulate capacity, resistance to airflow, and particulate removal efficiency. These parameters are described more fully in Appendix A.

There are four principal types of filters currently used: (1) fiberglass cartridges, (2) multilayered, honeycombed paper rolls or pads, (3) accordion-pleated paper sheets, and (4) cloth rolls or pads. These filter types are described in Appendix A.

Fiberglass cartridge filters are characterized by low installation costs, reasonable particulate capacities, and high particulate removal efficiencies. These filters are fairly expensive per square foot, and the

downtime associated with their replacement is high. They are generally installed in booths which are used one shift per day or less.

Multilayered honeycombed filters and cloth filters are characterized by moderate installation costs, good particulate capacities, low filter replacement costs per square foot, and moderate to high particulate removal efficiencies. The downtime associated with their replacement can be quite low, and they may be used in either light, moderate, or high production rate booths.

Accordion pleated paper sheet filters are characterized by low to moderate installation cost, low to moderate filter replacement costs per square foot, high particulate capacities, and poor removal efficiencies. The downtime associated with their replacement is low, thus they may be used in virtually any type of booth, providing sufficient air pollution control is achieved.

In selecting an appropriate dry filter PECS, all applicable particulate emission regulations must be considered. In areas where emissions regulations are stringent (such as in California), booths with filters having low particulate removal efficiencies may not be in compliance. Thus, the accordion pleated paper sheet filter may not be applicable in some paint booth facilities.

## 3.2 PAINT SPRAY BOOTH VENTILATION SYSTEMS

### 3.2.1 Crossdraft Ventilation Systems

A schematic diagram of a typical crossdraft paint spray booth is provided in Figure 3-2 (Reference 1). Fresh air is ducted in through dry filters covering one side of the booth. The function of these filters is to ensure that the ventilation air brought into the booth does not contain any particulate contaminants. The air traverses the booth, picking up solvent

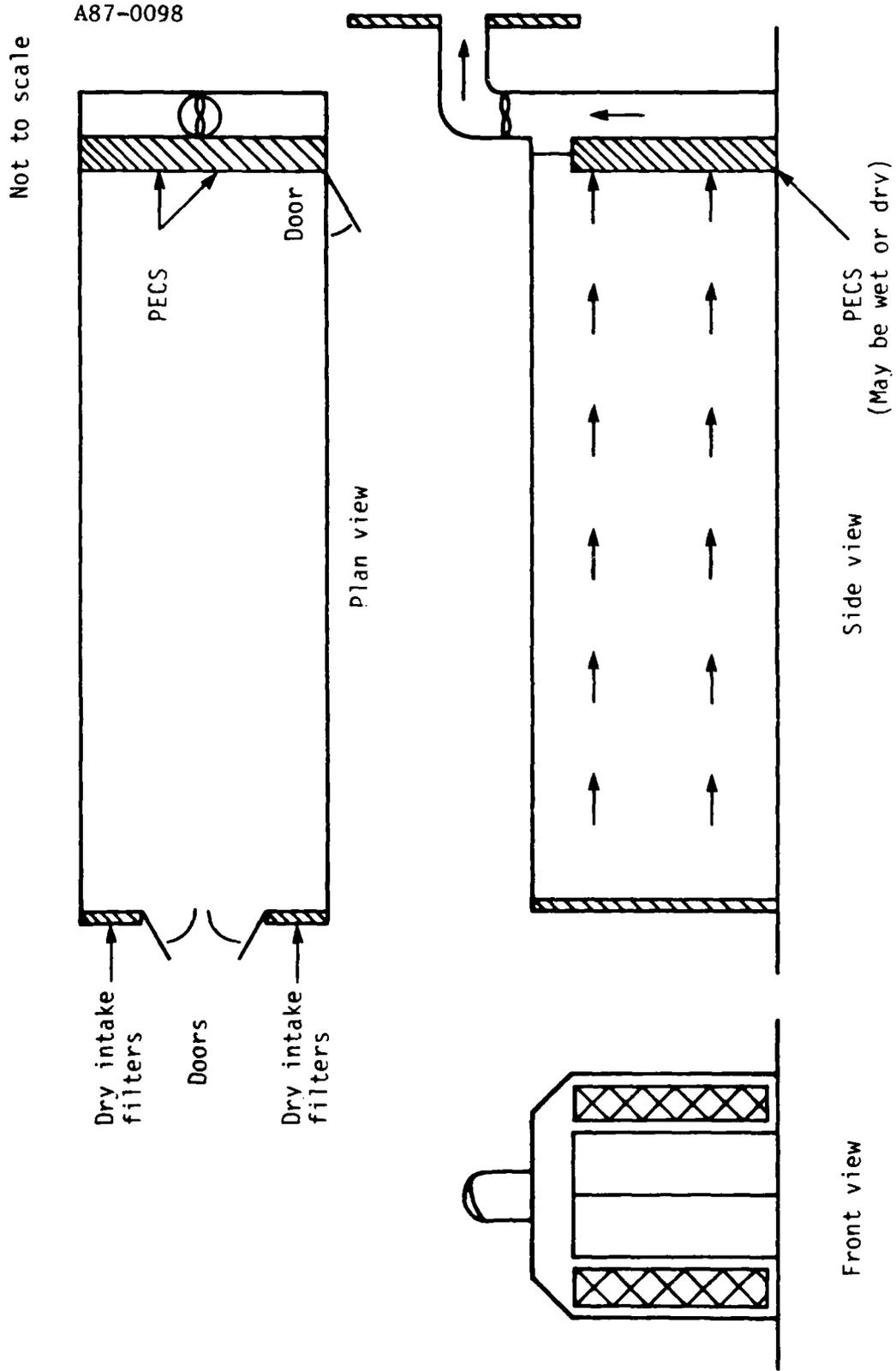


Figure 3-2. Schematic of a Typical Crossdraft Paint Spray Booth

vapors and paint overspray, and flows through a PECS located opposite the air intake filters.

There are variations of the crossdraft ventilation system described above, however all such booths have a PECS located above the paint booth floor in front of a large plenum chamber. Some crossdraft booths are "open", meaning that one or more sides of the booth are not enclosed. Other booths have large openings in the sides, to accommodate work pieces that are brought into the booth via an overhead conveyor system. Both these systems generally allow the paint spray operator greater freedom of movement.

### 3.2.2 Downdraft Ventilation Systems

A schematic of a typical downdraft spray booth is provided in Figure 3-3 (Reference 1). Water curtain PECSs are associated with nearly all downdraft ventilation facilities, hence a water curtain system is illustrated in Figure 3-3. Fresh air is ducted into the booth through dry intake filters (which ensure that only clean, filtered air enters the booth) located on the ceiling, and flows down through the booth, picking up solvent vapors and paint overspray. The solvent- and particulate-laden air is drawn down through grates in the floor, over a sump and through a water curtain.

There are variations on the booth described here, however almost all downdraft booths have water curtain PECSs with sumps located beneath the paint booth floor in front of a large plenum chamber. In addition, most large downdraft water curtain booths are custom made, thus it is often difficult to find standard replacement parts such as sumps and baffles.

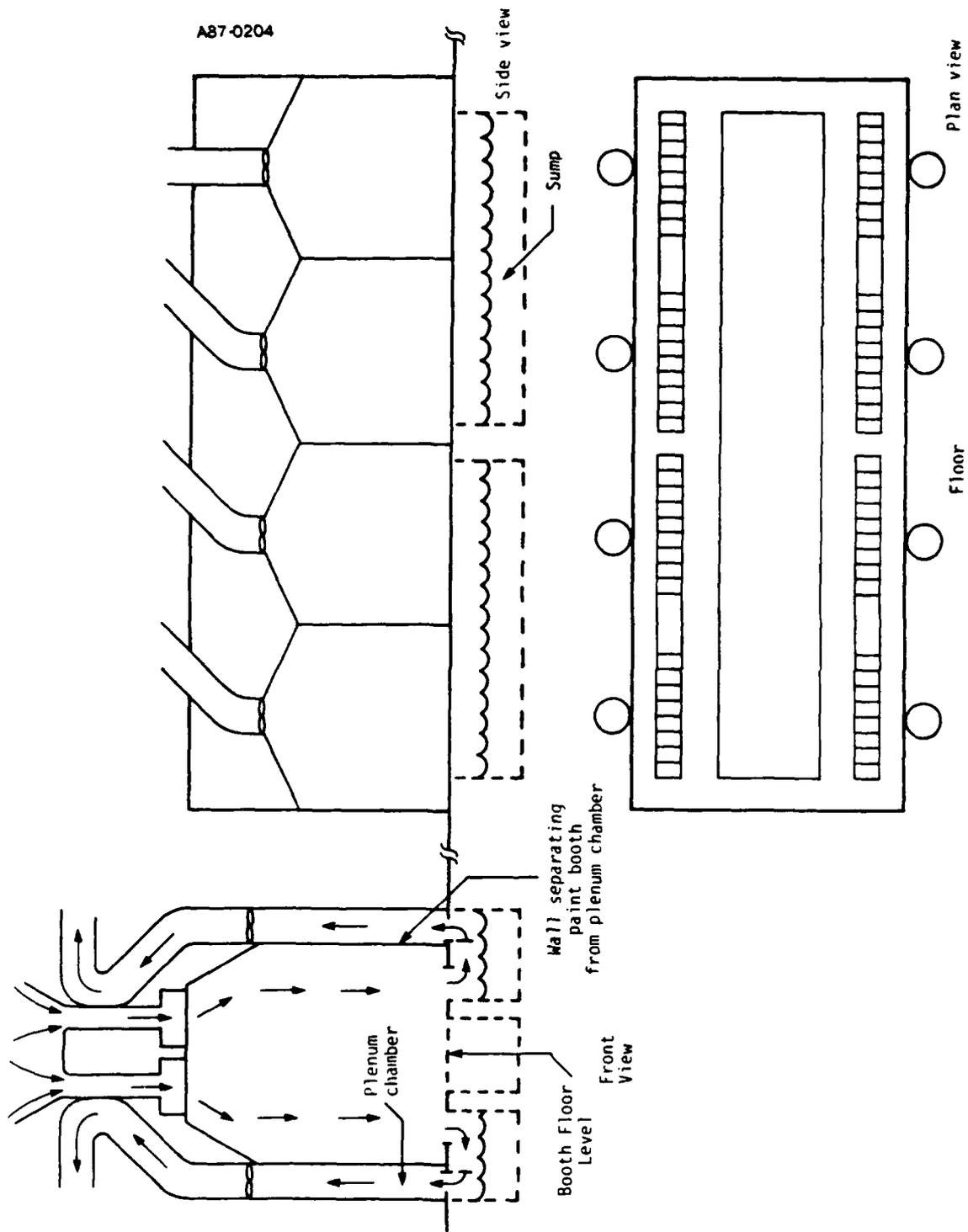


Figure 3-3. Schematic of a Typical Downdraft Paint Spray Booth

## SECTION 4

### WASTES GENERATED BY WATER CURTAIN AND DRY FILTER PARTICULATE EMISSION CONTROL SYSTEMS

The wastes generated by the two types of PECSS are extremely different; dry filter systems produce filters caked with paint solids, and water curtain systems produce large quantities of wastewater containing paint solvents, particulate and, in many cases, coagulating and flocculating chemicals. Each type of waste is described fully in this section.

#### 4.1 WASTES GENERATED BY DRY FILTER SYSTEMS

Filter media caked with paint and other coating residues is the only waste generated by dry filter PECSS. If the paint on the filter is dry when it is replaced, it can probably be disposed of as nonhazardous waste at a municipal landfill. If the paint residue collected on the filter must be cured in order to dry, the filter will remain wet and tacky for some time after filter changeout. In this case, the spent filters will require disposal as hazardous waste. This can be avoided if the filters are cured sufficiently in a paint drying chamber to allow the paint residue to dry.

Filter curing may or may not be an option for a particular facility, depending on the curing process (i.e. low heat, high heat or ultra violet light), and the filter type. In industrial operations, fiberglass filters have been cured with a low-heat process, thus it is possible to transform wet filters to nonhazardous waste. It is not anticipated that filter curing will be required at NSY and NADEP activities, because more than 99 percent of the

paint used at these activities is air dried, and does not require any curing process.

The uncertainty as to whether or not spent filters are classified as hazardous waste stems from the fact that states have different laws regarding their disposal. The State of California requires that filters that are coated with a wet paint residue and are not dry to the touch, be disposed of as hazardous waste (Reference 5). However, if the waste filter is completely dry (as is the case if the paint on the filter media and the objects to which it is applied are air dried at room temperature), then the filter may be discarded at a municipal landfill. The State of California has relatively strict laws regarding disposal of hazardous wastes, thus it is unlikely that laws in other states are more stringent.

The costs associated with the disposal of spent filters obviously depend on their classifications as waste. If the filters are designated nonhazardous, the disposal costs are negligible. If designated a hazardous waste, the spent filters must be packed into waste containers and shipped to an offsite treatment, storage and disposal facility (TSDF). These filters will most likely be incinerated.

#### 4.2 WASTES GENERATED BY WATER CURTAIN SYSTEMS

Contaminated sump water is the only waste stream generated by water curtain PECSs. The sump water generally contains paint solvents, particulate, and coagulating and flocculating chemicals. Due to the presence of hazardous constituents, the sump water is designated a hazardous waste. The wastewater generated is treated and disposed of at considerable cost. These are methods available to reduce disposable costs by improving the water treatment process. However, the associated disposal costs are still quite high compared to waste disposal costs associated with dry filter systems.

In some cases, the water that is drained from the sump may be treated at an industrial wastewater treatment plant (IWTP), provided one capable of processing the sump water is available. Because few painting facilities have access to onsite wastewater treatment plants that will accept the hazardous sump water, this is generally not a feasible option. Another option is to drum and ship the wastewater to a TSDF without any pretreatment. Sumps contain anywhere from 280 to 5,000 gallons or more and maybe drained as often as once per month. Due to the large volumes of wastewater involved, this option is generally too expensive to consider.

A variety of techniques may be employed to greatly reduce the volume of waste water requiring treatment by concentrating the hazardous constituents. However, these are concentration processes only, and cannot be considered as ultimate waste disposal methods. Thus the concentrated waste that results is hazardous, and must be disposed of accordingly. The most straightforward method of concentrating the coagulants and paint particulate collected in the sump is to filter the wastewater. The filtrate may then be recycled back into the sump, or sent to an IWTP for final treatment. At one NSY activity, the filtrate is sent through a carbon adsorption system to remove the remaining solvents, and then recycled back into the sump. In this case, the spent carbon will require subsequent treatment or disposal as a hazardous waste, because it contains concentrated paint solvents.

The sludge generated by the filtration process, which contains both solvents and solids, is drummed and hauled to a TSDF. The disposal cost, per drum, for this sludge is moderate to high, depending on the quality of the sludge (i.e., the percent solids content). The general rule is: the more

concentrated the waste, the more cost-effective the disposal. Some NSY and NADEP activities dispose of highly concentrated sludge, while others generate waste of low concentrations.

SECTION 5  
PAINT BOOTH CONVERSION OPTIONS AND ISSUES

The feasibility and cost-effectiveness of converting a paint booth PECS from wet to dry operation is a function of both the paint booth ventilation system and facility operating procedures (i.e., usage rates, maintenance practices, wastewater treatment practices). In this section, design considerations for converting booths having crossdraft and downdraft ventilation systems, and the impact operating procedures have on conversion cost, are presented. In addition, general site-specific conversion issues are addressed. The site-specific issues are not explored in great detail, because such an analysis is beyond the immediate scope of this project.

5.1 DESIGN CONSIDERATIONS FOR CONVERTING A CROSSDRAFT BOOTH

The first step in converting a crossdraft booth from water curtain to dry filter operation is to determine the surface area of filters required for safe and effective operation. In doing so, parameters such as linear and volumetric air flowrates, and filter face velocities must be considered. The filter face velocity is the design flowrate through a clean filter which allows safe and efficient operation. This flowrate is determined by the manufacturer.

According to Occupational Safety and Health Administration (OSHA) regulations, the linear air flowrate, or velocity, through a paint spray booth must be sufficiently high as to ensure that 100 feet per minute (fpm) is

maintained in the vicinity of the paint booth workers (Reference 6). For a margin of safety, 125 fpm is generally used as the design flowrate. The converted booth must be designed to accommodate this flowrate. The volumetric flowrate through the booth is calculated by multiplying the linear velocity by the cross-sectional area of the booth perpendicular to the direction of flow. The required filter surface area is calculated by dividing the volumetric flowrate by the design filter face velocity, which varies significantly depending on filter type and manufacturer. For this reason, the type of dry filter system must be selected and the filter face velocity specified before the final design of the converted booth is completed.

In converting a crossdraft booth, much of the wall separating the plenum chamber from the booth is removed and replaced with framework used to support the dry filter system. The sumps and ductwork generally do not require removal or significant alteration. In many cases, fans located downstream of the filter system must be downsized to match the maximum allowable flowrate through the dry filter system. In a few cases, fan replacement may be required. Because booths having crossdraft ventilation systems require relatively minor alteration, they are generally the least expensive to convert.

Open crossdraft booths may be slightly more complicated to convert due to the higher linear flowrates required for safe operation. The linear flowrate at the PECS of an open booth may be 200 fpm or higher to ensure that a flowrate of 100 fpm passes the operator. For safety reasons, high volume flowrate requirements must be considered when converting an open booth.

As with all filtration systems, partial blinding of the filter media will occur as the quantity of overspray collected increases. In a crossdraft booth, blinding will occur in those filter sections in front of which frequent

painting occurs. This blinding should not cause any ventilation problems, as long as the filters are replaced when the maximum design pressure differential across them is reached.

## 5.2 DESIGN CONSIDERATIONS FOR CONVERTING A DOWNDRAFT BOOTH

As with a crossdraft ventilation system, the first step in converting a downdraft booth from water curtain to dry filter operation is to determine the surface area of filters required for safe and effective operation.

Again, the converted booth must be designed to accommodate a linear flowrate of 100 fpm, however 125 fpm is generally used for a margin of safety. The volumetric flowrate through the booth is calculated by multiplying the linear velocity by the floor area (width x length) of the booth. The required filter surface area is calculated by dividing the volumetric flowrate by the design filter face velocity.

There are a number of ways in which a downdraft booth may be converted. Filters may be installed horizontally under grates in place of the sumps. In almost all cases, this is not a feasible option because the grates must be removed each time the filters require replacement. In addition, paint spills and other debris falling through the grates onto the filters will cause unnecessary blockage and frequent filter replacement.

It is generally more economical to reconstruct the wall separating the paint booth from the plenum chamber located above the water sumps on both sides of a downdraft booth to allow vertical placement of the filter media (See Figure 3-3). The lower part of the walls separating the plenum chamber from the booth are removed and replaced with framework used to support the dry filter system. In some cases, the sumps must be partially blocked off to prevent leakage of contaminated air. In addition, downsizing of the fans located downstream of the filter system may be required to match the maximum

allowable flowrate through the dry filter system. Fan replacement is generally not required.

As with a crossdraft dry filter system, partial blinding of the filter media will occur. The top part of the filter loads more quickly than the bottom part, however this causes no appreciable increase in pressure differential; rather the flow is directed through the lower part of the filter. No upstream air distribution system is required, nor is any structural alteration of downstream equipment required.

Because the conversion of a downdraft booth requires more reconstruction of the walls and ductwork than a crossdraft booth of equal size, the associated conversion costs are generally higher.

### 5.3 THE IMPACT OF OPERATING PROCEDURES ON CONVERSION OPTIONS

The frequency with which a booth is used, along with the overspray rate, are the primary factors which determine the type of dry filter system to be installed in the converted booth. As described previously, a cartridge filter system, which is inexpensive to install, but requires some downtime for filter replacement, may be best suited to a booth that is used relatively infrequently. An easily deployed filter system having a higher installation cost is probably better suited to a moderate- to high-production booth.

### 5.4 OTHER CONVERSION ISSUES

There are a number of conversion issues that are site-specific, such as building fire and safety codes, local air pollution control regulations and waste disposal requirements. Because of the site-specific nature of these issues, they cannot be completely addressed in this report; they are however, briefly outlined here.

#### 5.4.1 Building Fire and Safety Codes

It is possible that modification of the booth fire sprinkler system will be required before the converted booth can receive an operating permit. In addition, some regions have very strict rules regarding the size and orientation of air intake and exhaust systems. Although these systems should not be affected by the conversion of a paint spray booth, an inspection and a new building permit may be required.

#### 5.4.2 Air Pollution Control Statutes

Because of the difference in removal efficiencies between filters, it is important that the dry filter PECS selected have a sufficiently high particulate removal efficiency to ensure that applicable state and local particulate emission levels are met. Because water curtain systems have high particulate removal efficiencies, it is most likely sufficient that the dry filter system have a removal efficiency equal to the water curtain system being replaced. However, this issue should be addressed before a dry filter system is selected and installed.

The conversion of a booth may require a new permit to be issued by the local air quality management board. It was requested that air quality boards in Southern and Northern California, Florida, North Carolina, and Hawaii send information regarding repermitting procedures for converted booths. All of the responses indicated that new operating permits would be required. However, they can be easily obtained (Reference 7).

#### 5.4.3 Waste Disposal Requirements

As described more fully in Section 4, the State of California classifies filters coated with dry paint as nonhazardous waste. As such, these filters may be disposed of in a municipal landfill. This may not be the case in all states, thus the classification of these filters must be

determined prior to disposal. However, even if they are considered hazardous in other states, the disposal costs may be considerably less than those associated with contaminated water from water curtain PECSs.

SECTION 6  
NSY AND NADEP PAINTING FACILITIES

6.1 SURVEY OBJECTIVE

In order to perform a cost/benefit analysis of converting a "typical" NADEP or NSY water curtain paint booth, it was necessary to acquire general information describing the water curtain painting facilities in place at these activities. An informal phone survey was accordingly performed in which half the NADEP and NSY installations located in the United States were contacted. In the survey, the following information was requested from paint booth supervisors and operators:

- Approximate number types, (i.e., crossdraft, downdraft) and sizes of water curtain paint booths located at the activity
- Approximate paint booth duty cycles (i.e., 1, 2, or 3 shifts/day)
- Types and approximate quantities of coatings used at the painting facilities (i.e., number of gallons per shift)
- Paint drying method (i.e., dried at ambient conditions or heat cured)
- Sump maintenance practices (i.e., sump drainage and cleaning rate, wastewater treatment and disposal method)
- Approximate quantity of sludge generated by all painting facilities at the activity

- General conditions of the booths, and how satisfactorily they perform

The survey performed was by nature, informal, thus exact information concerning some of these parameters was neither requested nor expected.

Most of the information obtained from this informal survey of seven NSY and NADEP activities was very reliable; all of the paint facility supervisors and managers gave accurate information concerning the number, types, sizes, and duty cycles of paint booths under their jurisdiction, as well as the types of paint used. However, the information gathered pertaining to waste treatment methods and schedules, and the quantity of sludge generated at these activities is not very reliable.

Sludge generation rate data from five of the seven activities surveyed is not reliable for a variety of reasons. In some cases, the estimates were given over the phone with little or no data review. In other cases, the quantity of sludge generated by onsite IWTPs was not discernable. In two cases, sludge generation information was not available. Most of the information concerning wastewater treatment, and sump maintenance practices is not very reliable, because it was also given without any data review.

The results of the survey indicate that most paint booth operating parameters varied considerably within a particular naval activity, as well as from site to site. The only similarity is that every activity uses coatings that are air dried at ambient temperatures almost exclusively. Two activities reported the use of coatings requiring heat-curing, however these comprise less than 3 percent of the total amount of coatings used at these particular activities.

## 6.2 NADEP AND NSY PAINT BOOTH CHARACTERISTICS

Both crossdraft and downdraft water curtain spray booths are used at NSY and NADEP installations. At some NSY and NADEP activities, dry filter booths are also used (these are discussed at the end of this section). The number of water curtain paint booths found at each installation varies from 2 to more than 25. Booth sizes vary tremendously; some booths are 5 feet wide, 4 feet deep, and 6 feet high and one booth is 100 feet wide, 250 feet deep, and 40 feet high. Most large booths are the downdraft type, while most small booths are the crossdraft type.

Many of the smaller booths use less than 1 gal/day of paint, and operate one shift per day or less. Most large booths operate 6 days per week at two shifts per day, although depending on the backlog, some operate three shifts/day. In the large booths, a paint usage rate of 50 gal/day is not uncommon.

### 6.2.1 Sump Maintenance and Wastewater Treatment Practices

The sump maintenance schedule varies significantly depending on the facility and the size of the sump. Smaller booth sumps are drained anywhere from once a week to once every 6 to 8 weeks. The drainage frequency of large booths vary from once a week to once a year. Large quantities of chemicals and coagulants are used in the sumps that are drained infrequently.

The wastewater treatment processes used at the NSY and NADEP activities surveyed are summarized in Table 6-1. Several of the NSY and NADEP activities surveyed have onsite IWTP's capable of processing the solvent and metal contaminated wastewaters. At these activities, the water is generally drained and sent to the IWTP, and the particulate sludge collected at the bottom of the sump is drummed and shipped as hazardous waste.

Table 6-1. Waste Generation Rates at Several NSY and NADEP Painting Facilities

Site	Number of Water Curtain Booths	Paint Booth Duty Cycle	Waste Treatment Method	Quantity of Waste Generated Each Year
Pearl Harbor NSY	2	1 shift per day 5 days per week	Filter particulate, recirculate water back into sump	110 gallons of sludge
Mare Island NSY	5	12 hours per day 5 days per week	All water drained to an IMTP	Unknown
Pensacola NADEP	20 to 25	Most are 2 shifts per day, 5 days per week	Water drained to IMTP, sludge collected on bottom of sump is drummed and shipped as hazardous waste	Approximately 2,500 gallons of sludge
Cherry Point NADEP	3	1 booth is 2 to 3 shifts per day, other booths are 1 shift per day 5 to 6 days per week	Water drained to IMTP, sludge collected on bottom of sump is drummed and shipped as hazardous waste	6,100 lbs of sludge (approximately 800 gallons)
Long Beach NSY	>6	Slightly more than 1 shift per day 5 to 6 days per week	Flocculating agents added to facilitate particulate collection. Water is filtered, sent through carbon adsorption system, and recycled.	35 cubic yards of sludge (approximately 7,100 gallons)
San Diego North Island NADEP	7	2 shifts per day, 6 days per week	Water is drained, filtered, and recirculated. The low solids content waste is disposed of as hazardous waste	31,200 gallons of low solids content waste -- disposal cost approximately \$100 per 55-gallon drum
Puget Sound NSY	18	Variable, 1 to 3 shifts per day 5 to 6 days per week	Water is drained to IMTP, sludge collected on bottom of sump is concentrated in a clarifier with polymers, and sent to a filter press	2,640 gallons of high-density (>50% solids) sludge
Alameda NADEP	>5	Variable, 1 to 2 shifts per day, 5 to 6 days per week	Water is filtered and sent to municipal IMTP. If T10 content is too high, it is disposed of as hazardous waste	Unknown

A few of the sites surveyed use a particulate strainer system to remove the particulate and coagulants from the wastewater. The filtered water is then either recycled, sent to an onsite treatment system, or treated by the local municipal treatment system. In the latter case, the effluent is carefully monitored to ensure that total toxic organic (TTO) and metal concentrations are below limits set by the municipal treatment works. If the hazardous compound levels exceed the limit, the water is drummed and hauled offsite as hazardous waste. The collected sludge is drummed and shipped as hazardous waste. At one activity, a carbon adsorption system is also used to remove the solvents from the wastewater, which is then recycled back into the sump.

#### 6.2.2 Sludge Generation Rates

The quantity of sludge generated at each site depends on the number and duty cycles of the water curtain booths, the sump maintenance practices, and the wastewater treatment procedures. This fact is illustrated in Table 6-1. One activity with seven booths (all medium- to large-sized) reported approximately 450 drums of low solids content waste generated each year. Another activity, with at least seven booths (of which at least three are large-sized and at least three are medium-sized), reported 128 drums of high solids content waste generated each year. This activity utilizes a particulate filter and carbon adsorption system to clean the sump wastewater. However, a comparison between these two facilities is not necessarily conclusive, because the paint booth sizes and booth duty cycles at the two facilities may be very different.

The disposal costs for drummed waste depend on the characteristics of the waste; if it has a high solids content, the associated disposal cost is approximately \$300 per 55-gallon drum. If the solids content is low, the

disposal cost may be on the order of \$100 per 55-gallon drum. It is generally more cost-effective to concentrate the waste as much as possible before disposal.

It should be noted that activities that do not filter wastewater before sending it to an IWTP generally report a lower quantity of sludge than was actually generated, because the particulate deposited in the wastewater treated by the IWTP is not included in the total quantity of sludge reported. For this reason, the quantity of waste reported by some installations in Table 6-1 may be low.

### 6.2.3 Operating Conditions and Operational Quality of Water Curtain Booths

Several paint booth supervisors were queried on the condition of the water curtain booths as well as how effectively they operated. One activity with three large downdraft water curtain paint booths reported that one is badly rusted, and the other two are in a state of some disrepair. The booths are all less than 10 years old, but are used quite heavily. Another activity with a large downdraft booth that is less than 6 years old reported that the water curtain baffles and sump are very corroded. The booth is barely able to generate a water curtain, which implies that either the sump pump is not operating properly or the water curtain system is severely damaged. At this facility, significant quantities of paint particulate are doubtless emitted.

Paint booth supervisors at the Pearl Harbor NSY and Cherry Point NADEP activities operating dry filter PECSs were also interviewed. The booths at the first activity are used on the average one shift per day, 5 days per week and are equipped with easily deployed accordion pleated paper filters. The supervisor is pleased with the performance of the dry filter system, and is currently in the process of decommissioning one water curtain booth and installing two dry filter booths.

The paint booth supervisor at the other activity did not endorse the dry filter booths under his supervision. The booths are equipped with manually installed cartridge filter systems. Because the booths are used rather heavily, frequent changeout is required, which results in significant downtime. It appears that the dry filter system for these booths was not properly selected. As discussed in Section 3, it is important that dry filter systems be selected based on, among other things, the paint booth duty cycle.

## SECTION 7

### COST/BENEFIT ANALYSIS

To perform an accurate cost/benefit analysis of a particular process, the process under consideration must be well defined and characterized. A cost/benefit analysis of the conversion of a water curtain paint spray booth to dry filtration must consider the following:

- Size of the booth
- Type and size of the water curtain system
- Booth duty cycle (i.e., one to three shifts per day)
- Approximate quantity of paint overspray generated per shift
- Air flowrate through the booth
- Capacity of the fans located in the ducts

As the results of the phone survey on NSY and NADEP painting facilities presented in Section 6 indicate, no "typical" NADEP or NSY paint booth exists. Four different paint booth scenarios were therefore conceived, and a cost/benefit analysis was performed for each. The paint booth scenarios, or cases, are described and the cost/benefit analyses presented in the following sections.

#### 7.1 COST BENEFIT ANALYSIS ASSUMPTIONS AND JUSTIFICATIONS

The maintenance schedules, paint usage rates, transfer efficiencies, percent solids content of the paint, and wastewater treatment techniques

assumed in the following examples were used to calculate waste sludge generation rates. For some parameters, such as transfer efficiencies and percent paint solids content, conservative assumptions were made based on the results of previous studies performed by Acurex at military painting facilities (Reference 1). The values of the remaining parameters were selected in order to simulate general conditions existing at NSY and NADEP activities.

Information regarding actual quantities of waste sludge generated from painting operations at NSY and NADEP activities were available in some cases, but not on a per booth basis. In cases where such information was available, estimates of sludge generation rates per booth were made based on the size and number of booths and the frequency with which they are used. Because these estimates vary tremendously from site to site, it is not possible to assign an absolute sludge generation rate to a paint booth based on size and duty cycle. For this reason, the information on sludge generation rates resulting from the NSY and NADEP activities survey has been used only as a nominal check on the calculated values in the following examples.

In addition to manufacturer estimates of two dry filter system installation costs, engineering estimates were developed. There was acceptable agreement between these two estimates. Information regarding filter system capital costs, particulate removal efficiencies, and filter capacities were obtained from several manufacturers. As discussed in Section 3 and Appendix A, there is a variety of dry filter systems available on the market. The three different systems presented in the following examples were selected to illustrate their applicability in specific situations. However, they are not the only systems that may be used in these situations.

Because virtually all the paints used at NSYs and NADEPs are air dried at ambient temperatures, it was assumed that the spent filters could be disposed of at a municipal landfill. The cost to dispose of dry paint filters in a municipal landfill is approximately \$2.50 per cubic yard. These costs are negligible compared to the other operating costs (1 cubic yard is approximately 150 cartridge filters, or 1 cloth filter roll), thus they need not be included in the following scenarios.

## 7.2 COST/BENEFIT ANALYSIS TECHNIQUES

The technique used to perform the cost/benefit analysis for each of the four paint booth conversion scenarios is the same as that outlined in the Naval Facilities Engineering Command Economic Analysis Handbook (NAVFAC P-442) (Reference 8). The first three scenarios are classified as Type I economic analyses, because they represent situations in which the existing condition may be modified to reduce life-cycle costs. The fourth scenario requires a Type II analysis, because it represents a situation in which one of a number of alternatives may be selected.

### 7.2.1 Issues and Assumptions Made in Performing the Type I Economic Analyses for Paint Booth Scenarios 1, 2, and 3

The three steps involved in carrying out a Type I analysis are: identification of all costs, calculation of the savings to investment ratio, and determination of the discounted payback period.

#### Step 1: Identification of All Costs

The initial step in performing a Type I economic analysis is to identify both one-time costs and recurring annual costs. In the following analyses, the only one-time cost considered is the replacement of the water curtain PECS with a dry filter system. The annual recurring costs considered are: waste treatment, electricity, labor, replacement water, and

replacement filters. A cash flow diagram in base year dollars illustrating these costs is provided for each scenario.

#### Step 2: Calculation of the Savings to Investment Ratio

The second step in comparing the economics of a proposed alternate (i.e., a dry filter system) to a present system (i.e., a water curtain system) is to calculate the savings to investment ratio (SIR), which is defined as the amount of savings accrued by each dollar of investment. It is mathematically defined as:

$$\text{SIR} = \frac{\text{Net Present Value (Savings)}}{\text{Net Present Value (Investment)}}$$

In order for the proposed alternative to be cost effective, the SIR must be greater than 1. The SIR is calculated in each of the following scenarios.

The SIR is determined over the economic life of the alternative. An economic life of 10 years is assumed in the paint booth conversion scenarios for a variety of reasons. Water curtain paint PEC systems may require replacement or significant rebuilding within 10 years. In addition, system upgrades may occur within 10 years in response to improved paint application technologies and more stringent emission regulations.

To estimate the net present value (NPV) of a proposed alteration, some assumptions must be made regarding cost escalations due to inflation and other factors. Generally, if the anticipated rise in operating and maintenance (O&M) costs is the same as the general inflation rate (assumed to be 5-percent), a 10-percent discount factor may be applied to calculate the NPV (savings). However, if O&M costs increase at a significantly different rate than the general inflation rate, an adjusted escalation rate must be determined.

In the paint booth conversion scenarios, it is assumed that sludge waste disposal costs (which represent a significant fraction of the O&M costs) will not increase over the next 5 years, and will rise only after the sixth year at the general inflation rate of 5 percent. This cost structure was developed as a result of several conversations with marketing representatives of Chem Waste Management. Many factors, including a more competitive market, decreased waste generation rates and improved waste disposal techniques, contribute to the predicted short-term stabilization of sludge waste disposal costs. All other O&M costs are assumed to increase at the general inflation rate of 5 percent (Reference 9).

To account for the differences in escalation rates between waste disposal costs and other O&M costs, an adjusted rate escalation calculation was performed for each scenario. The method used (which is similar to example 6G in NAVFAC P-442), involves applying an adjusted discount factor to current dollar costs for each year. Current dollar costs are derived by increasing the constant dollar values by the expected inflation rate, which differs in each scenario. The adjusted discount factor is derived by assuming a real rate of return of 10 percent, and a general inflation rate of 5 percent.

### Step 3: Determination of Discounted Payback Period

The final step in performing a Type I economic analysis is to determine the discounted payback period, or the time required to accrue sufficient present value savings to offset the discounted investment cost. The discounted payback period is determined by calculating the accrued year by year savings, and comparing the results to the initial investment in present value dollars. The point at which the two are equal defines the payback period.

### 7.2.2 Issues and Assumptions made in Performing the Type II Economic Analysis for Paint Booth Scenario 4

In paint booth scenario 4, the entire PECS requires replacement, and the most cost-effective of the two possible PECSs must be selected. Such a comparison requires a Type II economic analysis, as outlined in the NAVFAC P-442 Handbook. Because both alternatives have equal lead times, and are assumed to have equal economic lifetimes, the NPVs of the alternatives are evaluated and compared.

As described in Section 7.2.1, the NPV calculation for the water curtain system was more complicated than for the dry filter system because the expected water curtain system O&M cost escalation does not follow general inflationary trends. For this reason, a differential escalation rate was used to determine the water curtain system NPV. The dry filter system NPV calculation was performed assuming a general inflation rate of 5 percent, and therefore a standard government discount factor of 10 percent was used.

### 7.3 PAINT BOOTH CONVERSION COST/BENEFIT ANALYSES

Four paint booth conversion scenarios are presented; Case 1 is a small booth used infrequently, Case 2 is a medium-sized booth used moderately, Cases 3 and 4 are a large booth that is constantly in use. The difference between Case 3 and Case 4 is that the booth in Case 4 is rusted, and the sump, ductwork, and water curtain system require replacement. The results of comparisons between the economics of the water curtain and proposed dry filter systems are summarized in Table 7-1.

#### Case 1 -- A Small Crossdraft Water Curtain Booth Used Infrequently (Approximately 1/2 Shift Per Day)

For this case, the following assumptions were made to determine annual paint booth operating costs before conversion:

Table 7-1. Summary of Cost/Benefit Analyses Performed for Four Paint Booth Scenarios

Case	Description	Annual Operating Cost in Present Dollars		Conversion Cost	Savings to Investment Ratio	Discounted Payback Period
		Present Water Curtain System	Proposed Dry Filter System			
1	Small crossdraft booth used infrequently	\$ 2,456	\$ 1,493	\$ 1,400	3.01	1.9 years
2	Medium-sized crossdraft booth used one shift per day	9,590	2,683	4,000	9.06	8 months
3	Large downdraft booth used 2 shifts per day	71,200	18,000	43,400	6.62	1 year
4	Large downdraft booth used 2 shifts per day with significant rust damage	71,200	18,000	43,400 <sup>a</sup> vs 68,400 <sup>b</sup>	N/A	N/A

<sup>a</sup>Install a dry filter system

<sup>b</sup>Install a water curtain system

- The crossdraft booth is 6 feet wide, 9 feet deep and 9 feet high. The water curtain is 6 feet high and occupies the entire width of the back wall of the booth. The sump contains approximately 280 gallons of water.
- One and a half gallons of paint containing 40 percent solids by volume are used per day. The average transfer efficiency is 35 percent, which implies that 0.4 gallons of solids are deposited in the water sump per day.
- The water sump is drained and filtered once every 4 weeks. 80 percent of the solids deposited in the sump during various painting operations is collected as sludge, which is composed of 25 percent solids. The sludge is drummed and shipped away as hazardous waste, and the liquid is discharged to an IWTP.
- A 3-hp fan is used in the duct to draw air through the water curtain, and a 5-hp water pump is used to generate the water curtain.

Given these assumptions, approximately 26 gallons of sludge are generated at this facility every 4 weeks. The volume of replacement water to the sump is 3,360 gallons per year.

The following assumptions were made to determine annual operating costs associated with a dry filter PECS, as well as conversion costs.

- A fiberglass cartridge filter system is selected for the replacement APC system. The reasoning behind this selection is that the booth is used infrequently, thus an inexpensive system with moderate downtime needed for filter replacement may be used. The cost to install such a system in 1988 is approximately \$280 per linear foot.

- The clean flowrate through the fiberglass filter is assumed to be 150 fpm. The capacity of the filter is 0.02 gal/ft<sup>2</sup>, and the replacement cost for such a filter is \$0.20/ft<sup>2</sup> in 1988 dollars.
- The linear flowrate through the booth after conversion will be approximately 125 fpm. The resulting volume flowrate is 6,750 cfm. The cartridge filter surface area required to handle this volume flowrate is 45 ft<sup>2</sup>. To ensure a sufficiently low pressure drop across the filter media, a surface area of 50 ft<sup>2</sup> is used. The dimensions of the filter face are 10 feet high and 5 feet wide.
- The surface area of the cartridge filter is 50 ft<sup>2</sup>; thus 1.0 gallons of solids may be collected on the filter before replacement is required. Given the overspray rate of 0.39 gallons of overspray solids per day calculated above, the cartridge filters will require replacement approximately two times per week.
- The fan in the duct may be downsized from 3-hp to 2-hp operation.
- Because the booth is used less than one shift per day, no process downtime will be experienced during filter replacement. The time required for filter replacement is approximately 1 hour per week.

Given these assumptions, annual recurring costs for operating water curtain and dry filter PECSs in present dollars were calculated and are presented in Table 7-2. A cash flow diagram was generated based on the recurring cost calculations, and is presented in Figure 7-1. Assumptions and parameters used to calculate the SIR are summarized in Table 7-3, along with the 10-year discounted NPV savings calculations performed for the present and proposed system.

Table 7-2. Case 1 -- Calculations of Annual Recurring Costs In Present Dollars of Water Curtain and Dry Filter Systems.

Assumed Rate Structure:

Electricity: \$0.06/KWH  
 Waste Disposal: \$300/drum  
 Labor: \$8.00/hr  
 Filters: \$0.20/ft<sup>2</sup>  
 Water: \$0.001/gal

Item	Water Curtain System		Dry Filter System	
	Requirement	Annual Cost	Requirement	Annual Cost
Waste Treatment	26 gal/month 5.6 drums/year	\$1,680	0.0	\$0
Electricity	23.9 KWH/day * 6206 KWH/year	\$372	5.97 KWH/day ** 1551 KWH/year	\$93
Labor	4 hr/month 50 hr/year	\$400	1 hr/week 50 hr/year	\$400
Water	280 gal/month 3360 gal/year	\$3	0.0	\$0
Filter Replacement	0.0	\$0	100 ft <sup>2</sup> /week 5000 ft <sup>2</sup> /year	\$1,000
Total		\$2,456		\$1,493

\* Based on 1 3-hp fan and 1 5-hp water pump operated 4 hours per day  
 \*\* Based on 1 2-hp fan operated 4 hours per day

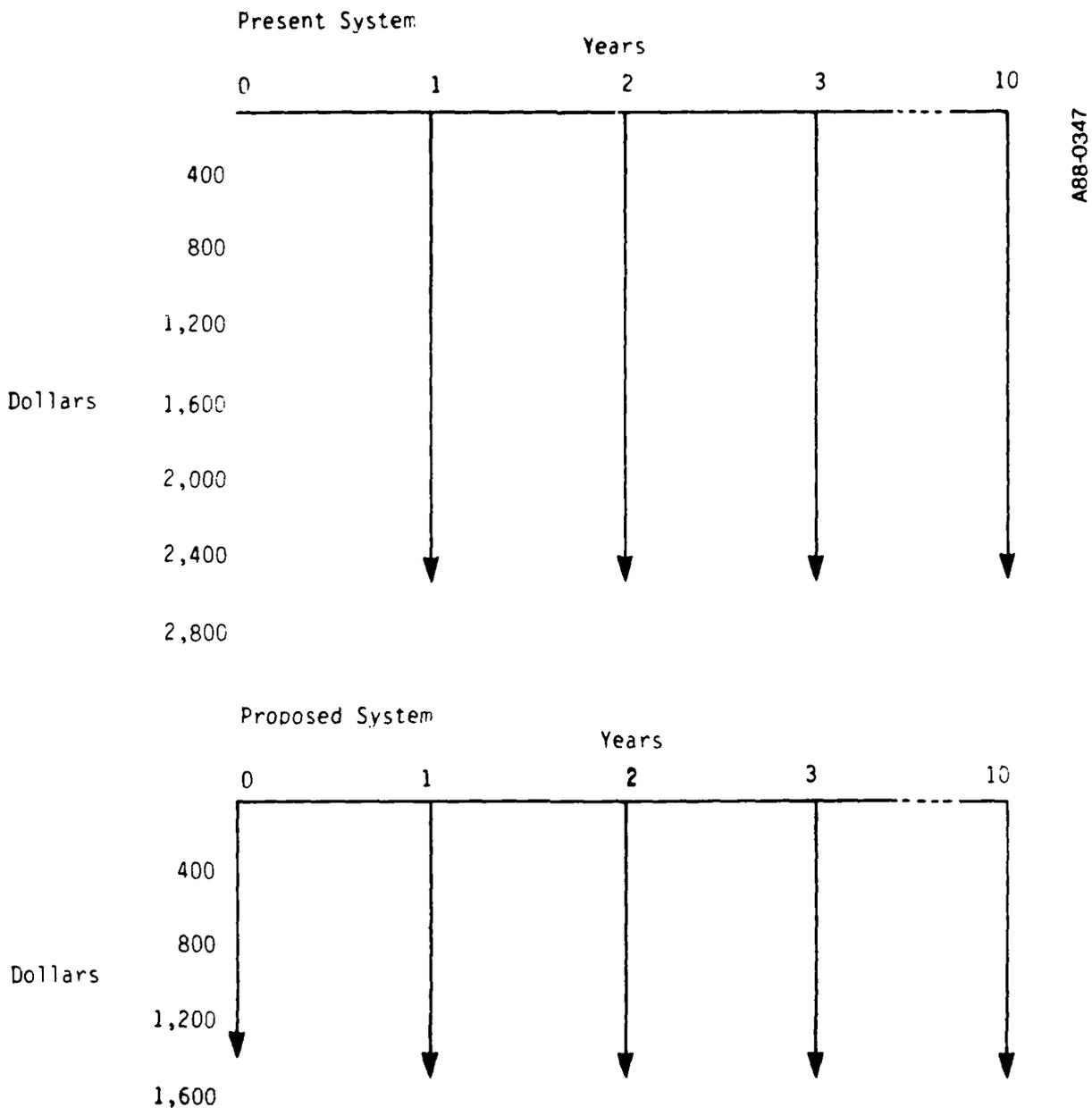


Figure 7-1. Cash Flow Diagram -- Case 1

Table 7-3. Case 1 -- Savings to Invest Ratio and Discounted Payback Period Calculations

Assume A 1.6% cost escalation for the present system in the first 5 years  
 A 5% cost escalation for the present system in the final 5 years  
 A 5% cost escalation for the proposed system for 10 years  
 Initial annual O&M costs for present system are \$2,456  
 Initial annual O&M costs for proposed system are \$1,493  
 Initial investment cost for proposed system is \$1,400

Year	Recurring Costs *		Difference	Discount Factor **	Discounted Savings	Cummulative Discounted Savings
	Present	Proposed				
1	\$2,495	\$1,568	\$928	0.866	\$803	\$803
2	\$2,535	\$1,646	\$889	0.750	\$667	\$1,470
3	\$2,576	\$1,728	\$847	0.649	\$550	\$2,020
4	\$2,617	\$1,815	\$802	0.562	\$451	\$2,471
5	\$2,659	\$1,905	\$753	0.487	\$367	\$2,837
6	\$2,792	\$2,001	\$791	0.421	\$333	\$3,170
7	\$2,931	\$2,101	\$831	0.365	\$303	\$3,473
8	\$3,078	\$2,206	\$872	0.316	\$275	\$3,749
9	\$3,232	\$2,316	\$916	0.273	\$250	\$3,999
10	\$3,393	\$2,432	\$962	0.237	\$228	\$4,226

\* Based on current dollars

\*\* Based on a nominal rate of return of 15.5%, which is derived from a real rate of return of 10% and a general inflation rate of 5%

Total Discounted Savings: \$4,226

Savings to Investment Ratio:  $\frac{\$4,226}{\$1,400} = 3.01$

Discounted Payback Period: 1.9 Years

As described in Section 7.2, a differential rate escalation calculation was performed because the waste treatment (and therefore the O&M) cost escalations for the present system do not follow general inflationary trends. This differential rate escalation value was used to obtain both the NPV for savings accrued and the SIR, as given in Table 7-3. An overall annual inflation rate (Z) for the initial five year operation of the present system was calculated in the following manner:

$$Z = \frac{\text{O\&M costs due to waste treatment} \times a + \text{O\&M costs not due to waste treatment} \times b}{\text{Total O\&M Costs}}$$

Where :

a = Waste treatment cost escalation over the next 5 years  
= 0 percent

b = Escalations of other O&M costs over next 5 years  
= 5 percent

Thus

$$Z = \frac{0.0 \times (1,680) + .05 \times (776)}{2,456}$$

= .016 or 1.6 percent overall inflation

The result of this calculation indicates that a 1.6-percent inflation rate should be used for the economic analysis of the present system for the

first 5-year projected period. The economic analysis of the present system during the subsequent 5-year period assumes a general 5-percent inflation rate.

The savings to investment ratio over the expected 10-year economic life is 3.01, thus the proposed paint spray booth conversion is cost-effective. The discounted payback period is 1.9 years.

It should be noted that there are other dry filter systems currently available on the market that, in the long run, are less expensive and more effective than the fiberglass cartridge filter system adopted for Case 1. However, it was used in this example because a fiberglass system has traditionally been installed in this type of booth.

In the following examples in which the conversion of somewhat larger paint booths is discussed, higher transfer efficiencies are used in determining paint overspray quantities. This is because large booths are generally used to coat big workpieces with continuous surfaces having little or no gaps or holes, which allows a higher transfer efficiency.

Case 2: -- A Medium-Sized Crossdraft Water Curtain Booth Used One Shift Per Day

For this case, the following assumptions were made to determine annual paint booth operating costs before conversion:

- The crossdraft booth is 17 feet wide, 35 feet deep and 15 feet high. The water curtain is 10 feet high and it occupies the entire width of the back wall of the booth. The sump contains approximately 750 gallons of water.
- Eight gallons of paint containing 40 percent solids by volume are used per shift. The average transfer efficiency is 45 percent, which implies that 1.8 gallons of solids are deposited in the water sump per shift.

- The water sump is drained and filtered once every 6 weeks. 80 percent of the solids deposited in the sump during various painting operations is collected as sludge, which is composed of 30 percent solids. The sludge is drummed and shipped away as hazardous waste, and the liquid is discharged to an IWTP.
- Flocculating agents are added to the sump water at an approximate cost of \$15 per week.
- Two 7.5-hp fans are used in the duct to draw air through the water curtain, and two 5-hp water pumps are used to generate the water curtain.

Given these assumptions, approximately 140 gallons of sludge are generated at this facility every 6 weeks. The volume of water required to refill the sumps after drainage is 6,000 gallons per year.

The following assumptions were made to determine annual operating costs associated with a dry filter PECS, as well as conversion costs. The particular dry filter system was selected because an easily deployed, high-capacity collection system was required.

- A manually deployed honeycombed paper filter is selected for the replacement APC system. The cost to install such a system in 1988 is \$250 per linear foot.
- The clean flowrate through the paper filter is assumed to be 200 fpm. The capacity of the filter is 0.10 gallons of paint overspray solids per square foot, and the replacement cost for such a filter is \$0.30/ft<sup>2</sup> in 1988 dollars.
- The linear flowrate through the booth after conversion will be approximately 125 fpm. The resulting volume flowrate is 31,875 cfm. The filter surface area required to process this

volume flowrate is 160 ft<sup>2</sup>. The dimensions of the filter face will be 10 feet high and 16 feet wide.

- The surface area of the paper filter is 160 ft<sup>2</sup>; thus 16 gallons of solids may be collected on the filter before replacement is required. Given the overspray rate of 1.8 gallons of solids per shift calculated above, the filter will require replacement every 1-1/2 weeks.
- The fans in the duct may be downsized to 5-hp each.
- The manhours required to change the filters in this example is minimal; less than 1 hour per week is required to unroll, cut, and install clean filter media and dispose of the used filters. Because the booth in this example is not in continuous use, no process interruptions should occur for filter replacement, provided that proper maintenance procedures are followed.

Given these assumptions, annual recurring costs in present dollars were calculated and are presented in Table 7-4. A cash flow diagram was generated based on the recurring cost calculations, and is presented in Figure 7-2. Assumptions and parameters used to calculate the SIR are summarized in Table 7-5, along with the 10-year discounted NPV savings calculations performed for the present and proposed system.

As previously described, a differential rate escalation calculation was performed because the waste treatment (and therefore the O&M) cost escalations for the present system do not follow general inflationary trends. This differential rate escalation value is needed to obtain both the NPV for savings accrued and the SIR, as given in Table 7-5. An overall annual inflation rate of 1.8 percent for the initial 5-year operation of the present system was calculated in a manner similar to that presented in the previous

Table 7-4. Case 2 -- Calculations of Annual Recurring Costs in Present Dollars of Water Curtain and Dry Filter Systems

Assumed Rate Structure:

Electricity: \$0.06/KWH  
 Waste Disposal: \$300/drum  
 Labor: \$8.00/hr  
 Filters: \$0.30/ft<sup>2</sup>  
 Water: \$0.001/gal

Item	Water Curtain System		Dry Filter System	
	Requirement	Annual Cost	Requirement	Annual Cost
Waste Treatment	93 gal/month 20.3 drums/year	\$6,090	0.0	\$0
Electricity	150 KWH/day * 38792 KWH/year	\$2,328	59.7 KWH/day ** 15511 KWH/year	\$931
Labor	4 hr/month 52 hr/year	\$416	2 hr/month 24 hr/year	\$192
Water	500 gal/month 6000 gal/year	\$6	0.0	\$0
Chemicals	\$15/week	\$750	0.0	\$0
Filter Replacement	0.0	\$0	106 ft <sup>2</sup> /week 5300 ft <sup>2</sup> /year	\$1,560
Total		\$9,590		\$2,683

\* Based on 2 7.5-hp fans and 2 5-hp water pumps operated 8 hours per day  
 \*\* Based on 2 5-hp fan operated 8 hours per day

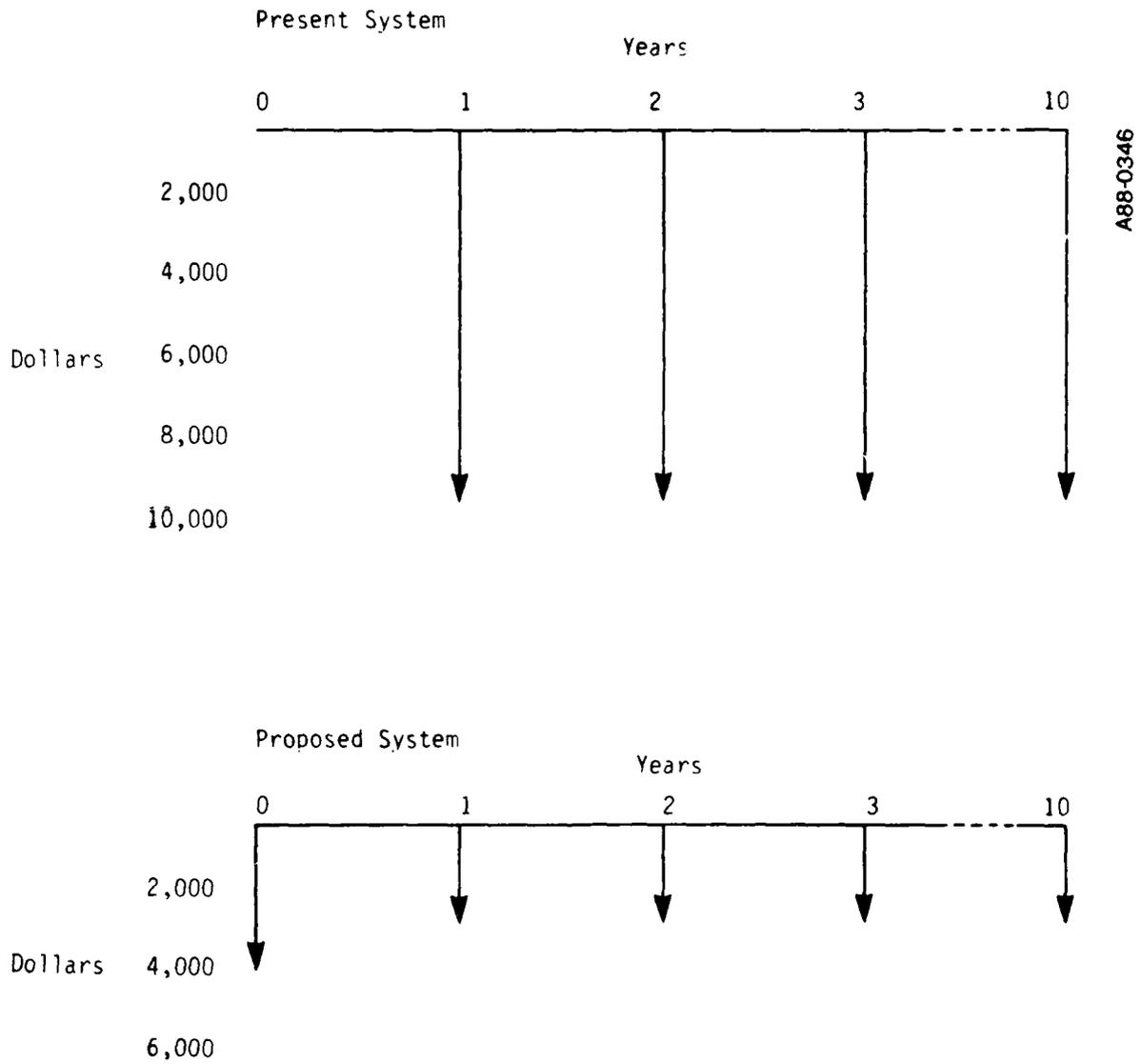


Figure 7-2. Cash Flow Diagram -- Case 2

Table 7-5. Case 2 -- Savings to Investment Ratio and Discounted Payback Period Calculations

Assume A 1.8% cost escalation for the present system in the first 5 years  
 A 5% cost escalation for the present system in the final 5 years  
 A 5% cost escalation for the proposed system for 10 years  
 Initial O&M costs for present system: \$9,590  
 Initial O&M costs for proposed system: \$2,683  
 Initial investment cost for proposed system is \$4,000

Year	Recurring Costs *		Difference	Discount Factor **	Discounted Savings	Cummulative Discounted Savings
	Present	Proposed				
1	\$9,763	\$2,817	\$6,945	0.866	\$6,013	\$6,013
2	\$9,938	\$2,958	\$6,980	0.750	\$5,233	\$11,246
3	\$10,117	\$3,106	\$7,011	0.649	\$4,550	\$15,796
4	\$10,299	\$3,261	\$7,038	0.562	\$3,955	\$19,751
5	\$10,485	\$3,424	\$7,060	0.487	\$3,435	\$23,186
6	\$11,009	\$3,595	\$7,413	0.421	\$3,123	\$26,309
7	\$11,559	\$3,775	\$7,784	0.365	\$2,839	\$29,148
8	\$12,137	\$3,964	\$8,173	0.316	\$2,581	\$31,728
9	\$12,744	\$4,162	\$8,582	0.273	\$2,346	\$34,075
10	\$13,381	\$4,370	\$9,011	0.237	\$2,133	\$36,207

\* Based on current dollars

\*\* Based on a nominal rate of return of 15.5%, which is derived from a real rate of return of 10% and a general inflation rate of 5%

Total Discounted Savings: \$36,207

Savings to Investment Ratio:  $\frac{\$36,207}{\$4,000} = 9.06$

Discounted Payback Period: 8 Months

example. The economic analysis of the present system during the subsequent 5-year period assumes a general 5-percent inflation rate.

The savings to investment ratio over the expected 10-year economic life is 9.06, thus the proposed paint spray booth conversion is cost-effective. The discounted payback period is approximately 8 months.

An automatically deployed cloth roll filter would also have been a suitable choice for the type of booth described in Case 2. Although the installation costs for such a system are slightly higher than for the manually deployed paper filter system, the associated operating costs are much lower.

Case 3: -- Large Downdraft Water Curtain Booth Used Two Shifts per Day, 6 Days per Week

The booth selected for this case is similar to the one illustrated in Figure 3-3. For this case, the following assumptions were made to determine annual paint booth operating costs before conversion:

- The downdraft booth is 30 feet wide, 70 feet deep and 30 feet high. The booth has four water curtain sumps that are located on each side of the booth, and run the full length of the booth. Each sump contains two water pumps to circulate 1,100 gallons of water.
- 20 gallons of paint containing 40 percent by volume solids are used per shift. The average transfer efficiency is 45 percent, which implies that 4.4 gallons of solids are distributed amongst the water sumps per shift. The booth is operated for two shifts per day, thus 2.2 gallons of solids are deposited in each of the sumps per day.
- The water sumps are drained once every 8 weeks. 70 percent of the solids deposited in a particular sump is collected at the bottom of the sump as sludge, which is composed of 25 percent solids. The

sludge is drummed and shipped away as hazardous waste, and the liquid is recirculated back into the water curtain sump.

- Flocculating agents are added to the sump water at an approximate cost of \$100 per week.
- A 10-hp fan is located inside each of the eight exhaust ducts to draw air through the water curtain. Two 5-hp pumps are required in each sump to generate the water curtain.

Given these assumptions, approximately 1,200 gallons of sludge are generated at this facility every 8 weeks. The volume of water required to top off the sumps after drainage is approximately 6,000 gallons per year.

The following assumptions were made to determine annual operating costs associated with a dry filter PECS, as well as conversion costs. The particular dry filter system was selected because an easily deployed, low cost, high capacity filter is required.

- A manually deployed cloth filter is selected for the replacement APC system. The cost to install such a system in 1988 is \$310 per linear foot.
- The clean flowrate through the cloth filter is assumed to be 300 fpm. The capacity of the filter is  $0.06 \text{ gal/ft}^2$ , and the replacement cost for such a filter is  $\$0.04/\text{ft}^2$  in 1988 dollars.
- The linear flowrate through the booth after conversion will be approximately 125 fpm. The resulting volume flowrate is 262,500 cfm. The minimum cloth filter surface area required to handle this volume flowrate is  $875 \text{ ft}^2$ . To ensure a sufficiently low pressure drop across the filter media, a surface area of  $900 \text{ ft}^2$  will be used. The filters will be installed along both sides of the booth, and will extend down into the emptied sump,

below floor level. On each side, the filter face dimensions will be 6.5 feet high and 70 feet long.

- The surface area of the cloth roll filter is 900 ft<sup>2</sup>; thus 54 gallons of solid paint overspray may be collected on the filter before replacement is required. Given the overspray rate of approximately 9 gallons of solids per day, the filter will require replacement once per week.
- The fans in each duct may be downsized to 9-hp each.

Given these assumptions, annual recurring costs in present dollars were calculated and are presented in Table 7-6. A cash flow diagram was generated based on the recurring cost calculations, and is presented in Figure 7-3. Assumptions and parameters used to calculate the SIR are summarized in Table 7-7, along with the 10-year discounted NPV savings calculations performed for the present and proposed system.

As previously described, a differential rate escalation calculation was performed because the waste treatment (and therefore the O&M) cost escalations for the present system do not follow general inflationary trends. This differential rate escalation value is needed to obtain both the NPV for savings accrued and the SIR, as given in Table 7-7. An overall annual inflation rate of 2.3 percent for the initial 5-year operation of the present system was calculated in a manner similar to that presented in the previous example. The economic analysis of the present system during the subsequent 5-year period assumes a general 5 percent inflation rate.

The savings to investment ratio over the expected 10-year economic life is 6.62, thus the proposed paint spray booth conversion is cost-effective. The discounted payback period is approximately 1 year.

Table 7-6. Case 3 -- Calculations of Annual Recurring Costs In Present Dollars of Water Curtain and Dry Filter Systems.

Assumed Rate Structure:

Electricity: \$0.06/KWH  
 Waste Disposal: \$300/55-gallon drum  
 Labor: \$8.00/hr  
 Filters: \$0.04/ft<sup>2</sup>  
 Water: \$0.10/100 gallons

Item	Water Curtain System		Dry Filter System	
	Requirement	Annual Cost	Requirement	Annual Cost
Waste Treatment	600 gal/month 131 drums/year	\$39,300	0.0	\$0
Electricity	8593 KWH/week 429650 KWH/year	\$25,779	5156 KWH/week 257818 KWH/year	\$15,469
Labor	12 hr/month 144 hr/year	\$1,152	8 hr/month 96 hr/year	\$768
Water	500 gal/month 6000 gal/year	\$6	0.0	\$0
Chemicals	\$100/week	\$5,000	0.0	\$0
Filter Replacement	0.0	\$0	900 ft <sup>2</sup> /week 45000 ft <sup>2</sup> /year	\$1,800
Total		\$71,237		\$18,037

\* Based on 8 10-hp fans and 8 5-hp water pumps operated 96 hours per week  
 \*\* Based on 8 9-hp fan operated 96 hours per week

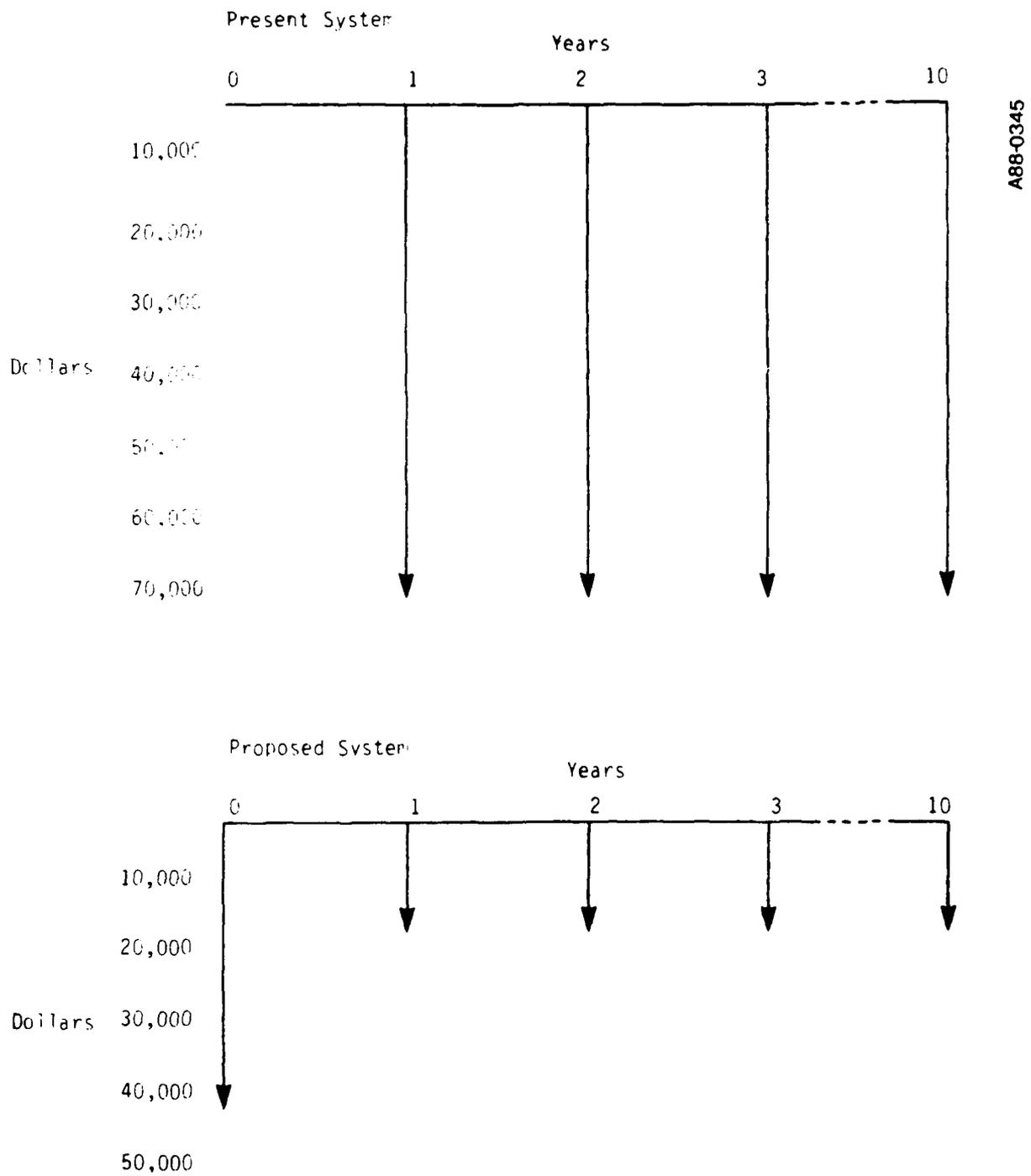


Figure 7-3. Cash Flow Diagram -- Case 3

Table 7-7. Case 3 -- Savings to Investment Ratio and Discounted Payback Period Calculations

Assume A 2.3% cost escalation for the present system in the first 5 years  
 A 5% cost escalation for the present system in the final 5 years  
 A 5% cost escalation for the proposed system for 10 years  
 Initial O&M costs for present system: \$71,237  
 Initial O&M costs for proposed system: \$18,037  
 Initial investment cost for proposed system is \$43,400

Year	Recurring Present Costs *	Recurring Proposed Costs *	Difference	Discount Factor **	Discounted Savings	Cummulative Discounted Savings
1	\$72,875	\$18,939	\$53,937	0.866	\$46,698	\$46,698
2	\$74,552	\$19,886	\$54,666	0.750	\$40,978	\$87,676
3	\$76,266	\$20,880	\$55,386	0.649	\$35,946	\$123,623
4	\$78,020	\$21,924	\$56,096	0.562	\$31,521	\$155,144
5	\$79,815	\$23,020	\$56,795	0.487	\$27,631	\$182,775
6	\$83,806	\$24,171	\$59,634	0.421	\$25,119	\$207,894
7	\$87,996	\$25,380	\$62,616	0.365	\$22,836	\$230,730
8	\$92,396	\$26,649	\$65,747	0.316	\$20,760	\$251,490
9	\$97,015	\$27,981	\$69,034	0.273	\$18,872	\$270,362
10	\$101,866	\$29,380	\$72,486	0.237	\$17,157	\$287,519

\* Based on current dollars

\*\* Based on a nominal rate of return of 15.5%, which is derived from a real rate of return of 10% and a general inflation rate of 5%

Total Discounted Savings: \$287,519

Savings to Investment Ratio:  $\frac{\$287,519}{\$43,400} = 6.62$

Discounted Payback Period: 1 Year

There is a possibility that, in less than 10 years, the sumps, fans and much of the ductwork associated with water curtain PECSs will require replacement due to corrosion. The long-term savings that may be realized in converting a rusted booth from wet to dry operation rather than replacing the rusted equipment are substantial. This is illustrated in the following example.

Case 4 -- Large Downdraft Water Curtain Paint Booth, Similar to Case 3, that is Severely Rusted

In this example, the configuration and groundwork are the same as Case 3 except the water curtain PECS has extensive rust damage. The ducts and fans in the rusted system require replacement whether or not the system is converted to dry operation. Thus, the comparison will be made between the cost to replace the sumps and water curtain generating system, and the cost to install a dry filter system. As described in Section 7.2, this cost comparison is classified as a Type II economic analysis, and is treated as such according to the NAVFAC P-442 document procedures.

The following assumptions were made to determine the construction costs of installing a new water curtain PECS. As described in Section 3, most downdraft water curtain facilities are custom made, thus replacement sumps and water curtain generating equipment must also be custom made.

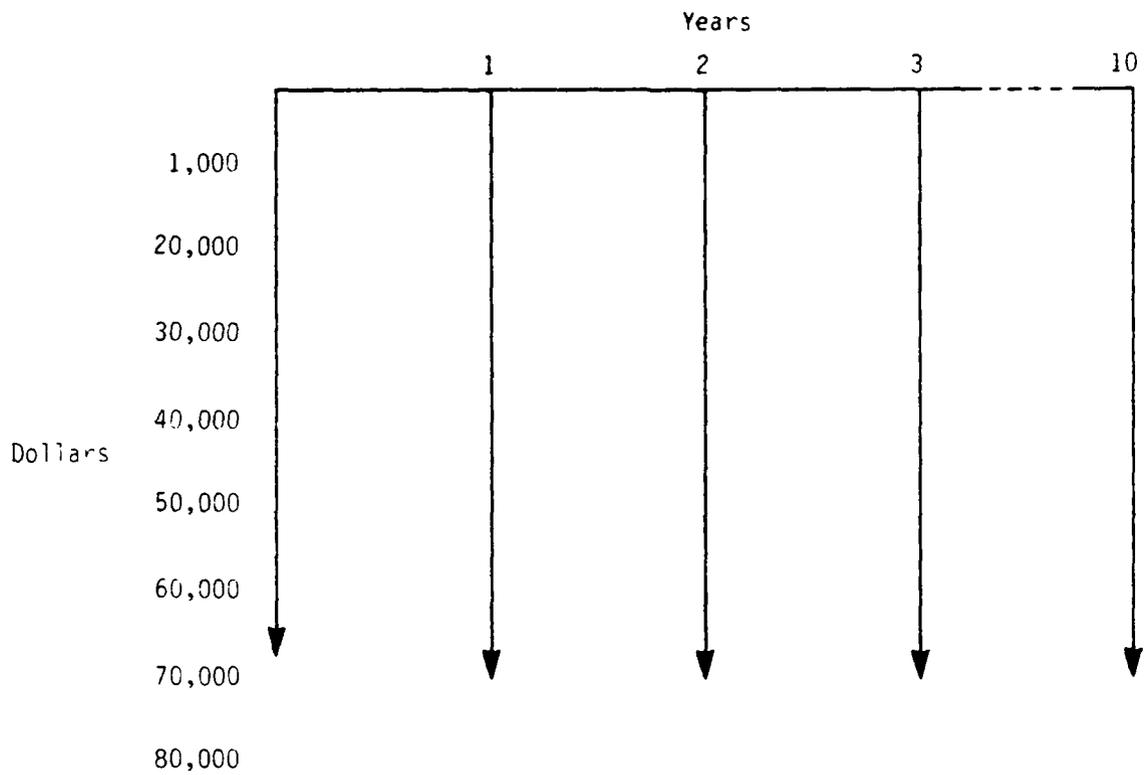
- Material costs for a replacement sump for the system illustrated in Figure 3-3 is \$54 per linear foot. Installation costs are on the order of \$71 per linear foot. The overall cost per linear foot to replace the water sumps is \$125.
- The total materials and installation cost for replacement pumps is \$3,000 each.
- The price per linear foot to replace the water curtain system is \$245, which includes baffle, nozzle, and pipe installations.

Based on these assumptions, the total cost to install a new water curtain system, including sumps and pumps, is approximately \$68,400. The total cost to install a dry filter system in place of the water sump was determined in Case 3 to be \$43,400.

The annual O&M costs for both the water curtain and dry filter PECSs were determined in Case 3, and are given in Table 7-6. These values were used to perform the net present value comparison between the two PECSs. A cash flow diagram for each alternative is presented in Figure 7-4.

As described in Section 7.2.2, a differential rate escalation value was used in the water curtain net present value calculation because the waste treatment (and therefore the O&M) cost escalations for this system do not follow general inflationary trends. However, the net present value calculation for a dry filter system was performed using the standard government 10 percent discount factor for the estimated 10-year economic life. The results of the net present value calculations for both PECSs are presented in Table 7-8. The dry filter PECS is the preferred alternative because it has a much lower NPV cost.

Alternative A: Water Curtain PECS



Alternative B: Dry Filter PECS

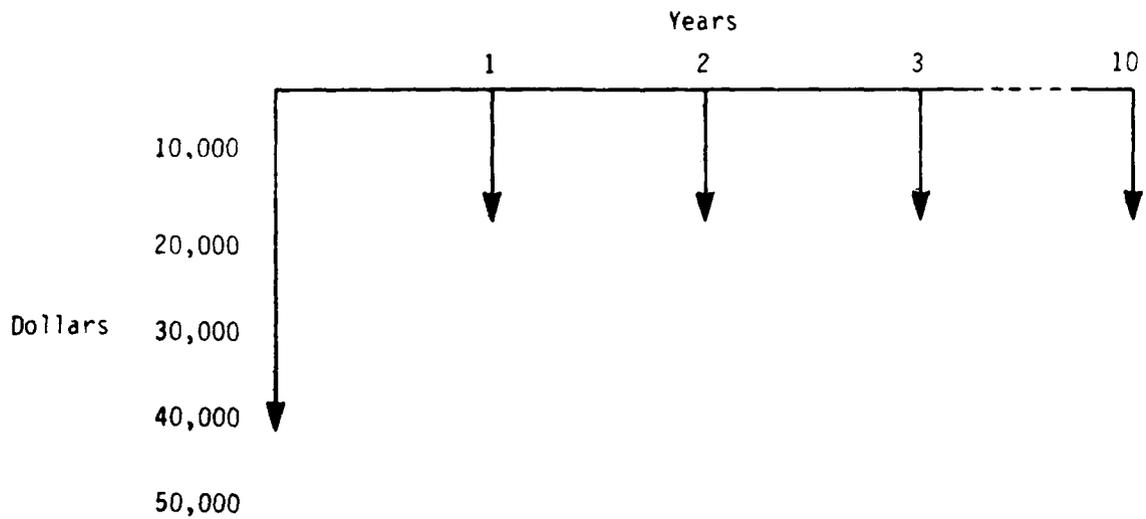


Figure 7-4. Cash Flow Diagram -- Case 4

Table 7-8. Case 4 -- Net Present Value Comparison

Alternative A: Water Curtain PECS

Project Years	Cost Element	Present Dollar Amount	Current Dollar Amount *	Discount Factor **	Discounted Cost
0	Construction	\$68,400	\$68,400	1.000	\$68,400
1	O&M	\$71,237	\$72,875	0.866	\$63,096
2	O&M	\$71,237	\$74,552	0.750	\$55,885
3	O&M	\$71,237	\$76,266	0.649	\$49,498
4	O&M	\$71,237	\$78,020	0.562	\$43,841
5	O&M	\$71,237	\$79,815	0.487	\$38,831
6	O&M	\$71,237	\$83,806	0.421	\$35,301
7	O&M	\$71,237	\$87,996	0.365	\$32,091
8	O&M	\$71,237	\$92,396	0.316	\$29,174
9	O&M	\$71,237	\$97,015	0.273	\$26,522
10	O&M	\$71,237	\$101,866	0.237	\$24,111

Total NPV Cost: \$466,748

\* Based on a 2.3% cost escalation per year for the first 5 years, and a 5% cost escalation rate for the remaining 5 years.

\*\* Based on a Nominal Rate of Return of 15.5%, which is derived from a real rate of return of 10% and a general inflation rate of 5%

Alternative B: Dry Filter PECS

Project Years	Cost Element	Amount	Discount Factor	Discounted Cost
0	Construction	\$43,400	1.000	\$43,400
1-10	O&M	\$18,037	6.145	\$110,837

Total NPV Cost: \$154,237

## SECTION 8

### FACILITIES COST-EFFECTIVELY CONVERTED

In an effort to determine the technical and operational problems associated with converting paint spray booths from wet to dry operation, it was necessary to contact facilities that have successfully completed paint booth conversion efforts. Both military and nonmilitary facilities were surveyed. The most successful of the facilities surveyed is the Naval Industrial Reserve Ordnance Plant (NIROP) in Pomona, California. The NIROP plant converted five paint booth PECSs from wet to dry operation. The paint booth characteristics and operating parameters were:

- The booths were all approximately the same size: 8 feet wide, 8 feet long and 6 feet high.
- Most booths were used one shift per day.
- The sumps were drained approximately once every 3 months, and 2,000 gallons of wastewater were removed.
- Shortly after the sumps were cleaned out, the water turned green and the odor emanating from the sumps was usually overpowering. Because of this, worker complaints were frequent.
- The paints used at the facility were all air dried, thus the costs incurred for disposing of filters was negligible.

Because of the paint booth size and low to moderate usage rates, a fiberglass cartridge filter system was selected to replace the water curtain

system. The only problem encountered with the filter system was that, as the filters became clogged, significant leakage occurred between the filter and the frame. This problem is common with fiberglass cartridge filters, as described in Appendix A.

The facility foreman maintains that the paint booth conversions cost less than the expense incurred for disposing of 2,000 gallons of wastewater, thus the conversion costs were recovered within 3 months. In addition to the cost savings attained, employee attitude improved due to the elimination of the sump odor. Work was therefore more easily accomplished (Reference 10).

Another successful paint booth conversion effort was performed by a private corporation headquartered in Michigan. The company converted 66 booths across the country. In the original water curtain system, the paint sludge collected from the sumps was incinerated in an onsite kiln to remove the paint solvents from the sludge and concentrate the waste. The wastewater was sent to an offsite waste treatment system. In the converted system, paper filters are used, and the spent filters are disposed of via incineration.

The corporation did not convert the booths out of concern for reducing hazardous waste disposal costs, but rather because the new, water-based paints they were required to use were not suited to the facility wastewater treatment system.

SECTION 9  
CONCLUSIONS

The results of this study indicate that there is little if any doubt as to the technical and economic feasibility of wet to dry conversion of paint booth particulate emission control systems at NSY and NADEP activities. A cost/benefit analysis of several conversion scenarios (performed according to NAVFAC P-442 procedures) indicates that small, medium and moderately large booths can be cost-effectively converted, with a payback period ranging from 8 months to 1.9 years. It is very likely that these results may also be extrapolated to large booths (100 feet long or more,) however these booths must be evaluated on a case by case basis.

By converting current particulate emission control systems from wet to dry operation, a 100 percent reduction in the quantity of hazardous waste generated at NSY and NADEP painting facilities may be realized. The conversion will have no impact on booth operations, nor will it increase facility downtime. Furthermore, the same degree of air pollution control is achievable with dry filter systems as with water curtain systems, because both control particulate emissions, and neither are capable of controlling VOC emissions.

## REFERENCES

1. "Volatile Organic Compound and Particulate Emission Studies of Air Force Paint Booth Facilities," a study performed by Acurex Corporation for the U.S. Air Force and the U.S. EPA. Contract No. 68-02-4285, or Dept. No. January, 1988.
2. Binks Spray Booth and Related Equipment Catalogue. Received March, 1988.
3. Private telephone conversations with Binks sales people and technical personnel. May, June, July, 1988.
4. Private telephone conversation with Flakt technical representative. May, 1988.
5. Confirmation letter from the State of California Department of Health Services. Dated June 27, 1988.
6. Code of Federal Regulations -- Labor. 29.94 part C6, 1984.
7. Confirmation letters from SCAQMD; State of Hawaii DOHEPB; BAAQMD; State of Florida DERBAQMD; conversation with State of North Carolina Air Quality personnel.
8. Naval Facilities Engineering Command Economic Analysis Handbook, Document NAVFAC P-442, June, 1986.
9. Private conversations with marketing and business supervisor of Chem Waste Management, June, July, 1988.
10. Private conversation with paint booth facility supervisor at the NIROP in Pomona, California. April and May, 1988.
11. Paint Arrestor Manual of Overspray Control, from Research Products Corporation. Received June, 1988.
12. Binks Training Division Spray Application Processes manual. Received March, 1988.

APPENDIX A  
CHARACTERISTICS OF TYPICAL DRY FILTER SYSTEMS

A-1. DRY FILTER CHARACTERISTICS

Particulate Capacity

Clean filters are rated for operation at a certain flowrate and pressure differential across the media. As the filter becomes laden with overspray particulate, the flowrate decreases and the pressure differential across the media increases due to filter blockage. The filter requires replacement when the maximum pressure differential specified by the manufacturer is reached. The particulate capacity of the filter is the quantity of overspray the media is able to retain before filter replacement is required.

Resistance to Airflow

Minimizing the resistance to airflow through the filter is necessary to maintain the required volume flowrate through the booth and, in some cases, eliminate leakage around the filters. Ideally, dry filters operate with very little flow resistance until the particulate holding capacity is reached. This is generally not the case however, because airflow resistance increases as the quantity of particulate captured by the filter increases.

Particulate Removal Efficiency

Particulate removal efficiency is a measure of how effectively the filter is able to remove paint particulate from spray booth exhaust. It is

generally expressed as the percent of overspray removed from the airflow. The particulate removal efficiency is primarily dependent on the particulate size, the spacing between obstructions presented by the filter media, and the velocity of air passing through the filter.

Small particles remain entrained longer than large particles because they are better able to follow the flow of air around obstructions presented by the filter media. By tightly packing the filter media, small particles are removed more efficiently, however the filter may quickly become clogged. The air velocity also affects particulate removal efficiency; the higher the flowrate, the higher the particulate inertia and, correspondingly, the more likely the particulate is to impact the filter media.

#### A-2. DRY FILTER TYPES

There are four principal types of filters: fiberglass cartridge, multilayered honeycombed paper, accordion-pleated paper, and cloth filters.

##### Fiberglass Cartridge Filters

This type of filter finds widespread use due to low installation costs, reasonable capacities, and high particulate removal efficiencies. However, filter replacement costs per square foot are relatively high compared to other filter types. Filter media is composed of thin, closely packed fiberglass filaments, and is generally encased in a cardboard frame held in place by an easily assembled metal support structure. Cartridge sizes are approximately 20 in. long, 20 in. high and 1 in. deep. The primary advantage to this type of filter system is the associated low installation cost.

There are several disadvantages to this type of filter. When filter changeout is required, each cartridge must be individually replaced. This can result in considerable downtime if the booth is heavily used because of the high filter replacement rate. The support structure is generally not built so

that the filters fit tightly in the frame. Thus, as the filters become clogged and airflow resistance through them increases, significant leakage of exhaust air around the cartridges occurs.

The fiberglass cartridge type filters are best deployed in booths that have light or intermittent usage (less than 1 shift per day).

#### Multilayered Honeycombed Paper Roll or Pad Filters

Low to moderate installation and filter replacement costs, moderate capacities and reasonable particulate removal efficiencies characterize the multilayered honeycombed paper filter systems. A picture of a typical honeycombed paper filter is presented in Figure A-1 (Reference 11). The filter media is composed of sheets of thin, loosely connected paper strips that are combined to form a multilayered honeycomb. The paint booth exhaust flows through the strips, which become covered with paint overspray. These filters are available in pads or rolls.

The advantage of multilayered honeycombed paper rolls are that they are quickly and easily replaced. The downtime associated with their replacement per square foot is much less than the time required to replace cartridge filters. In addition, the price per square foot for rolls is lower than for pads.

The honeycombed paper filter pads, in contrast to the rolls, generally require as much time to replace as the fiberglass cartridges. Pads are normally installed in two layers to increase particulate emissions control, while rolls are often used in single thicknesses. The replacement costs for pads are generally higher than for rolls, but lower than for cartridge filters.

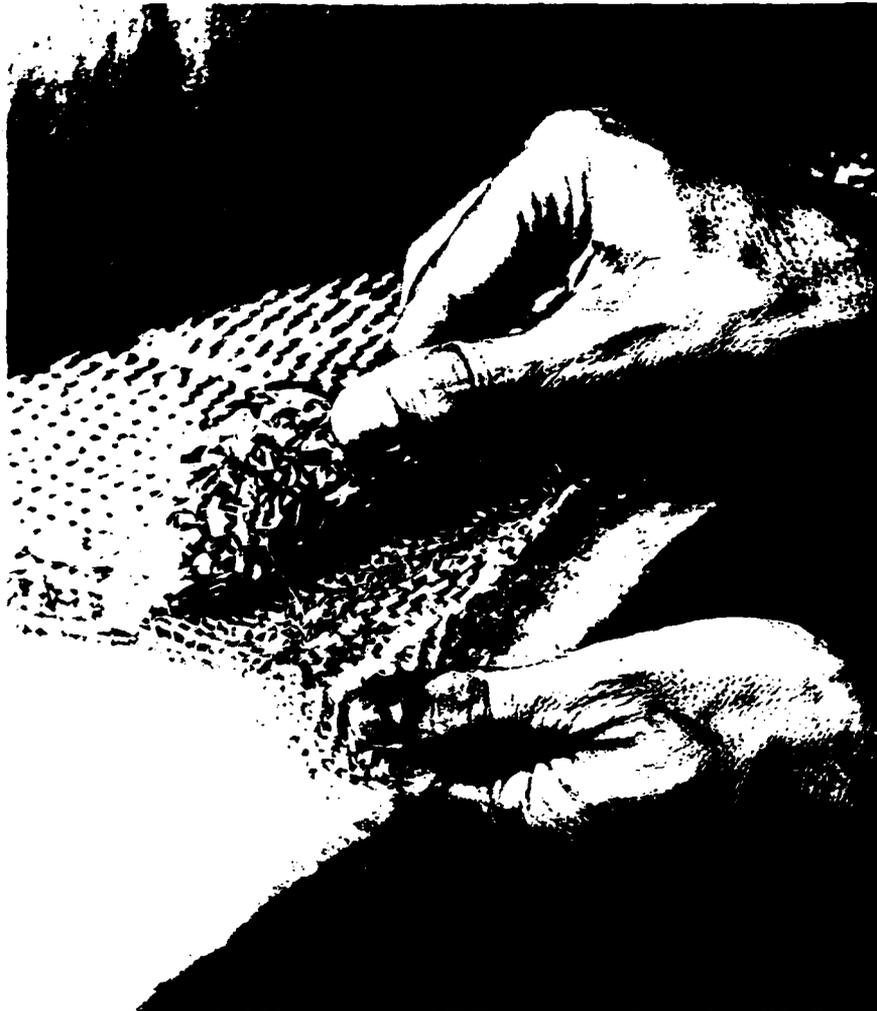


Figure A-1. Multilayered Honeycombed Paper Filter

### Accordion-Pleated Paper Sheet Filters

Low to moderate installation and operating costs, high capacities and low particulate removal efficiencies are associated with accordion-pleated paper sheet filters. The filter media is composed of layers of pleated paper attached at the folds. The paint booth exhaust air flows through staggered rows of perforations which honeycomb the layers of paper. A schematic diagram illustrating how these filters operate is given in Figure A-2 (Reference 2).

The advantage of pleated paper filters is that they are quickly and easily replaced. The downtime associated with pleated paper filter replacement is roughly the same as with the multilayered honeycombed paper filter rolls and much less, per square foot, than the time required to replace cartridge filters. In addition, the pleated paper filters generally last longer than multilayered honeycombed paper and fiberglass cartridge filters due to a higher capacity.

The primary disadvantage of the pleated paper filter is that the particulate removal efficiency of pleated paper filters may be fairly low compared to the other filter types. This could be of great concern in regions where there are stringent environmental regulations concerning particulate emissions rates. In addition, difficulties may arise if they are used in areas of constant, high humidity or if significant quantities of water-based paints are used. The presence of excess moisture can cause the filter to sag and allow unfiltered air to be emitted.

### Cloth Filters

A variety of cloth filters are currently on the market. The operating costs associated with these filters are very low; however, installation costs are the same or higher than the other filter types. Cloth roll filter particulate removal efficiencies and capacities are both high. Filter media

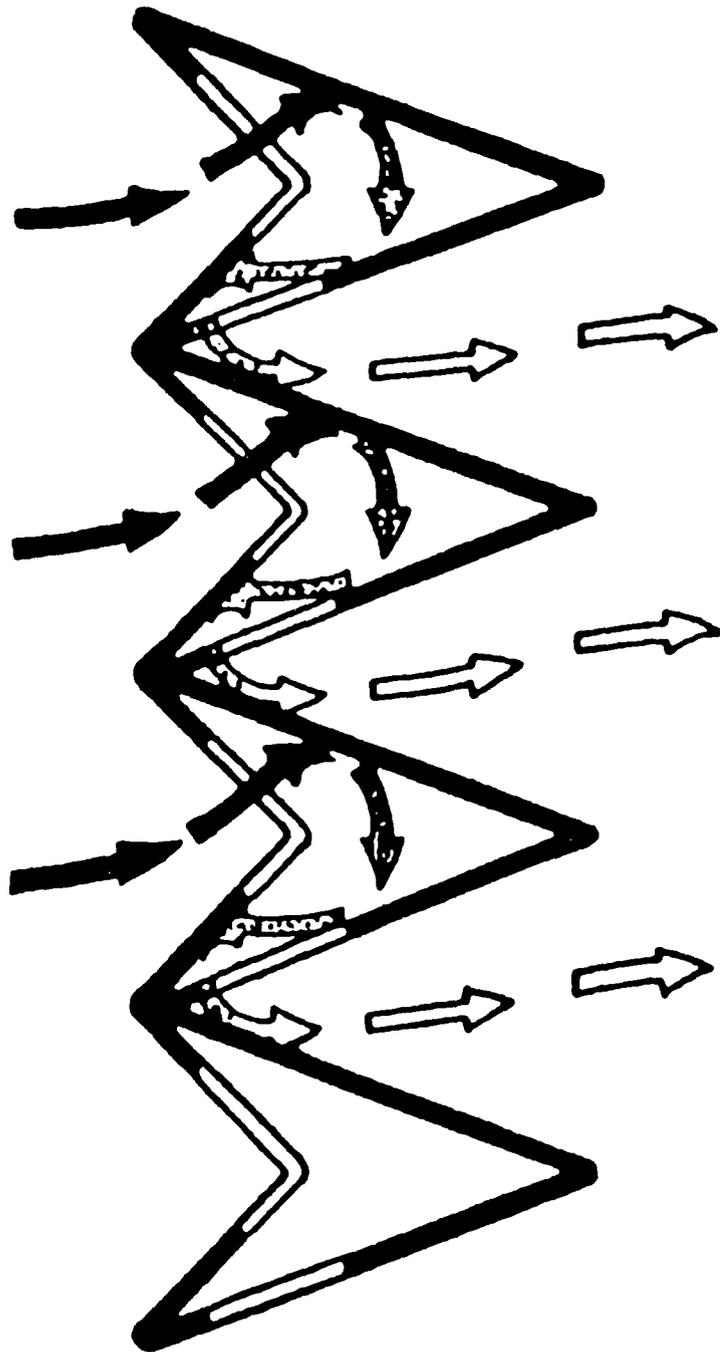


Figure A-2. Filtering Action of Accordion-Pleated Paper Sheet

is composed of specially designed, woven or nonwoven cloth. It is available in thicknesses ranging from 1/4 to 1 inch and is available in pads or rolls of up to 400 feet in length.

Cloth filters have several distinct advantages over other types of filters. They are generally much less expensive per square foot than other filters. One manufacturer claims that the capacity of their rolled cloth filter is four times higher than pleated paper filter capacities and replacement filter costs are one half as much per square foot. The cloth filter can therefore be replaced much less frequently. In addition, the particulate removal efficiencies are almost, if not equally, as high as fiberglass cartridge filters and higher than paper filters. Furthermore, cloth filters may be used in very humid environments that can prove detrimental to paper filters. As with both the pleated and the rolled honeycombed paper filters, the downtime associated with replacing cloth filters is significantly less per square foot than that required to replace cartridge filters.

Another advantage that cloth filters have over the pleated and honeycombed paper filters is that they can be automatically deployed. In an automatic deployment system, the pressure differential across the filter media is constantly monitored. When it reaches the limit specified by the manufacturer, clean filter media is unrolled from the top to replace used filter media which is collected on a roll at the bottom. The advantage of automatic versus manual deployment is that the filter is changed only when necessary, not when the filter "appears" dirty. This reduces operating and filter disposal costs and eliminates most of the down time associated with filter replacement.

The primary disadvantage associated with cloth roll filter systems is that installation costs may be higher than for other systems, especially if an automatic deployment system is installed. This is balanced to some extent by much lower replacement filter costs and a significant reduction in downtime required for filter replacement. In general, automatically deployed filters are most suitable to high production booths (2 or more shifts); however, manually deployed systems are suitable for most types of booths, regardless of booth usage.

### A.3 SUMMARY

The results of a comparison study between pleated paper, honeycombed paper, and cloth roll filters are provided in Table A-1 (Reference 12). The comparison was made between three product lines marketed by the manufacturer performing the study. As indicated in Table A-1, the cloth roll filter has the highest overall performance ratings.

Use of the four filter types described in this section need not be exclusive; different filter types may be combined to produce a highly efficient particulate emission control system. For example, one manufacturer successfully combined the multilayered honeycombed paper filter with a cloth roll filter to create a system having high removal efficiencies and low resistance over a range of particle sizes.

Table A-1. Overall Filter Performance Rating:  
 3 = Good, 2 = Better, 1 = Best

Parameter	Honeycombed Paper Filter	Pleated Paper Filter	Cloth Filter
High overall filtration	2	3	1
Low initial resistance paint it can filter	2	1	3
Types of coatings it can filter	1	2	3
Replacement rate	2	3	1
Time required for filter replacement	3	2	1
Filter replacement cost in relation to production	3	2	1
Filter replacement cost per ft <sup>2</sup>	3	2	1
Installation cost	1	2	3
Shipping and storage cost	3	1	2

## DISTRIBUTION LIST

AF AFIT/DET, Wright-Patterson AFB, OH  
AF HQ ESD/DEE, Hanscom AFB, MA  
AFB 42 CES/Ready Offr, Loring AFB, ME: AUL/LSE 63-465, Maxwell AFB, AL: HQ MAC DEEE, Scott  
AFB, IL: HQ TAC/DEMM (Pollard), Langley AFB, VA  
AFESC DEB, Tyndall AFB, FL: TST (Library), Tyndall AFB, FL  
AFSC DEEQ (P. Montoya), Peterson AFB, CO  
ARMY 416th ENCOM, Akron Survey Tm, Akron, OH: CECOM R&D Tech Lib, Ft Monmouth, NJ:  
CEHSC-FU-N (Krajewski), Ft Belvoir, VA: Ch of Engrs, DAEN-CWE-M, Washington, DC: Ch of Engrs,  
DAEN-MPU, Washington, DC: HHC, 7th ATC (Ross), Grafenwohr, GE: HQ Europe Cmd,  
AEAEN-FE-U, Vaihingen, GE: HQDA (DAEN-ZCM), Washington, DC: Kwajalein Atoll,  
BMDSC-RKL-C, Marshall Is: POJED-O, Okinawa, Japan  
ARMY BELVOIR R&D CEN STRBE-AALO, Ft Belvoir, VA: STRBE-BLORE, Ft Belvoir, VA  
ARMY CERL CERL-EN, Champaign, IL: CERL-ZN, Champaign, IL: Library, Champaign, IL  
ARMY CRREL A, Iskandar, Hanover, NH  
ARMY DEPOT Letterkenny, SDSLE-EF, Chambersburg, PA: Letterkenny, SDSLE-SF, Chambersburg, PA  
ARMY EHA Dir, Env Qual, Aberdeen Proving Grnd, MD: HSE-RP-HG, Aberdeen Proving Grnd, MD:  
HSHB-EA-S, Aberdeen Proving Grnd, MD: HSHB-EW, Aberdeen Proving Grnd, MD: HSHB-ME-A,  
Aberdeen Proving Grnd, MD  
ARMY ENGR DIST Library, Portland, OR: Library, Seattle, WA  
ARMY ENGR DIV ED-SY (Loyd), Huntsville, AL: HNDED-SY, Huntsville, AL: New England, NEDED-D,  
Waltham, MA  
ARMY LMC Fort Lee, VA  
ARMY MMRC DRXMR-SM (Lenoe), Watertown, MA  
CBC Code 10, Davisville, RI: Code 15, Port Hueneme, CA: Code 430, Gulfport, MS: Code 470.2, Gulfport,  
MS: Library, Davisville, RI: PWO (Code 400), Gulfport, MS: PWO (Code 80), Port Hueneme, CA: Tech  
Library, Gulfport, MS  
CBU 401, OIC, Great Lakes, IL  
CHINFO OI-50D (Cronk), Washington, DC  
CINCUSNAVEUR London, UK  
CNO DCNO, Logs, OP-452, Washington, DC  
COMDT COGARD Library, Washington, DC  
COMFLEACT PWO, Kadena, Japan: SCE, Yokosuka, Japan  
COMNAVAIRSYSCOM Code 422, Washington, DC  
COMNAVMARIANAS Code N4, Guam  
COMNAVRESFOR Code 08, New Orleans, LA: Code 823, New Orleans, LA  
COMNAVSUPFORANTARCTICA DET, PWO, Christchurch, NZ  
COMOCEANSYS Lant, Code N9, Norfolk, VA  
COMSC Washington, DC  
COMSUBLANT Code N404, Norfolk, VA  
DOD DFSC-FE, Cameron Station, Alexandria, VA  
DTIC Alexandria, VA  
DTRCEN Code 2834, Annapolis, MD: Code 42, Bethesda MD: Code 522, Annapolis, MD  
EPA Reg III Lib, Philadelphia, PA: Reg VIII, Lib, Denver, CO  
FAA Code APM-740 (Tomita), Washington, DC  
GIDEP OIC, Corona, CA  
GSA Code PCDP, Washington, DC  
LIBRARY OF CONGRESS Sci & Tech Div, Washington, DC  
MAG 16, CO, MCAS Tustin, CA  
MARCORBASE Code 405, Camp Lejeune, NC: Code 406, Camp Lejeune, NC: Maint Offr, Camp Pendleton,  
CA: PAC, PWO, Camp Butler, JA: PWO, Camp Lejeune, NC: PWO, Camp Pendleton, CA: Pac, FE,  
Camp Butler, JA  
MARINE CORPS HQ LFL, Washington, DC  
MARITIME ADMIN MMA, Library, Kings Point, NY  
MCAF Code C144, Quantico, VA  
MCAS Code 6EDD, Iwakuni, Japan: Criminal Invest Div, Kaneohe, HI: PWO, Kaneohe Bay, HI: PWO,  
Yuma, AZ  
MCLB Code B520, Barstow, CA  
MCRDAC M & L Div Quantico, VA: NSAP Rep, Quantico, VA: PWO, Quantico, VA  
NAF AROICC, Midway Island  
NALF OIC, San Diego, CA

NAS Chase Fld. Code 18300, Beeville, TX; Chase Fld. PWO, Beeville, TX; Code 072E, Willow Grove, PA;  
 Code 110, Adak, AK; Code 163, Keflavik, Iceland; Code 187, Jacksonville, FL; Code 70, Marietta, GA;  
 Code 70, South Weymouth, MA; Code 8, Patuxent River, MD; Memphis, Dir. Engrg Div, Millington, TN;  
 Memphis, PWO, Millington, TN; Miramar, PWO, San Diego, CA; NI, Code 183, San Diego, CA; OL,  
 Alameda, CA; OLF-1, Alameda, CA; PW Engrg (Branson), Patuxent River, MD; PWO (Code 182)  
 Bermuda; PWO, Adak, AK; PWO, Cecil Field, FL; PWO, Dallas, TX; PWO, Glenview, IL; PWO,  
 Keflavik, Iceland; PWO, Key West, FL; PWO, Kingsville, TX; PWO, New Orleans, LA; PWO, Sigonella,  
 Italy; PWO, South Weymouth, MA; PWO, Willow Grove, PA; SCE, Barbers Point, HI; Whidbey Is, PW-2,  
 Oak Harbor, WA; Whiting Fld, PWO, Milton, FL  
 NAVAIRDEVCCEN Code 832, Warminster, PA  
 NAVAIRENGCEN PWO, Lakehurst, NJ  
 NAVAIRPROPCCEN CO, Trenton, NJ; Code PW-3, Trenton, NJ  
 NAVAIRTESTCCEN PWO, Patuxent River, MD  
 NAVAUDSVCHQ Director, Falls Church VA  
 NAVAVIONICCCEN Code D 701, Indianapolis, IN; PWO, Indianapolis, IN  
 NAVAVNDEPOI Code 61000, Cherry Point, NC; Code 611, Jacksonville, FL; Code 61101 (Van Name),  
 Norfolk, VA; Code 61630, San Diego, CA; Code 640, Pensacola, FL; SCE, Norfolk, VA  
 NAVCAMS PWO (Code W-60), Wahiawa, HI; PWO, Norfolk, VA; SCE (Code N-7), Naples, Italy  
 NAVCOASTSYSCCEN Code 2360, Panama City, FL; Code 423, Panama City, FL; Code 740, Panama City, FL;  
 Tech Library, Panama City, FL  
 NAVCOMMSTA Code 401, Nea Makri, Greece; PWO, Exmouth, Australia  
 NAVCONSTRACEN CO, Port Hueneme, CA  
 NAVELEXCEN DET, OIC, Winter Harbor, ME  
 NAVEODTECHCCEN Tech Library, Indian Head, MD  
 NAVFAC Centerville Beh, PWO, Ferndale, CA; PWO, Oak Harbor, WA  
 NAVFACENGCOM Code 00, Alexandria, VA; Code 03, Alexandria, VA; Code 03T (Essoglou), Alexandria,  
 VA; Code 04A, Alexandria, VA; Code 04A1, Alexandria, VA; Code 04A3, Alexandria, VA; Code 051A,  
 Alexandria, VA; Code 083, Alexandria, VA; Code 09M124 (Lib), Alexandria, VA; Code 163, Alexandria,  
 VA; Code 1651, Alexandria, VA; Code 18, Alexandria, VA  
 NAVFACENGCOM - CHES DIV EPO-IPE, Washington, DC  
 NAVFACENGCOM - LANT DIV Code 1112, Norfolk, VA; Code 403, Norfolk, VA; Code 405, Norfolk, VA;  
 Library, Norfolk, VA  
 NAVFACENGCOM - NORTH DIV CO, Philadelphia, PA; Code 04, Philadelphia, PA; Code 04AL,  
 Philadelphia, PA; Code 114 (Rhoads), Philadelphia, PA  
 NAVFACENGCOM - PAC DIV Code 09P, Pearl Harbor, HI; Library, Pearl Harbor, HI  
 NAVFACENGCOM - SOUTH DIV Code 1112, Charleston, SC; Code 406, Charleston, SC; Library,  
 Charleston, SC  
 NAVFACENGCOM - WEST DIV 09P 20, San Bruno, CA; Code 04A2.2 (Lib), San Bruno, CA; Code 04B, San  
 Bruno, CA; Code 09B, San Bruno, CA; Code 102, San Bruno, CA; Code 405, San Bruno, CA; Code 408.2  
 (Jeung) San Bruno, CA; Pac NW Br Oile, Code C 50, Silverdale, WA  
 NAVFACENGCOM CONTRACTS AROICC, Quantico, VA; Code 923, Everett, WA; DROICC, Rota, Spain;  
 OICC, Guam; OICC ROICC, Virginia Beach, VA; ROICC (Code 495), Portsmouth, VA; ROICC, Corpus  
 Christi, TX; ROICC, Crane, IN; ROICC, Keflavik, Iceland; ROICC, Point Mugu, CA; SW Pac, OICC,  
 Manila, RP; SW, Code 114C, San Diego, CA; Trident, OICC, St Marys, GA; OICC NW, Code 114NW,  
 Silverdale, WA  
 NAVFUEI DET OIC, Yokohama, Japan  
 NAVHOSP CO, Millington, TN; Hd, Fac Mgmt, Camp Pendleton, CA; SCE (Knapowski), Great Lakes, IL;  
 SCE, Pensacola, FL; SCE, Yokosuka, Japan  
 NAVMARCORESCEN LTIG Davis, Raleigh, NC  
 NAVMIDCOM NWREG, Fac Engr, PWD, Oakland, CA; NWREG, Head, Fac Mgmt Dept, Oakland, CA; SE  
 REG, Hd, Fac Mgmt Dept, Jacksonville, FL; SWREG, Code 29, San Diego, CA; SWREG, SCE, San Diego,  
 CA  
 NAVMI DRSCHINSTITUTE Code 47, Bethesda, MD  
 NAVOCEANCOMCEN CO, Guam, Mariana Islands; Code 115, Guam, Mariana Islands  
 NAVOCEANO Library, Bay St Louis, MS  
 NAVORDSTA PWO, Louisville, KY  
 NAVPENTIS Director, Washington DC  
 NAVPGSCOI F, Thornton, Monterey, CA  
 NAVPHIBASI PWO, Norfolk, VA; SCE, San Diego, CA  
 NAVSCOICICOFI Code C35, Port Hueneme, CA  
 NAVSICGRI Code G43, Washington, DC  
 NAVSICGRUACT PWO (Code 40), Edzell, Scotland; PWO, Adak, AK; PWO, Sabana Seca, PR  
 NAVSICSTA Code 60, Washington, DC; Code N70, Washington, DC  
 NAVSHIPRIPEAC SCE, Subic Bay, RP; SCE, Yokosuka, Japan

NAVSHIPYD Carr Inlet Acoustic Range, Bremerton, WA: Code 202.5 (Library), Bremerton, WA: Code 420, Long Beach, CA: Code 440, Portsmouth, NH: Code 903, Long Beach, CA: Mare Island, Code 202.13, Vallejo, CA: Mare Island, Code 401, Vallejo, CA: Mare Island, Code 421, Vallejo, CA: Mare Island, Code 457, Vallejo, CA: Mare Island, PWO, Vallejo, CA: Norfolk, Code 380, Portsmouth, VA: Norfolk, Code 411, Portsmouth, VA: Norfolk, Code 440, Portsmouth, VA: Norfolk, Code 450-HD, Portsmouth, VA: PWO (Code 400), Long Beach, CA: PWO, Bremerton, WA: PWO, Charleston, SC

NAVSTA CO, Brooklyn, NY: CO, Long Beach, CA: CO, Roosevelt Roads, PR: Code 4216, Mayport, FL: Code 423, FPBO Guantanamo Bay: Engrg Dir, PWD, Rota, Spain: PWO, Mayport, FL

NAVSUPPACT PWO, Holy Loch, UK

NAVSUPPFAC Ch Engr (Popp), Diego Garcia; Contract Admin Tech Library, Diego Garcia

NAVSUPPO Sec Offr, La Maddalena, Italy

NAVSWC Code E211 (Miller), Dahlgren, VA: Code W42 (GD Haga), Dahlgren, VA: PWO, Dahlgren, VA

NAVTECHTRACEN SCE, Pensacola FL

NAVUSEAWARENGSTA Code 073, Keyport, WA

NAVWARCOL Code 24, Newport, RI

NAVWPNCEN AROICC, China Lake, CA: Code 24, China Lake, CA: Code 2637, China Lake, CA: PWO (Code 266), China Lake, CA

NAVWPNSTA Code 093, Yorktown, VA: Dir, Maint Control, PWD, Concord, CA: Earle, Code 092, Colts Neck, NJ: Earle, PWO (Code 09B), Colts Neck, NJ: PWO, Charleston, SC: PWO, Seal Beach, CA: PWO, Yorktown, VA

NAVWPNSUPPCEN PWO, Crane, IN

NETC Code 42, Newport, RI: PWO, Newport, RI

NCR 20, CO

NMCB 5, Ops Dept

NOAA Dir, Pac Marine Cen, Seattle, WA: Library, Rockville, MD

NORDA Code 410, Bay St. Louis, MS

NRL Code 2530.1, Washington, DC

NSC Cheatham Annex, PWO, Williamsburg, VA: Code 43, Oakland, CA: Code 54.1, Norfolk, VA: Code 700, Norfolk, VA: SCE, Charleston, SC: SCE, Norfolk, VA

NSD SCE, Subic Bay, RP

NUSC DET Code 44 (RS Munn), New London, CT: Code 5202 (S Schady), New London, CT

OFFICE OF SECRETARY OF DEFENSE OASD, (P&I)E (Wm H. Parker), Washington, DC: ODDR&E, Environ & Life Sci, Washington, DC

PHIBCB 1, CO, San Diego, CA: 1, P&E, San Diego, CA: 2, CO, Norfolk, VA

PWC ACE Office, Norfolk, VA: Code 10, Great Lakes, IL: Code 10, Oakland, CA: Code 101 (Library), Oakland, CA: Code 1013, Oakland, CA: Code 102, Oakland, CA: Code 123-C, San Diego, CA: Code 30, Norfolk, VA: Code 30V, Norfolk, VA: Code 400, Great Lakes, IL: Code 400, Pearl Harbor, HI: Code 400, San Diego, CA: Code 412, San Diego, CA: Code 420, Great Lakes, IL: Code 420, Oakland, CA: Code 420B (Waid), Subic Bay, RP: Code 422, San Diego, CA: Code 423, San Diego, CA: Code 424, Norfolk, VA: Code 500, Great Lakes, IL: Code 500, Oakland, CA: Code 590, San Diego, CA: Code 600, Great Lakes, IL: Code 612, Pearl Harbor, HI: Code 614, San Diego, CA: Code 615, Guam, Mariana Islands: Code 700, Great Lakes, IL: Code 700, San Diego, CA: Library (Code 134), Pearl Harbor, HI: Library, Guam, Mariana Islands: Library, Norfolk, VA: Library, Pensacola, FL: Library, Yokosuka, Japan: Tech Library, Subic Bay, RP: Util Dept (R Pascua), Pearl Harbor, HI

SPCC PWO (Code 08X), Mechanicsburg, PA

SUPSHIP Tech Library, Newport News, VA

US DEPT OF INTERIOR BLM, Engrg Div (730), Washington, DC

US GEOLOGICAL SURVEY J Bales, Raleigh, NC: Marine Geology Oite (Piteleki), Reston, VA

US NATL MARINE FISHERIES SVC Sandy Hook Lab, Lib, Highlands, NY

USAF RGNHOSP SGPB, Fairchild AFB, WA: SGPM, Fairchild AFB, WA

USCINCPAC Code J44, Camp HM Smith, HI

USDA Ext Serv (J Maher), Washington, DC: For Svc Reg 8, (Bowers), Atlanta, GA: For Svc, Equip Dev Cen, San Dimas, CA: For Svc, Tech Engrs, Washington, DC

USNA Mech Engrg Dept (Power), Annapolis, MD: PWO, Annapolis, MD: Sys Engrg, Annapolis, MD

USS USS JASON, Rpr Offr

BROOKHAVEN NATL LAB M. Steinberg, Upton, NY

CALIFORNIA Nav & Ocean Dev (Armstrong), Sacramento, CA

CITY OF BERKELEY PW, Engr Div (Harrison), Berkeley, CA

CITY OF LIVERMORE Dackins, PE, Livermore, CA

CLEVELAND STATE UNIVERSITY CE Dept (Akimmusuru), Cleveland, OH

CORNELL UNIVERSITY Library, Ithaca, NY

DAMES & MOORE Library, Los Angeles, CA

FLORIDA INST OF TECH CE Dept (Kalajian), Melbourne, FL

FOREST INST FOR OCEAN & MI Library, Carson City, NV

INSTITUTE OF MARINE SCIENCES Library, Port Aransas, TX

KEENE STATE COLLEGE Sci Dept (Cunningham), Keene, NH  
LAWRENCE LIVERMORE NATL LAB FJ Tokarz, Livermore, CA; Plant Engrg Lib (L-654), Livermore, CA  
LEHIGH UNIVERSITY Linderman Library, Bethlehem, PA  
MAINE Energy Rscs Ofc, Augusta, ME  
MISSOURI Nat Res Dept, Energy Div, Jefferson City, MO  
MIT Engrg Lib, Cambridge, MA; Lib, Tech Reports, Cambridge, MA  
NATL ACADEMY OF SCIENCES NRC, Naval Studies Bd, Washington, DC  
NEW MEXICO SOLAR ENERGY INST Dr. Zwibel, Las Cruces, NM  
NEW YORK Energy Office, Lib, Albany, NY  
NEW YORK STATE MARITIME COLLEGE Longobardi, Bronx, NY  
NY CITY COMMUNITY COLLEGE Library, Brooklyn, NY  
PURDUE UNIVERSITY Engrg Lib, W. Lafayette, IN  
SEATTLE PORT W Ritchie, Seattle, WA  
SRI INTL J.L. Jones, Chem Engr Lab, Menlo Park, CA  
STATE UNIVERSITY OF NEW YORK CE Dept, Buffalo, NY  
TEXAS A&M UNIVERSITY CE Dept (Machemehl), College Station, TX  
UNIVERSITY OF ALABAMA Dir Fac Mgmt (Baker), Birmingham, AL  
UNIVERSITY OF CALIFORNIA CE Dept (Mitchell), Berkeley, CA  
UNIVERSITY OF HARTFORD CE Dept (Keshawarz), West Hartford, CT  
UNIVERSITY OF HAWAII Manoa, Library, Honolulu, HI  
UNIVERSITY OF ILLINOIS Arch Scol (Kim), Champaign, IL; Library, Urbana, IL; Metz Ref Rm, Urbana,  
IL  
UNIVERSITY OF NEBRASKA Polar Ice Coring Office, Lincoln, NE  
UNIVERSITY OF NEW MEXICO NMERI (Falk), Albuquerque, NM; NMERI (Leigh), Albuquerque, NM;  
NMERI (Tapscott), Albuquerque, NM  
UNIVERSITY OF TEXAS CE Dept (Thompson), Austin, TX  
UNIVERSITY OF WASHINGTON Engrg Col (Carlson), Seattle, WA  
UNIVERSITY OF WISCONSIN Great Lakes Studies Cen, Milwaukee, WI  
VENTURA COUNTY Deputy PW Dir, Ventura, CA; PWA (Brownie), Ventura, CA  
VIRGINIA INST OF MARINE SCI Library, Gloucester Point, VA  
WORCESTER POLYTECH INST Mech Engrg Dept (Sullivan), Worcester, MA  
ADVANCED TECHNOLOGY, INC Ops Cen Mgr (Bednar), Camarillo, CA  
APPLIED SYSTEMS R. Smith, Agana, Guam  
ARVID GRANT & ASSOC Olympia, WA  
BABCOCK & WILCOX CO Tech Lib, Barberton, OH  
BATTELLE New Eng Marine Rsch Lab, Lib, Duxbury, MA  
BECHTEL CIVIL, INC Woolston, San Francisco, CA  
BRITISH EMBASSY Sci & Tech Dept (Wilkins), Washington, DC  
CORRIGAN, LCDR S. USN, CEC, Stanford, CA  
CONSOER TOWNSEND & ASSOC Schramm, Chicago, IL  
CONSTRUCTION TECH LABS, INC AE Fiorato, Skokie, IL  
DYNAMAC CORP HMT-C, Rockville, MD  
GDM & ASSOC, INC Fairbanks, AK  
GEOTECHNICAL ENGRS, INC Murdock, Winchester, MA  
GRUMMAN AEROSPACE CORP Tech Info Ctr, Bethpage, NY  
HIRSCH & CO L Hirsch, San Diego, CA  
IRE-ITTD Input Proc Dir (R. Danford), Eagan, MN  
JOHN J MC MULLEN ASSOC Library, New York, NY  
KATSURA CONSULTING ENGRS Y. Katsura, Ventura, CA  
LINDA HALL LIBRARY Doc Dept, Kansas City, MO  
MC CLELLAND ENGRS, INC Library, Houston, TX  
MOFFATT & NICHOL ENGRS R Palmer, Long Beach, CA  
EDWARD K NODA & ASSOC Honolulu, HI  
NUHN & ASSOC A.C. Nuhn, Wayzata, NM  
PACIFIC MARINE TECH (M. Wagner) Duvall, WA  
PRESNELL ASSOC, INC DG Presnell, Jr, Louisville, KY  
RAYMOND INTL, INC Soil Tech Dept (E Colle), Pennsauken, NJ  
RILEY STOKER CORP Library, Worcester, MA  
SAUDI ARABIA King Saud Univ, Rsch Cen, Riyadh  
SCIENCE APPS INTL CORP Alexandria, VA  
SHANNON & WILSON, INC Librarian, Seattle, WA  
SRI INTL J.L. Jones, Chem Engr Lab, Menlo Park, CA  
SURFACE COMBUSTION VR Daiga, Maumee, OH  
TREMCO, INC M Raymond, Cleveland, OH

TRW INC Rodgers, Redondo Beach, CA  
UNITED KINGDOM Inst of Oceanographic Sci, Lib, Wormely  
UNITED TECHNOLOGIES Hamilton Std Div, Lib, Windsor Locks, CT  
VSE Ocean Engrg Gp (Murton), Alexandria, VA  
WOODWARD-CLYDE CONSULTANTS R. Cross, Oakland, CA; West Reg. Lib, Oakland, CA  
BULLOCK, TE La Canada, CA  
HANDLEY, DM Gulf Breeze, FL  
PADILLA, LM Oxnard, CA  
PETERSEN, CAPT N.W. Pleasanton, CA  
PODELL, H.I. New Rochelle, NY  
STEVENS, TW Fairborn, OH  
VAN ALLEN, B Kingston, NY