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DEMONSTRATION OF A PAINT SPRAY BOOTH EMISSION CONTROL STRATEGY USING RECIRCULATION/PARTITIONING AND UV/OZONE POLLUTANT EMISSION CONTROL

Volume 1. Technical Report

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16. ABSTRACT The report describes in detail the source testing, construction, and data reduction/analysis activities that comprise the three phases of a technology demonstration program. Phase I consisted of a detailed basline evaluation of several paint spray booths operated at the Barstow (California) Marine Corps Logistics Base to establish key operating parameters and air toxic emission profiles. This information was used to design a safe recirculation/flow partitioning system for the paint booths involved in the study to efficiently reduce the overall exhaust flow rate. Under Phase II, the necessary booth construction and retrofit modifications were made, and the air pollution control device was installed. The recirculation/flow partitioning system was tested extensively as part of the Phase III effort to ensure that the booths operated in accordance with health and safety standards mandated by the Occupational Safety and Health Administration (OSHA) and the National Fire Protection Association (NFPA).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Prevention	13B
Spray Painting	Stationary Sources	13H
Emission	Booths	14G
Circulation	Recirculation	
Ultraviolet Radiation	Flow Partitioning	20F
Ozone		07B

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and groundwater; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

PREFACE

This report was prepared for the U.S. Environmental Protection Agency (EPA) Air Pollution Prevention and Control Division by Air Quality Specialists, 2280 University Drive, Newport Beach, CA 92660. Air Quality Specialists developed this document under EPA Contract 68-D4-0111 with Acurex Environmental Corporation, 555 Clyde Avenue, Mountain View, CA, 94039.

This report describes in detail the source testing, construction, and data reduction/analysis activities that comprise the three phases of the Technology Demonstration Program. Phase I consisted of a detailed baseline evaluation of several paint spray booths operated at the Barstow Marine Corps Logistics Base to establish key operating parameters and air toxic emission profiles. This information was used to design a safe recirculation/flow partitioning system for the paint booths involved in the study to efficiently reduce the overall exhaust flow rate. Under Phase II, the necessary booth construction and retrofit modifications were made, and the air pollution control device was installed. Extensive testing of the recirculation/flow partitioning system was performed as part of the Phase III effort to ensure that the booths operated in accordance with Health and Safety Standards mandated by the Occupational Safety and Health Administration (OSHA) and the National Fire Protection Association (NFPA).

Numerous agencies were involved in this Program, which was executed via cooperative agreement between the U.S. Marine Corps Maintenance Directorate and the EPA's Air Pollution Prevention and Control Division (APPCD).

CONTENTS

LIST OF FIGURES

LIST OF TABLES

List of Tables (Continued)

UNIT CONVERSION TABLE

English	SI	SI Symbol	To convert from English to SI, Multiply by
Length			
Inch Foot	Centimeter Meter	cm m	2.54 0.3048
Area			
Square inch Square foot	Square centimeter Square meter	cm^2 m^2	6.452 0.09290
Volume			
Cubic inch Cubic foot	Cubic centimeter Cubic meter	cm^3 m^3	16.39 0.0283
Mass			
Pound	Kilogram	kg	0.4536
Energy			
Btu	Joule Kilowatt-hour	J kWh	1055 0.000293
Power			
Horsepower Btu/hr	Watt Watt	W W	745.7 0.2931
Temperature			
Fahrenheit	Celsius	°C	5/9 (°F - 32)
Flow Rate			
Cubic feet/minute	Cubic meters/minute	m^3/min	0.0283
Pressure			
1 inch of H_2O	Pascal	Pa	249
Velocity			
Ft/minute	Meter/second Kilometers/hour	m/s kph	0.005 0.0183

LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

ACGIH - American Conference of Governmental Industrial Hygienists
APCS - Air pollution control system
APPCD - Air Pollution Prevention and Control Division
APV - Armored personnel vehicle
ARL - Applied Research Laboratory at Pennsylvania State University
Btu - British thermal unit
CARC - Chemical agent resistant coating
cfm - Cubic feet per minute
CFR - Code of Federal Regulations
DOD - U.S. Department of Defense
DQI - Data quality indicator
DQO - Data quality objective
EPA - U.S. Environmental Protection Agency
EUAC - Equivalent Uniform Annual Cash Flow
FID - Flame ionization detector
fpm - Feet per minute
FTIR - Fourier transform infrared detector
HDI - Hexamethylene diisocyanate
HVLP - High volume low pressure
IDLH - Immediately dangerous to life and health
LEL - Lower explosion limit
MACT - Maximum Achievable Control Technology
MCLB - Marine Corps Logistics Base, Barstow
MC^3 - Marine Corps Multi-Commodity Maintenance Center
MEK - Methyl ethyl ketone
MIAK - Methyl isoamyl ketone
MIBK - Methyl isobutyl ketone
MSDS - Material Safety Data Sheet
NFPA - National Fire Protection Association
NIOSH - National Institute of Occupational Safety and Health
OSHA - Occupational Safety and Health Administration
PEL - Permissible Exposure Level
PGMEA - Propylene glycol monoethyl ether acetate

PID - Photoionization detector

PPE - Personal protective equipment

ppm - Parts per million

QA - Quality assurance

QAO - Quality Assurance Officer

QAPjP - Quality Assurance Project Plan

QC - Quality control

RPD - Relative percent difference

SERDP - Strategic Environmental Research and Development Program

STEL - Short term exposure limit

TLV - Threshold limit value

TWA - Time weighted average

USMC - United Stated Marine Corps

UV - Ultraviolet

VFD - Variable frequency drive

VOC - Volatile Organic Compound

SYMBOLS

C - Concentration

f^3 - Cubic feet

Hz - Hertz

kg - Kilograms

mA - Milliamp

mg - Milligram

m^3 - Cubic meters

Q - Flow rate

w.c. - water column

SUBSCRIPTS

$_i$ - Constituent i

$_r$ - Recirculation stream

$_m$ - Fresh make-up air stream

$_b$ - Booth

$_e$ - Exhaust stream

$_c$ - As carbon

SECTION 1

INTRODUCTION

Developing energy efficient and cost-effective strategies for controlling emissions of volatile organic compounds (VOCs) and hazardous air pollutants from paint application processes is a key objective of the U.S. Environmental Protection Agency (EPA) and the Department of Defense (DoD). Both the EPA and the DoD have sponsored extensive research and development programs that focus on new approaches and innovative solutions to reduce the economic and operational impacts of controlling low concentration VOC emission sources.

In the Fall of 1993, the EPA's Air Pollution Prevention and Control Division (APPCD) joined with the U.S. Marine Corps (USMC) under the Strategic Environmental Research and Development Program (SERDP) to launch a comprehensive technology demonstration program that combined several innovative strategies for cost effectively controlling VOC emissions from USMC paint spray booths. The Marine Corps Logistics Base in Barstow, CA (MCLB) was selected as the host site for the EPA/USMC Technology Demonstration Program; MCLB is a high production facility that generally operates year round at two-three shifts per day. These operating conditions provide an ideal situation for conclusively demonstrating the viability and applicability of the various technological innovations that were considered in the EPA/USMC Demonstration Program. Moreover, unlike most programs of this type, MCLB intends to maintain the hardware and system modifications that were installed for the EPA/USMC Demonstration Program. This will provide program participants with the opportunity to conduct a realistic, long-term performance evaluation of these innovative strategies.

The EPA/USMC Technology Demonstration Program consisted of two major system design and installation efforts which were carefully coordinated and integrated to ensure efficient system operation. The first effort entailed comprehensive ventilation system modifications to several of the paint spray booths operated at MCLB. The objective of these modifications was to significantly reduce the exhaust volume flow rate from these sources, thereby reducing the installation and operating costs associated with add-on emission controls. The second effort focussed on the installation and optimization of an innovative air pollution control system that relies on ultraviolet light and ozone to eliminate the VOCs present in the paint booth exhaust stream. The results of the paint booth modification/evaluation efforts and the UV/Ozone emission control system installation/optimization activities completed under the EPA/USMC Technology Demonstration Program are documented in this final report. This program, which concluded in the Fall of 1996, was conducted under the auspices of the U.S. EPA and the U.S. Marine Corp from funding made available by the EPA and the DoD.

1.1 BACKGROUND

In 1987, the EPA and the U.S. Air Force jointly initiated a comprehensive technology evaluation and demonstration program with the objective of identifying and evaluating cost-effective VOC emission control strategies for paint spray booth applications. The results of the first phase of that program, which focused on candidate process modifications for reducing emission control costs, indicated that the most straightforward and effective approach was simply to reduce the exhaust flow rate emitted from the paint application processes.[1] Reducing the exhaust volume flow rate allows a corresponding reduction in the size, capacity, installation cost, and operating requirements of the emission control device. For example, the capital and installation cost of a 2,832 m^3/min (100,000 ft^3/min) rotor concentrator catalytic oxidizer air pollution control system (APCS) is approximately $1,800,000 (1995 dollars). By reducing the exhaust flow rate to 1,216 m^3/min (50,000 cfm), the APCS installation cost is reduced to approximately $1,000,000 (1995 dollars). Annual operating costs are similarly reduced from $49,000 to $27,000 (equipment cost data supplied by Dürr Industries, Inc. of Plymouth, MI).

The significant economic advantages of flow reduction were readily apparent, thus the EPA/Air Force program targeted various flow reduction strategies for further investigation; these studies focussed on realistic limits that could be placed on the strategies which were considered. These limits relate to the health and safety aspects of ventilation system design, and are regulated by the Occupational Safety and Health Administration (OSHA) and the National Fire Protection Association (NFPA). Key safety issues that were addressed during the Air Force/ EPA program are discussed briefly in this section; additional details are provided in Section 2.

Recirculation was the first flow reduction strategy considered under the joint EPA/Air Force program. Recirculation involves venting only a portion of the booth exhaust to an APCS; the remainder of the exhaust is recirculated back into the booth after mixing with fresh make-up air. Unfortunately, in 1987 when the EPA first recommended the use of recirculation it was believed by the USAF to be prohibited by both OSHA and NFPA. Eventually research results from field studies developed by EPA convinced OSHA and Air Force officials that these prohibitions stemmed from concerns relating to fire and explosion hazards and not worker health considerations. After an extensive coordination and review by the EPA, OSHA, and USAF, OSHA revised their policy specifically stating that recirculation could be implemented if (and only if) the recirculation system adequately ensured compliance with applicable OSHA rules pertaining to worker health. A copy of this supplemental OSHA document is shown in Figure 1. NFPA had revised their standard relating to recirculation in 1985. That revision can be found in the 1985 edition of NFPA 33, section 5.5.2.[2]

Throughout this recirculation review period, EPA and Air Force continued to jointly develop and evaluate potential improvements to the basic recirculation technology. These efforts culminated in the development of an enhanced flow reduction strategy known as recirculation with flow partitioning; addition of the flow partitioning enhancement enables a further increase in the recirculation rate, and correspondingly an additional decrease in the

U.S. Department of Labor

Occupational Safety and Health Administration
Washington, D.C. 20210

Reply to the Attention of:

JAN 16 1990

Susan R. Wyatt, Chief
Chemicals and Petroleum Branch
Emission Standards Division
U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

Dear Ms. Wyatt:

This is in response to your letter of October 31, 1989, concerning the Occupational Safety and Health Administration (OSHA) regulation at 29 CFR 1910.107(d)(9) which prohibits the recirculation of exhaust air from spray finishing operations. Please excuse the delay in response.

As you are aware, 29 CFR 1910.107 was adopted from the NFPA 33-1969, Standard for Spray Finishing Using Flammable and Combustible Materials. The NFPA-33 standard is explicitly a fire and explosion safety standard. Therefore, the OSHA standard at 29 CFR 1910.107 pertains to the prevention of workplace fire and explosion hazards and does not pertain to health considerations.

Although the NFPA has updated their standard since the 1969 edition, OSHA has not. As a result, the current NFPA 33-1985, Spray Application Using Flammable and Combustible Materials, reflects the most up to date state of the art concerning the prevention of fire and explosion hazards during spray finishing operations.

Under an OSHA policy for "de minimis violations", employers are encouraged to abide by the most current consensus standard applicable to their operations, rather than with the standard in affect at the time of the inspection when the employer's action provides equal or greater employee protection. De minimis violations are violations of existing OSHA standards which have no direct or immediate relationship to safety or health. Such violations of the OSHA standards result in no citation, no penalty and no required abatement. A copy of the OSHA policy for de minimis violations is enclosed.

Figure 1. Supplemental OSHA Documentation Pertaining to Recirculation (page 1).

Employers who fully comply with the specifications and requirements of the NFPA 33-1989, concerning the recirculation of exhaust air to an occupied spray booth, would not be cited under 29 CFR 1910.107(d)(9) under the policy for de minimis violations. However, the quality of the respirable air in the booth must comply, at a minimum, with the requirements set forth by 29 CFR 1910.1000 which establishes permissible exposure limits (PEL's).

If we may be of further assistance, please contact us.

Sincerely,

Thomas J. Shepich, Director
Directorate of Compliance Programs

Figure 2. Supplemental OSHA Documentation Pertaining to Recirculation (page 2).

exhaust flow rate.[3]

The Recirculation/Flow Partition technology was successfully demonstrated in a small paint booth at Travis Air Force Base (AFB) in 1992.[4] However, the Travis AFB demonstration did not include integration of the booth ventilation system with an add-on APCS; rather the exhaust was discharged to atmosphere. Additional information relating to the recirculation and recirculation/flow partitioning technologies are provided in Section 2.

Based on the successful results of the EPA/Air Force program, the USMC elected to implement a full-scale technology demonstration project that combined the recirculation/flow partitioning strategy with an innovative air pollution control strategy that relies on ultraviolet (UV) light and ozone to successfully remove VOCs and organic air toxic compounds from process exhaust streams. For the EPA/USMC Technology Demonstration Program described herein, three paint spray booths at MCLB were modified to accommodate recirculation/flow-partitioning. The exhaust streams from these booths were integrated and directed to the UV/Ozone APCS .

The EPA/USMC Technology Demonstration Program combines several new, "cutting edge" technologies; the innovative aspects of this program; therefore, necessitated careful consideration of safety and logistical issues during the system design and installation phase. For example, the correct recirculation rate for each booth was derived based on detailed and comprehensive baseline test data to ensure that the booths would always operate in compliance with OSHA health and safety requirements. To maintain compliance with these health and safety regulations, a VOC monitoring system that provides real-time, speciated organic concentration data was developed and installed to continuously monitor constituent concentrations in the recirculation ducts. Furthermore, to minimize the impact of paint overspray on the UV/Ozone control system and reduce overspray material in the recirculation stream, an evaluation of paint booth filtration systems was performed to select an advanced overspray collection media.

This report summarizes these innovative aspects of the Demonstration Program, and discusses in detail the comprehensive testing, engineering evaluation, design, construction, and system validation activities that were undertaken to ensure safe and efficient paint booth operations. The results of the APCS technology demonstration study are presented in a separate USMC/ARL report.

1.2 PROGRAM OBJECTIVE

The primary objectives of the EPA/USMC Technology Demonstration Program were: 1) to demonstrate that recirculation/flow partitioning ventilation provides a safe and cost-effective means of controlling pollutant emissions from military paint spray booths; and 2) to develop and install APCS system enhancements to further increase the effectiveness of the UV/Ozone system. The research activities undertaken to develop the UV/Ozone APCS system enhancements were conducted at the Pennsylvania State University Applied Research Laboratory (ARL). As part of the SERDP effort, the ARL system enhancements could then be implemented on the full scale UV/Ozone APCS installed at MCLB.

1.3 OVERALL PROGRAM APPROACH

The EPA/USMC Technology Demonstration Program was initiated in the Fall of 1993, and was implemented in three separate phases:

Phase I - Baseline evaluation of existing Barstow paint spray booth operations

Phase II - The design and installation of the recirculation/flow partition system. This Phase also included a complete booth characterization study performed immediately prior to any construction modifications to confirm that booth operations did not change significantly after the baseline study.

Phase III - The demonstration and testing of the recirculation/flow partition system.

The approach that was adopted to successfully complete these phases is summarized below.

1.3.1 Baseline Characterization Study

The objective of the Baseline Characterization Study was to develop a safe and efficient recirculation/flow partitioning system for each of the three paint booths targeted by this Demonstration Program. The Baseline Characterization Study comprised three steps:

1) Collect site-specific process operating information and correlate these results with facility data to establish the appropriate recirculation rate for each booth. This involved extensive source testing, and sample analysis activities, which are summarized in Section 4.

2) Reconcile the source test results with facility process data that were collected during the Step 1 sampling efforts, and project a safe and efficient recirculation rate and partition height for each of the paint spray booths. This step required a significant level of data reduction, correlation, and evaluation. Background data relating to the recirculation calculations that were performed and the key health and safety issues that were addressed are provided in Section 2.

3) Develop conceptual designs for the recirculation/flow partitioning ventilation systems to be installed on each of the paint spray booths. This step addressed important site-specific issues such as exhaust filter system requirements for

protecting the downstream APCS, fan system and make-up air intake configurations, flow control and safety system monitors, etc. Several key issues that were addressed during Step 3 of the Baseline Characterization Phase are discussed in Section 5. Two primary system constraints that relate to booth design were also addressed during this Phase. These constraints (discussed in detail in Section 2) include:

- The concentration of hazardous constituents in the recirculation stream (which dictates the level of recirculation that is achievable); and

- The 100 fpm volume flow rate level required by OSHA (which dictates the size and capacity of the ventilation equipment and the APCS).

1.3.2 Booth Ventilation System and APCS Installation

Phase II of the EPA/USMC Technology Demonstration Program consisted of two separate design and construct efforts which were completed in parallel. One of the design/construction efforts focussed on retrofitting the paint booth ventilation system and exterior structures to accommodate recirculation/flow partitioning. Information relating to some of the key ventilation system considerations and design decisions are summarized briefly in Section 5. The MCLB paint booths were then modified during the Phase II effort in accordance with the structural and ventilation system retrofit requirements specified in the final design drawings. This effort also included a complete booth characterization study performed immediately prior to any construction modifications to confirm that booth operations did not change significantly after the baseline study.

A second design/construction effort was undertaken to install the UV/Ozone air pollution control system. The system was designed, installed and tested under the direction of USMC program staff. The paint booth modification team coordinated their design/construct efforts with the UV/Ozone APCS installation team to ensure efficient system integration.

1.3.3 Technology Demonstration Study

The goal of the third and final phase of this Demonstration Program was to characterize in detail the performance of the recirculation/flow partition systems installed on each of the paint spray booths. The performance characterization activities included assessing the health and safety aspects of the recirculation system (discussed in Section 5), establishing the viability of an innovative safety monitoring system (discussed in Section 2), and evaluating the overall performance of the booth operations after the retrofit activities were completed.

SECTION 2

TECHNOLOGICAL INNOVATIONS OF THE PROGRAM

The EPA/USMC Technology Demonstration Program encompasses several technological innovations; indeed the primary objective of this program was to demonstrate the viability of these technologies at a full scale production facility. Although the technologies discussed in this section are truly innovative and; therefore, are not in widespread use, Barstow MCLB considers these retrofit modifications to be permanent installations, and as such, will rely on their continual and successful operation well into the next century. This was a key consideration in the overall design and installation approach employed for retrofitting the paint booths. This section focuses on the various technological innovations included in this demonstration program.

2.1 RECIRCULATION/FLOW PARTITIONING CONCEPT

There are numerous advantages to recirculation ventilation, including energy efficiency, cost effective ventilation system operation, and a significant reduction in air pollution control system capital, installation, and operating costs. The energy efficiency and cost effectiveness of recirculation is a function of the recirculation rate; thus maximizing recirculation will also maximize system efficiency and cost savings. However, as indicated in Section 1, the volume of air that may be recirculated is limited by various safety requirements relating to permissible exposure levels and minimum booth ventilation rates, as specified by OSHA. Therefore, a safe and efficient recirculation system will maximize the recirculation rate, yet ensure compliance with applicable OSHA requirements.

A common recirculation ventilation strategy, known as simple recirculation, is illustrated schematically in Figure 3. In simple recirculation, a portion of the booth exhaust is removed through a bleed-off duct and vented to an emission control device. The remainder of the exhaust passes back into the booth via a recirculation duct connected to the exhaust plenum. Prior to re-entering the paint booth, the recirculated air is mixed with fresh make-up air which is introduced to replace the bleed-off air. As discussed in detail below, the OSHA regulations which govern recirculation system operations specify that the hazardous constituent concentrations in the recirculation stream must not exceed safe levels. In simple recirculation, the hazardous constituent concentrations in the recirculated stream are the same as in the bleed-off stream, thus the flow reduction achievable by simple recirculation is limited by the bulk exhaust stream concentration. Therefore, it follows that recirculation may be safely enhanced by configuring the ventilation system such that the hazardous constituent concentrations in the bleed-off stream are higher than in the recirculation stream. This enhancement is achieved via recirculation/flow partitioning, which is illustrated schematically in Figure 4.

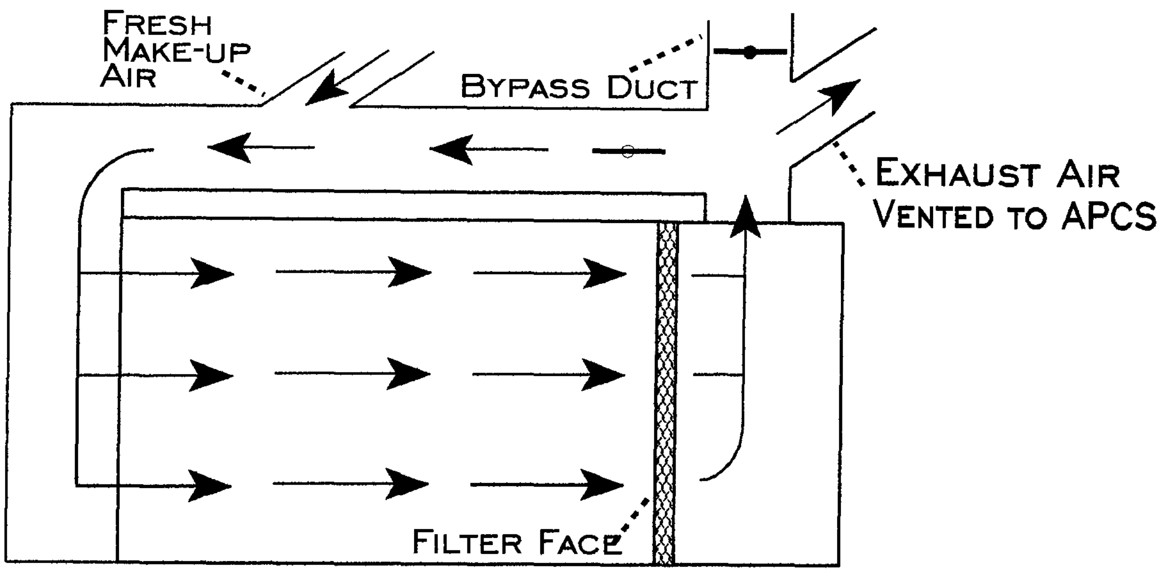


Figure 3. Schematic diagram of simple recirculation.

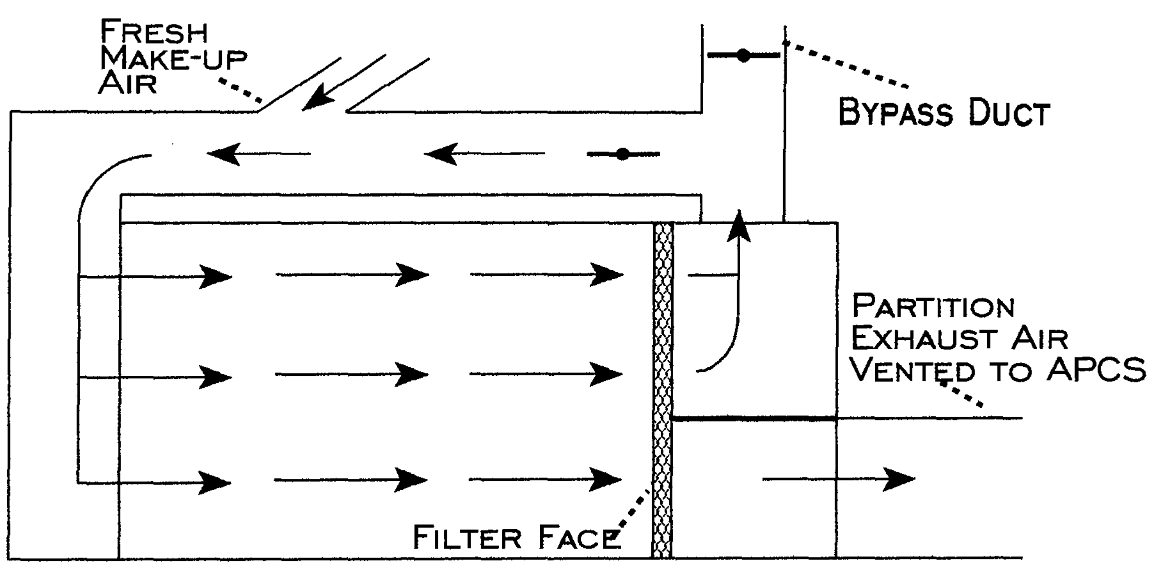


Figure 4. Schematic diagram of recirculation/flow partitioning.

The recirculation/flow partitioning system takes advantage of constituent stratification that occurs naturally in a laminar, cross-flow paint booth. The recirculation/flow partitioning strategy specifically relies on the fact that solid and vapor phase constituents tend to remain at or below the level at which they are released in the paint booth. This system withdraws air from the booth zone that has the highest paint overspray particulate and solvent vapor concentrations, and directs this contaminated air to an air pollution control system. Correspondingly, recirculated air is drawn from the zone within the booth that has the lowest constituent concentrations. The recirculation/flow partitioning strategy; therefore, safely enhances the recirculation rate and cost effectiveness of paint booth ventilation system operation beyond the level that is achieved by simple recirculation.

As indicated in Section 1, the recirculation/flow partitioning technology was developed under a joint EPA/Air Force recirculation technology study at Hill AFB.[3] Significant constituent stratification was found to occur in the paint booths that were tested; based on these findings, the concept of selectively recirculating from relatively low concentration zones in the booth was developed.

2.1.1 General Recirculation/Flow Partition System Design Considerations

Numerous system design and implementation issues must be addressed in developing a safe and efficient recirculation/flow partition system. The key safety requirements that must be considered are contained in federal health and safety regulations codified in the NFPA Standards and the Code of Federal Regulations (CFR). Other design issues that should be considered include fan system requirements for ensuring consistent booth ventilation flow rates, safety monitoring, and constituent concentration profiles at the exhaust face (necessary for calculating the partition height). These issues are discussed separately below.

Safety Regulations Codified in NFPA 33: The NFPA 33 standard is primarily motivated by concerns relating to fire and explosion hazards.[2] As such, the overriding section of the standard that impacts recirculation limits the airborne concentration of flammable compounds to less than 25% of the compound lower explosion limit (LEL). However, the LELs for solvents typically present in paint booth operations are much higher than the allowable worker exposure levels mandated by OSHA (discussed in detail below). Therefore, by complying with the OSHA exposure limit requirements, the NFPA standards are automatically met. For example, the allowable 8-hour worker exposure limit for xylene is 100 ppm, the LEL for xylene is 10,000 ppm, thus 25% of the LEL is 2,500 ppm. Therefore, if the recirculation system is properly designed to comply with OSHA requirements (i.e. the organic constituent concentrations remain well below the 100 ppm exposure limit), the recirculation system will, by default, comply with the 2,500 ppm LEL limit specified in the NFPA 33 standards.

Applicable Health and Safety Requirements Mandated in the CFR: The safety requirements that impact the recirculation/partition flow design are codified in 29 CFR 1910.94 (which governs minimum required ventilation flow rates that must be maintained in occupied paint spray enclosures), 29 CFR 1910.107 (which specifies exhaust system configuration requirements), and 29 CFR 1910.1000 (which governs worker exposure to hazardous constituent concentrations).[5,6,7]

29 CFR 1910.94 requires that, for spray enclosures in which non-electrostatic paint application equipment is used (such as the HVLP systems employed at Barstow MCLB), a minimum linear velocity of 100 feet per minute (fpm) must be maintained through the booth.[5] To ensure that this safety requirement is met for any and all equipment configurations that are encountered in the Barstow MCLB paint booths, the booth ventilation systems were designed to maintain a minimum 100 fpm linear velocity irrespective of the size or configuration of the workpiece that is coated. In addition, 29 CFR 1910.94 refers to NFPA Standard 33 and specifies that the solvent vapor concentrations remain below acceptable explosion limits; as indicated above, this requirement is met if the system is properly designed to conform with allowable worker exposure limits specified by OSHA.

29 CFR 1910.107 pertains to spray finishing operations in which flammable and combustible materials are employed.[6] In fact, subpart (d)(9) specifically states "Air exhaust from spray operations shall not be directed so that it will contaminate makeup air being introduced into the spraying area...". It further states "Air exhausted from spray systems shall not be recirculated". However, as indicated by OSHA in their interpretive letter (Figure 1), the objective of the 29 CFR 1910.107 prohibition is similar to that of the 29 CFR 1910.94 regulation; namely, it is intended to minimize fire and explosion hazards and is not related to worker health issues. The Figure 1 text continues to state that, if the recirculation system is designed to ensure compliance with worker exposure limits (codified in 29 CFR 1910.1000 and discussed in detail below), then the prohibition indicated in subpart (d)(9) is not applicable.

The purpose of 29 CFR 1910.1000 is to prevent worker exposure to excessive levels of hazardous airborne constituents; as such, OSHA has mandated that the hazardous constituent concentrations contained in the respirable air must remain below established safety limits.[7] Because the recirculation rate impacts the quality of respirable air in the booth (along with other factors such as airflow patterns in the booth, target configuration, etc.), it must be calculated based on these safety limits.

OSHA has defined three exposure limits below which the respirable air constituent concentrations must be maintained:

1) 8-hour time weighted average (TWA) constituent concentrations known as Permissible Exposure Limits (PELs).

2) 15-minute time weighted average (TWA) constituent concentrations known as Short Term Exposure Limits (STELs).

3) Ceiling limits referred to as Immediately Dangerous to Life and Health (IDLH). Under no circumstances are hazardous concentrations to exceed IDLH values.

The PEL is defined as the concentration at which no adverse health effects are expected for most workers exposed to the contaminant for eight hours per day, 5 days per week. Generally speaking, the PEL is the lowest exposure limit of those identified above, and therefore yields the most conservative safety limit.

In addition to OSHA, the National Institute of Occupational Safety and Health (NIOSH) and the American Conference of Governmental Industrial Hygienists (ACGIH) have established their own TWA levels for various time intervals that may also be used as guidelines for controlling worker exposure levels. Similar to the OSHA PEL values, the ACGIH Threshold Limit Values (TLVs) and the NIOSH Recommended Exposure Levels (RELs) are typically based on 10-hour time weighted average limits. Both NIOSH and ACGIH have also established short term limits and ceiling limits.

The NIOSH and ACGIH exposure limits are guidelines, and are not enforced by OSHA. However, there are numerous compounds for which NIOSH and/or ACGIH have established TWA limits, but OSHA has not; for example, OSHA has established only a ceiling limit of 0.1 mg/m^3 for hexavalent chromium (Cr^{+6}) as CrO_3, and does not currently have an 8 hour PEL for this compound. Conversely, NIOSH has proposed a 10 hour TWA value of 0.001 mg/m^3 as Cr^{+6} (rather than as CrO_3), which is considerably lower than the OSHA ceiling level. For the purpose of establishing safe and efficient recirculation rates under the EPA/USMC Technology Demonstration Program, the Cr^{+6} 10 hour TWA limit recommended by NIOSH was employed, as indicated in Appendix D. For chemicals with no established PEL or TLV, an exposure limit was either determined through review of published literature, or based on manufacturer's recommendations. These maximum exposure airborne chemical concentration limits (PELs, TLVs, or other limits) are referred to as TWAs throughout the remainder of this document.

For mixtures of hazardous constituents which are present in the respirable air, OSHA mandates that the additive effect of each constituent be considered in determining worker exposure limits. The OSHA additive rule for determining the bulk TWA for mixtures specifies that the sum of hazardous constituent concentrations divided by their respective TWAs must not exceed unity:

$$\sum_{i=1}^{n} \frac{[concentration]_i}{TWA_i} \leq 1 \qquad (1)$$

Where:

$[concentration]_i$ = Concentration of specific hazardous constituent

TWA_i = TWA of specific hazardous constituent

This equation, typically, is applied only to compound groups that have additive medical effects. However, to ensure more conservative results for the EPA/MCLB Technology Demonstration Program, all hazardous constituents were grouped together, and a single additive rule calculation was performed. Moreover, USMC staff elected to apply an additional safety factor of two in addition to the safety factor inherent in the PPE worn by the booth operators. Thus, the actual OSHA additive equation (subsequently referred to as OSHA Factor) employed to derive the partition height and associated recirculation rate for the EPA/USMC Technology Demonstration Program was:

$$\sum_{i=1}^{n} \frac{[concentration]_i}{TWA_i} \leq 0.65\ (Booth\ 1) \qquad \sum_{i=1}^{n} \frac{[concentration]_i}{TWA_i} \leq 0.5\ (Booths\ 2{,}3) \qquad (2)$$

<u>Other System Design Considerations</u>: Several other design elements were considered to derive the appropriate partition height (and associated recirculation rate) and to ensure compliance with OSHA safety requirements. For example, the tendency of paint overspray particulate to remain in the lower portion of the booth necessarily implies that the particulate will preferentially deposit in the filter medium located in the lower zone of the exhaust face. As the exhaust filter becomes loaded, the medium in the lower zone fills more rapidly, and; therefore, develops a relatively higher resistance (or pressure drop) compared to the medium in the upper zone. This can cause the ventilation air from the lower (highly contaminated) zone of the booth to migrate into the upper region of the exhaust face, thence into the recirculation stream. Under these conditions, the recirculated constituent concentrations could possibly exceed the safety levels mandated by OSHA.

This condition can be avoided by carefully monitoring and controlling the ventilation flow rates to maintain consistent operation irrespective of the pressure drop across the exhaust filters in front of the upper and lower plenums. Constant flow rates are maintained in the MCLB booths modified under the EPA/USMC Technology demonstration Program using variable frequency drive (VFD) controlled fan motors integrated with flow rate sensors; as the pressure drop across the lower exhaust face increases to the point where it impacts the exhaust flow rate, the sensors in the exhaust duct detect the change, and adjust the VFDs to maintain the correct flow rate.

Along with adequately addressing flow monitoring and control issues, a key element that should be incorporated in all recirculation system designs is a safety monitoring system which ensures that the hazardous constituent concentrations in the mixed recirculation/fresh make-up air remain below established safety levels. Although installing such a monitor is not required by either OSHA or NFPA, it is considered good engineering practice to do so because it provides an added level of worker safety. In the event that the monitor detects unacceptably high concentrations in the recirculation duct, the safety system should, at a minimum, activate a damper system that vents the recirculated air to atmosphere. This allows the booth to be flushed with 100 percent fresh make-up air, thereby returning the booth to a safe operating environment. Details relating to the MCLB paint booth safety monitors are provided in Section 2.3.

Other parameters that are critical for designing a safe and efficient recirculation/flow partition system include:

1) The hazardous constituent concentration profile at the exhaust face; this provides key stratification information necessary to determine the appropriate partition height. Extensive paint booth exhaust face testing was performed during the Baseline Characterization Study (Section 4) to derive the profile data required for determining the partition height.

2) The collection efficiency of the exhaust filter system; this is particularly critical for operations that rely on paints which contain inorganic hazardous constituents such as hexavalent chromium or phosphoric acid. For the Barstow MCLB Demonstration Program, three-stage high efficiency filters were installed in each of the paint booths to maximize particulate collection and, correspondingly, hexavalent chromium removal. The partition height calculations (discussed in Section 4) performed for each of the Barstow MCLB booths assumed a 99% filtration efficiency for hexavalent and total chrome.

3) Booth volumetric flow rate; this is dictated by the 100 fpm minimum velocity requirements established by OSHA and the booth cross sectional area.

2.1.2 Methodology for Calculating Partition Height

The first step in calculating the appropriate partition height is to derive a mathematical expression for the hazardous constituent concentrations occurring in the recirculation duct as a function of partition height. It is also necessary to define system limits with respect to the applicable safety standards. For example, USMC Staff provided guidance mandating that the partition height be selected to ensure that the limit established by Equation 2 apply to the recirculation air upstream of where it is mixed with fresh make-up air. By constraining the quality of the recirculated air as it exits the booth to the 0.5 OSHA Factor limit, a significant safety margin is included in the calculation, because no dilution factor benefit is considered in the final design.

The mathematical expression for determining a safe partition height is developed via a simple mass balance evaluation using standard control volume analysis techniques. The result of this analysis for non-steady state conditions yields an exponential expression in which time appears as an independent variable in the exponent. However, a more conservative result is obtained by assuming a steady state booth operation in which maximum (worst case) conditions prevail. Under steady state conditions, the mass balance equation at the booth intake face (Location A in Figure 5) reduces to:

$$(Q_r \times C_r) + (Q_m \times C_m) = (Q_b \times C_b) \tag{3}$$

Where:

Q_r = Volume Flow Rate of Recirculated Air
C_r = Hazardous Constituent Concentrations in Recirculated Air
Q_m = Volume Flow Rate of Fresh Makeup Air
C_m = Hazardous Constituent Concentrations in Fresh Makeup Air
Q_b = Volume Flow Rate Through Paint Booth
C_b = Hazardous Constituent Concentrations in Air Upstream of Painter Location

The first two terms in Equation 3 represent the constituent mass flow rates in the recirculation stream and the make-up air stream, respectively. The third term; therefore, defines the constituent mass flow rate at the booth intake face. If it is assumed that the makeup air is free of hazardous constituents, the mass balance equation at the intake face (Location A, Figure 5) simplifies to:

$$(Q_r \times C_r) = (Q_b \times C_b) \tag{4}$$

Similarly, under steady state conditions, the mass balance equation at the booth exhaust face (Location B, Figure 5) reduces to:

$$(Q_b \times C_b) + M_g = (Q_r \times C_r) + (Q_e \times C_e) \tag{5}$$

Where:

Q_e = Volume Flow Rate of Exhaust Air Vented to the APCS
C_e = Hazardous Constituent Concentrations in Exhaust Air Vented to the APCS
M_g = Hazardous Constituent Mass Generation Rate from Paint Application Process

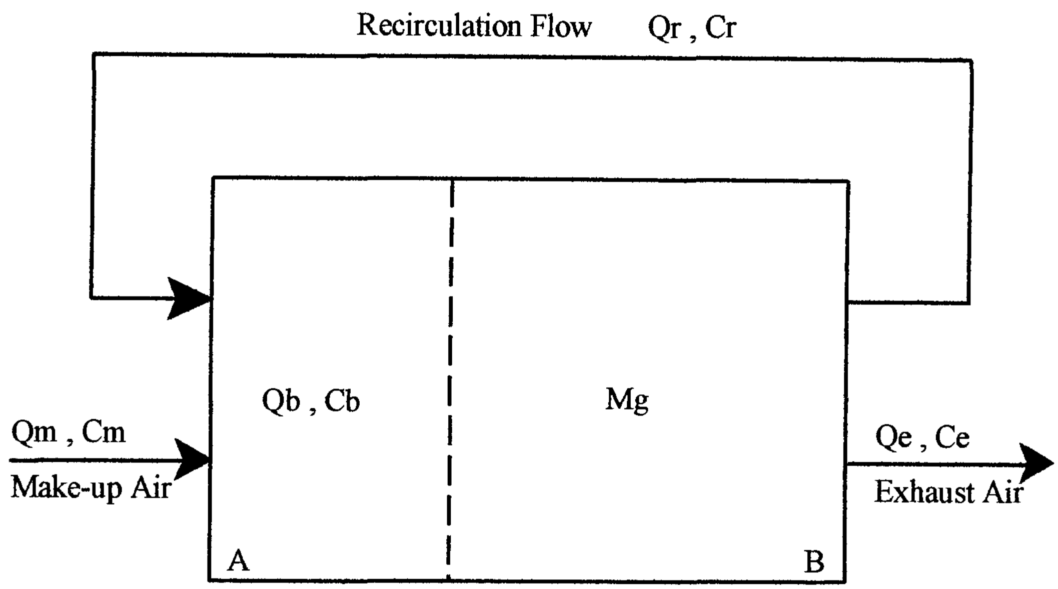


Figure 5. Paint booth control volume configuration for determining partition height.

The left side of Equation 5 represents the mass flow rate at the booth intake face and the hazardous constituent mass generated by the spraying operation occurring within the booth. The right side of Equation 5 defines the mass flow rate exiting the booth into the recirculation duct (Q_r x C_r) and into the exhaust duct vented to the APCS (Q_e x C_e). The constituent concentration profile at the booth exhaust face generated by the spray operation is not uniform, thus an additional relationship must be derived and incorporated into Equation 5 that relates the concentration profile at the exhaust face (Location B in Figure 5) to the constituent mass flow rate in the recirculation and exhaust streams. This relationship reduces Equation 5 to:

$$(Q_r \times C_r) = (Q_b \times C_b)(1 - \frac{a}{H}) + (M_g \times X) \quad (6)$$

Where:

a = Partition Height
H = Exhaust Face Height
X = Percent of Hazardous Constituents Generation in Booth Exiting above Height a

The second term in Equation 6 represents the hazardous constituent mass flow rate that is introduced at the intake face (Location A in Figure 5) which passes to the recirculation duct. The third term is the hazardous constituent mass flow rate contributed by the painting operation that passes to the recirculation duct. The mathematical expression defining the relationship between the constituent concentrations in the recirculation stream and the partition height (or recirculation rate) is derived by combining the booth intake face mass balance relationship (Equation 4) , with the booth exhaust mass balance expression (Equation 6):

$$C_r = \frac{M_g \times X}{Q_r \times (\frac{a}{H})} \tag{7}$$

The partition height and corresponding recirculation rate that yields acceptably low hazardous constituent concentrations in the booth intake stream may be derived iteratively from Equation 7. However, straightforward application of Equation 7 may not be necessarily appropriate, because filtration efficiency must be factored in for the solid or semi solid-phase constituents (e.g. isocyanate or hexavalent chromium containing aerosols). Moreover, the parameter X differs for the vapor phase and non vapor phase hazardous constituents due to particulate drop-out, flow patterns, etc. As such, it is apparent that the partition height and corresponding recirculation rate necessary to maintain safe intake concentrations depend on several booth operating parameters. The objective of the Phase I Baseline Study (discussed in detail in Section 4) was to accurately establish these operating parameters, which in turn were used to project safe and cost-effective recirculation system estimates.

2.2 UV/OZONE AIR POLLUTION CONTROL SYSTEM INNOVATIONS

A second innovation integrated into the EPA/USMC Technology Demonstration Program was the installation and operation of an efficient and cost-effective APCS that relies on ultraviolet light (UV) and ozone to successfully oxidize organic compounds present in the exhaust stream vented from the MCLB paint spray booths. The advantages of UV/Ozone systems over traditional thermal oxidation systems include:

High Energy Efficiency - The UV/Ozone system operates at ambient temperature, which eliminates the significant energy losses typically incurred by traditional APCS units that rely on high temperature oxidation. These traditional units must bring the control stream to elevated temperatures to ensure complete oxidation of the VOCs that are present.

Minimal Start-up Time - Because the UV/Ozone system operates at ambient temperature, it can switch from shut-down mode to fully operational in a matter of minutes. This is a significant advantage over traditional APCS systems, which often require continuous operation (such as in stand-by mode under minimal turn-down conditions), or significant start-up time to bring the unit to temperature prior to bringing the process on-line.

No Secondary Pollutants - The emission of secondary pollutants such as NO_X and CO (generated at elevated combustion temperatures) is virtually eliminated due to the low temperature operation of the UV/Ozone system.

Long Equipment Life - equipment integrity is maintained on a long term basis due to ambient temperature operation.

Low Cost Operation - The electricity cost of operating the UV lamps is much lower than the cost of supplying natural gas to traditional thermal systems.

The UV/Ozone technology involves a five step process to achieve adequate destruction efficiency. This process, illustrated schematically in Figure 6, comprises:

1) Direct Photolysis - Downstream of a particulate filter, the process exhaust stream is exposed to direct UV light to initiate oxidation.

2) Scrubber - The exhaust passes through a water scrubbing system where the miscible and water soluble compounds are transferred into the aqueous phase.

3) Adsorbing Media Module - Exhaust passes from the scrubber to an adsorbing media module which collects the remaining organics. The exhaust then vents to atmosphere.

4) Scrubber Water Clean-up - The scrubber liquid exiting the scrubber is treated with ozone to completely oxidize the collected organics; the liquid is then recycled back into the scrubber.

5) In-Situ Oxidation of Adsorbing Media - The organic compounds collected in the adsorbing module are oxidized via ozone which is introduced into the module during the media regeneration cycle.

The decision made by MCLB to install and operate a UV/Ozone system was motivated primarily by the numerous inherent advantages offered by this technology, as indicated above. Several UV/Ozone systems have been installed to control emissions from aerospace painting and depainting facilities, as well as other industrial coating process sources. The largest UV/Ozone system that has demonstrated long term operation is a 200,000 cfm system installed in 1992 in Arizona. The particular innovations encompassed by the MCLB UV/Ozone system were based on elements from the following:

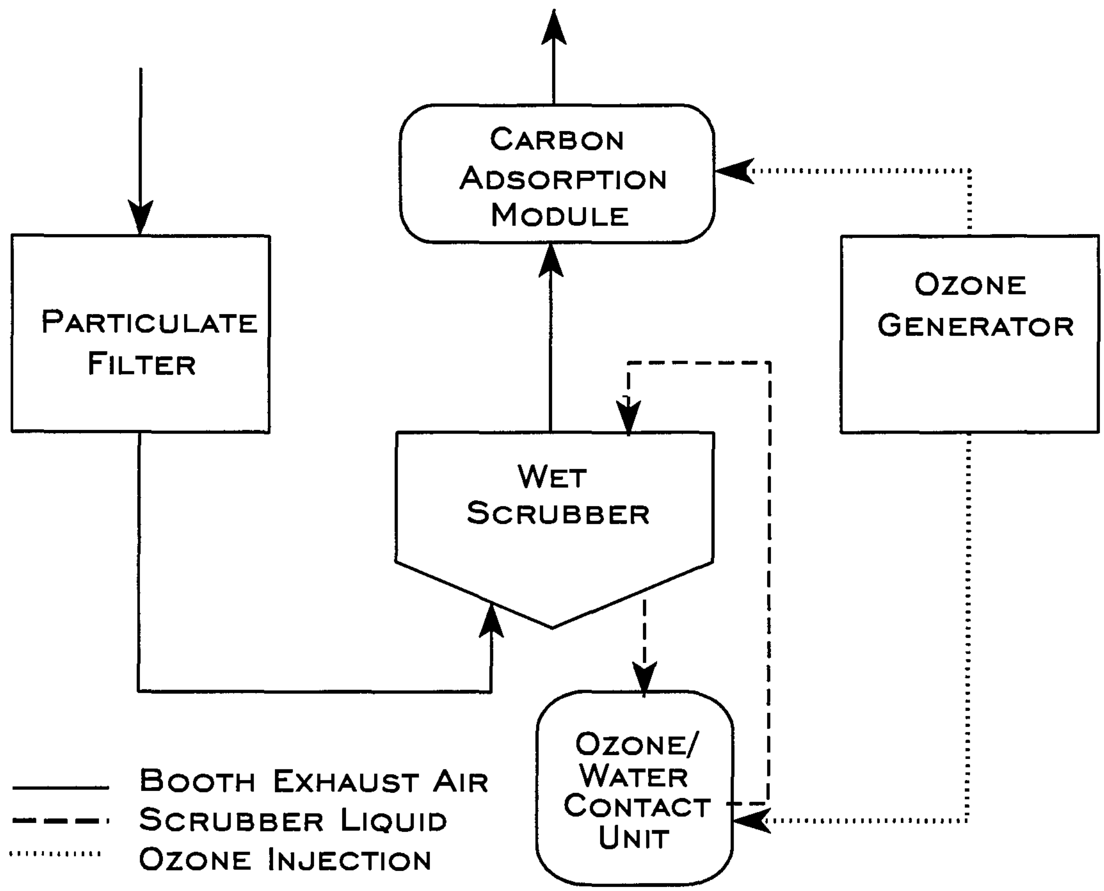


Figure 6. Schematic diagram of the UV/Ozone APCS system.

1) A detailed system research and development effort that was planned, managed and executed by the Applied Research Laboratory (ARL) at Pennsylvania State University (Penn State). The objective of this research was to identify process and system enhancements that may be implemented in full scale systems to further improve the destruction capabilities of the photolytic reactor (Step 1 of the UV/Ozone oxidation process).

2) A second research and development study, also performed by ARL, in which mechanisms were studied for improving the speed and efficiency of in-situ oxidation occurring in the adsorbing media module during the regeneration cycle.

3) Appropriate retrofit modifications and system adjustments to transfer the process and system enhancements developed by ARL into the full-scale MCLB UV/Ozone system.

The results of the ARL studies are summarized in a separate document that is published by the U.S. Marine Corps. To date, no modifications have been made to the MCLB UV/Ozone system to incorporate the system enhancements developed under the ARL research program. Therefore, the results of innovative UV/Ozone system enhancement activities undertaken at MCLB could not be included in this final report.

2.3 CONTINUOUS, SPECIATED ORGANIC CONCENTRATION MONITORING

A third innovation pioneered under the EPA/USMC Technology Demonstration Program is the development and installation of a fully automated continuous organic monitor which provides real-time, speciated organic concentration data. The monitor, which relies on Fourier Transform Infrared (FTIR) analysis, is employed as the safety monitoring device to continuously monitor hazardous constituent concentrations in the paint recirculation ducts. Continuous analyzers that have traditionally been used in this and other VOC monitoring applications rely on an ionization reaction to produce a signal which is proportional to the concentration of organic carbon present in the sample stream. The most common monitors of this type include flame ionization detectors (FIDs) and photoionization detectors (PIDs). It has long been recognized by industrial facilities and regulatory agencies alike that ionization detectors in general, and FIDs in particular, have significant drawbacks that limit their applicability and impact their performance and cost effectiveness. These limitations include:

Non-Specificity - The measured results are reported in units of parts per million of carbon (ppm_C) or propane, thus speciated organic concentration data is not provided. This is of particular concern when monitoring process streams in which the relative concentrations of various organic components vary significantly over time (such as in paint booth operations). For example, a 480 ppm_C measurement made by an FID could indicate the presence of either 120 ppm of methyl ethyl ketone (MEK), 80 ppm of methyl isobutyl ketone (MIBK), or 120 ppm of 2-butanol. Non-specificity problems are compounded in the recirculation duct monitoring application, because the OSHA PELs for these compounds differ significantly; the OSHA PELs for MEK, MIBK, and 2-butanol are 200 ppm, 100 ppm, and 100 ppm, respectively. Thus, in this example, it is not possible to determine if recirculation stream concentrations exceed the PEL (2-butanol), are approaching the PEL, (MIBK) or are well below the PEL (MEK).

Response factor variability - Ionization detectors do not respond linearly as a function of the number of organic carbon molecules present in the sample stream. A linear response implies that there is a one-to-one correspondence between the ppm_C value reported by the instrument and the actual number or organic carbon atoms that are present. For example, sample streams containing 100 ppm of xylene and MEK should correspond to FID measurements of 800 ppm_C and 400 ppm_C, respectively. However, the FID may actually indicate only 700 ppm and 380 ppm_C due to the non-linear characteristic of the instrument response. Note that the non linearity (referred to as response factor) varies as a function of compound. Thus a drop in ppm_C level measured by an FID could indicate a change in sample stream constituents, or a change in concentration, or both.

Excessive calibration and fuel gas requirements - It is necessary to frequently calibrate FIDs and PIDs to ensure accurate and reliable data. Furthermore, FIDs require a source of hydrogen gas as a fuel supply for the ionizing flame. While these calibration and fuel gas requirements are not impossible to meet, they tend to increase instrument operating and maintenance costs in continuous monitoring applications.

In an effort to maximize operational flexibility and data accuracy, and minimize system maintenance and operating requirements, the EPA, in concert with MCLB, elected to evaluate alternatives to ionization detectors for use in the recirculation safety monitoring system. The FTIR technology was selected for several reasons, including:

Real-Time, Speciated Organic Concentration Results - The FTIR provides concentration results for the organic hazardous constituents of concern that are present in the recirculation stream on a real time basis. Data are collected and analyzed in sampling intervals of less than 30 seconds.

Real-Time OSHA Compliance Assessment Capabilities - Because the FTIR provides real-time constituent concentration results, it is possible to determine the OSHA compliance status of the recirculation stream on a continuous basis. This is accomplished by programming the instrument control software to derive the additive OSHA Factor (Equation 2) for each measurement event.

Significantly Reduced Calibration Gas and Instrument Maintenance Requirements - The instrument requires neither fuel gas nor calibration gases to operate effectively. However, because this is a new application for this technology, and because of the importance of the safety monitoring system, it was decided to program the instrument control software to collect a reference spectrum with an appropriate check gas twice a day. This will provide a means of assessing instrument stability on a long term basis. This check may be discontinued after a period yet to be determined.

Despite the clear advantages of FTIR over other candidate monitoring systems, it was recognized that a continuously operated, fully automated FTIR system had never before been attempted in any application similar to that required by the recirculation safety system. It was; therefore, necessary to perform a detailed evaluation to assess the effectiveness and overall applicability of FTIR in this operation.

As part of this evaluation, a side-by-side comparison between traditional organic sampling methods and FTIR measurement procedures was conducted. This comparison, which involved collecting FTIR data simultaneously with integrated air toxic samples and continuous FID data, was performed during the source test activities undertaken as part of the Phase III Demonstration Study. The results of this analysis are summarized in Section 6. It is anticipated that the successful demonstration of FTIR in such a difficult and demanding application will provide a basis for further expanding the general acceptability of this versatile and highly useful technology.

SECTION 3

SITE DESCRIPTION

The U.S. Marine Corps Multi-Commodity Maintenance Center (MC^3) near Barstow, California provides extensive vehicle and ground equipment maintenance support services to the Marine Corps as well as other DOD operations. The facility provides a covered work space that spans 10 acres and houses 1,066 employees skilled in 78 different trades. There are 500 product lines operated within the enclosure, which rebuilds and refinishes up to 250 vehicles per month. MC^3 encompasses numerous industrial process operations, such as metal finishing, plating, equipment cleaning and repair, etc; many of which generate emissions of criteria and air toxic pollutants. In particular, the surface priming and painting operations at MC^3 are sources of significant VOC emissions, which made these sources prime candidate sites for the EPA/USMC Technology Demonstration Program.

This section describes the general location and configuration of three paint booths that were modified for this Demonstration Program, and provides booth-specific information that was employed during the Baseline and Technology Demonstration Studies, and while developing the retrofit modification packages. The paint booth modification efforts and the APCS design/ installation efforts were undertaken by separate contractors. However, the paint booth and APCS installation efforts were coordinated sufficiently to ensure the booth ventilation system operation and controls were adequately integrated with the APCS operation.

The sites targeted by the Demonstration Program are three paint booths located in the Northwestern sector of Building 573, in the Yermo Annex of Barstow MCLB. A schematic diagram indicating the locations and relative positions of the three paint booths and the UV/Ozone APCS is provided in Figure 8. Most of the coatings used in these booths are in the Marine Corps CARC (Chemical Agent Resistant Coatings) system, which includes wash primers, epoxy primers, and polyurethane topcoats.

3.1 BOOTH 1 GENERAL DESCRIPTION AND OPERATING CHARACTERISTICS

Booth 1 is a large vehicle drive-through paint booth that is primarily used for applying polyurethane topcoat to 2.5 and 5 ton armored personnel vehicles (APVs), Humvees, and other Marine Corps vehicles. Occasionally other types of equipment are painted in Booth 1 as well, such as helicopters and containers. The Booth 1 operating profile differs significantly from the profiles for Booths 2 and 3 in that it is used exclusively for topcoat applications; wash primer and epoxy primer are never used in Booth 1. This is significant, because the hazardous constituent concentrations in the polyurethane topcoat consist primarily of organic compounds,

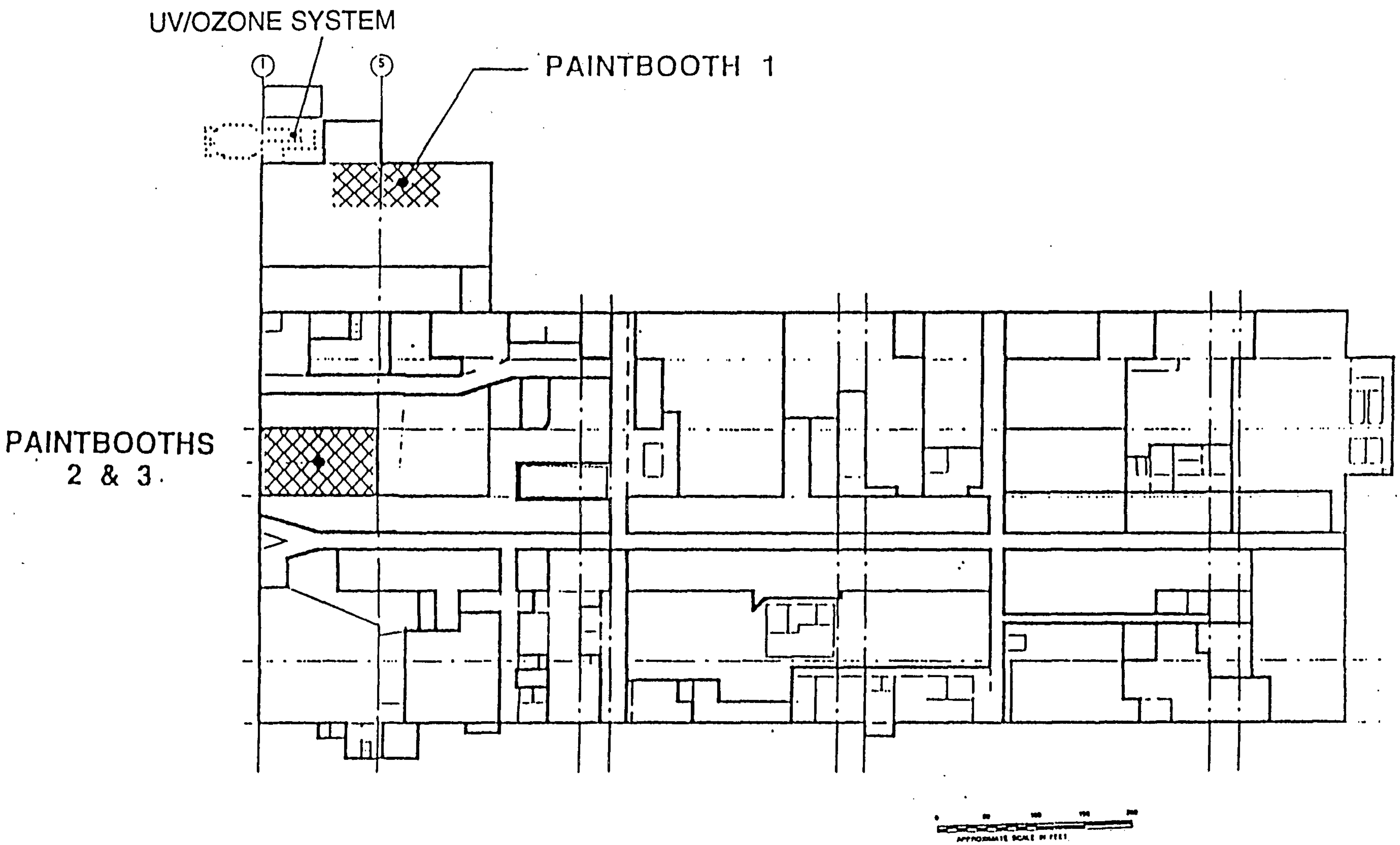


Figure 7. Schematic Diagram Indicating Location and Relative Position of the Paint Booths and APCS Targeted by the Demonstration Program.

thus the solvent constituent concentrations in the topcoat material tend to dominate the recirculation/flow partition calculation (Equations 2 and 7).

A schematic diagram of Booth 1 indicating the general arrangement of the recirculation and exhaust ducts is provided in Figure 8. The booth is approximately 5.5 meters (18 feet) high, 6.1 meters (20 feet) wide, and 18.2 meters (60 feet) deep. It is equipped with a cross draft ventilation system in which intake air is introduced into the front of the booth via an intake plenum. As the ventilation air passes through the booth, it picks up overspray particulate and solvent vapors. It then exits the booth and either passes to the APCS (if taken from below the partition), or is recirculated back into the booth (if taken from above the partition).

3.2 BOOTH 2 GENERAL DESCRIPTION AND OPERATING CHARACTERISTICS

Booth 2 is a cross draft facility equipped with an overhead conveyor system. The conveyor, which is used to transport equipment components and other items into the booth, facilitates painting by suspending the workpieces so that they are accessed easily and uniformly coated. Equipment that is painted in Booth 2 include small vehicle components such as wheel assemblies, battery cases, vehicle suspension components, etc. Although numerous coatings may be applied in Booth 2, the CARC system consisting of wash primer, epoxy primer, polyurethane topcoat and thinners is primarily used (> 87%). A component of the CARC wash primer is strontium chromate, which contains chromium in the hexavalent form. The OSHA PEL for hexavalent chromium is quite low. In fact, wash primer material usage proved to be the critical parameter in determining the Booth 2 partition height (which determines the recirculation rate).

Although only one painter is typically stationed in Booth 2 during normal operations, all tests conducted throughout the Demonstration Program on Booth 2 involved two painters. Therefore, the Booth 2 tests were conducted at high usage conditions to reflect worst case operations and therefore ensure conservative results and safe operation of the recirculation system. The results of the Phase III Technology Demonstration Study presented in Section 6 indicate an adequate safety margin to ensure that two painters can safely operate in Booth 2 if necessary.

A schematic diagram of Booth 2 indicating the general arrangement of the recirculation and exhaust ducts is shown in Figure 9. The booth is approximately 3.0 meters (10 feet) high, 9.1 meters (30 feet) wide, and 6.1 meters (20 feet) deep. It is equipped with a cross draft ventilation system in which intake air is introduced through the ceiling at the front of the booth; fresh make-up air which is taken from the area surrounding the booth is also drawn through the ceiling via a perforated plate. As the ventilation air passes through the booth, it picks up overspray particulate and solvent vapors. It then exits the booth and is either passed to the APCS (if taken from below the partition), or is recirculated back into the front of the booth (if taken from above the partition).

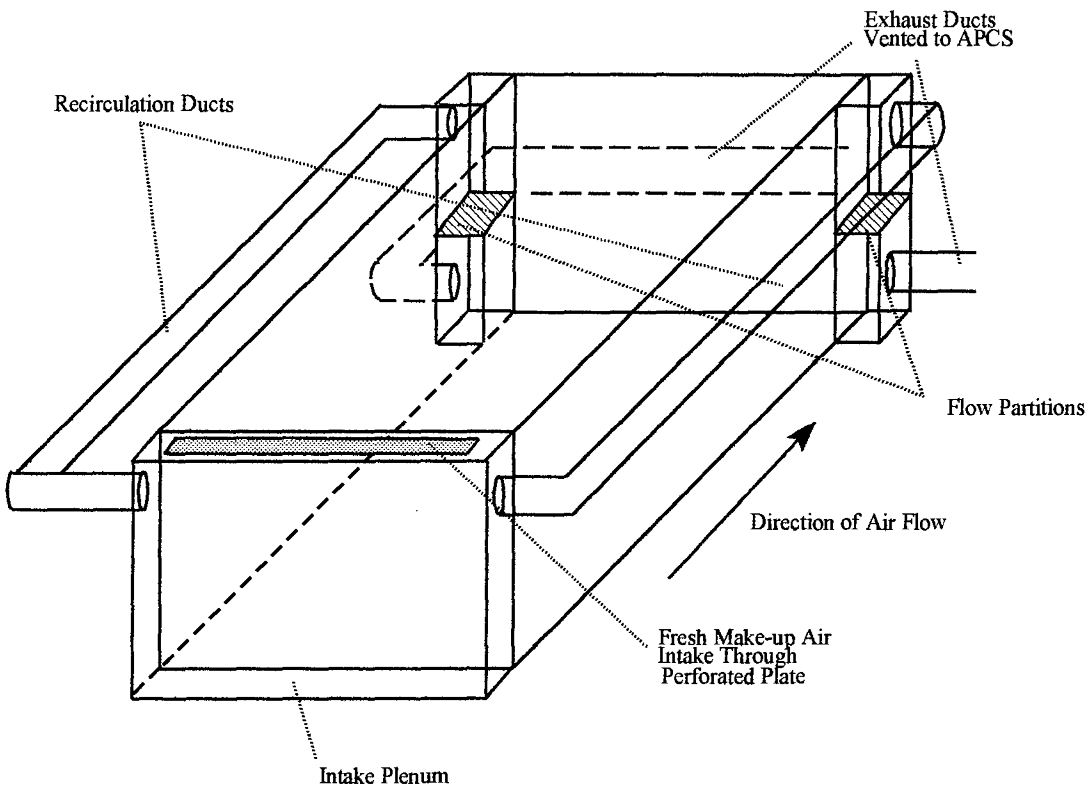


Figure 8. Schematic Diagram of MCLB Booth 1.

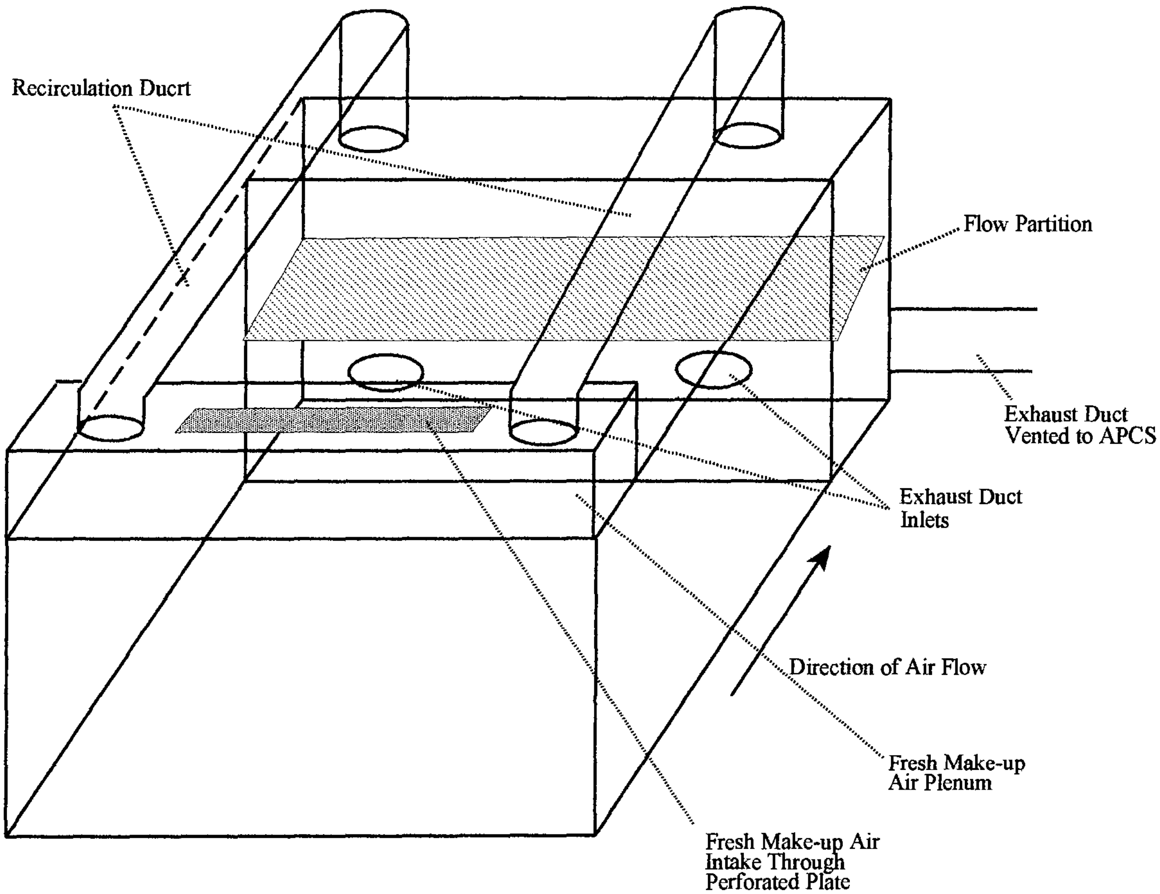


Figure 9. Schematic Diagram of MCLB Booth 2.

Booth 2 was originally constructed with an open face configuration, thus the painter typically operated outside the minimal enclosure that the open face booth provided. As is typical for open face paint booths, the volume flow rate exhausted from Booth 2 prior to modification was quite high to ensure that adequate ventilation is provided in the vicinity of the painter. By enclosing the work area as part of the retrofit modifications, the volume flow rate through Booth 2 was significantly reduced. A second advantage of enclosing Booth 2 is that the fugitive emissions previously released from the open face are now collected, and a capture efficiency of 100 percent is achieved.

3.3 BOOTH 3 GENERAL DESCRIPTION AND OPERATING CHARACTERISTICS

Booth 3 is a cross draft enclosure that houses a parts coating operation and which was moved from another area in Building 573. Booth 3 may be equipped with a pallet transportation system; large equipment components that are placed on a pallet may be transported into and through the booth on rollers. Although numerous coating materials may be applied in Booth 3, it is anticipated that the CARC system consisting of wash primer, epoxy primer, polyurethane topcoat and thinners will be used primarily. As with Booth 2, the presence of hexavalent chrome in the CARC wash primer tends to drive the Booth 3 partition height calculation. Although Booth 3 is typically used on an intermittent basis, the recirculation duct tests conducted in Booth 3 during the Demonstration Study were performed at very high usage rates to simulate worst case conditions (see Section 6).

A schematic diagram of Booth 3 that indicates the general arrangement of the recirculation and exhaust ducts is provided in Figure 10. The booth is approximately 3.0 meters (10 feet) high, 6.7 meters (22 feet) wide, and 3.0 meters (10 feet) deep. It is equipped with a cross draft ventilation system in which intake air is introduced through a wall of filters via an intake plenum. Fresh make-up air which is taken from the area surrounding the booth is drawn into the intake plenum via a perforated plate, where it is mixed with the recirculated air. As the ventilation air passes through the booth, it picks up overspray particulate and solvent vapors. It then exits the booth and either passes to the APCS (if taken from below the partition), or is recirculated back into the front of the booth (if taken from above the partition).

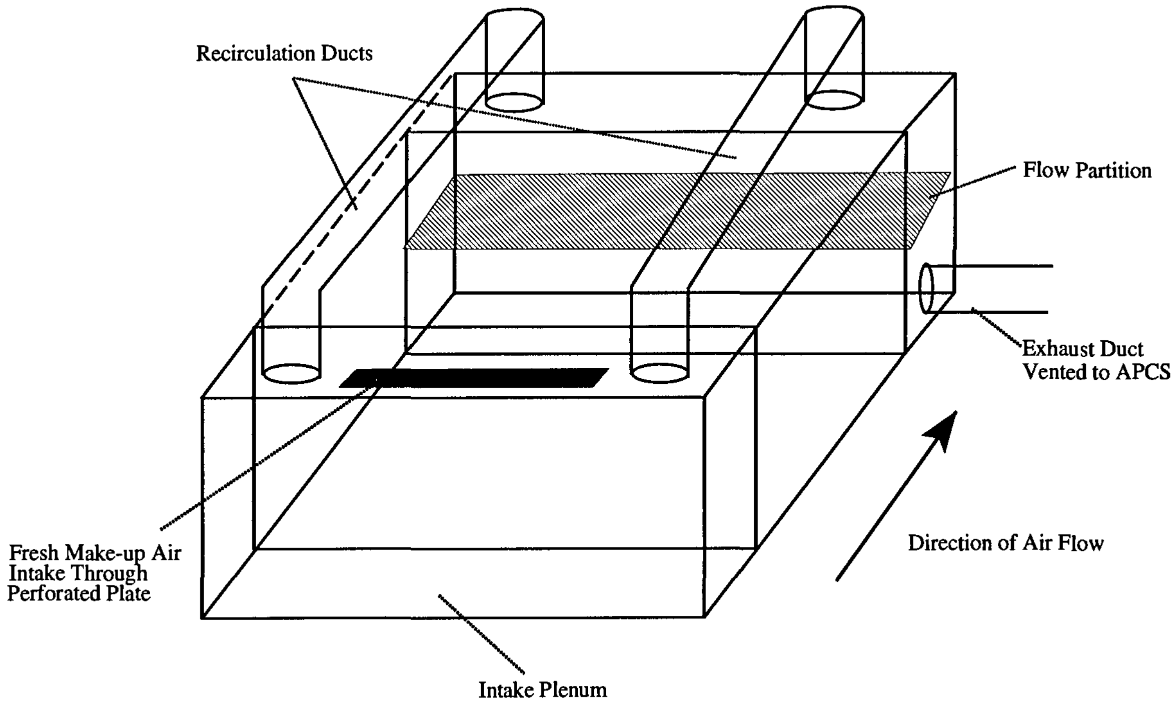


Figure 10. Schematic diagram of MCLB Booth 3.

SECTION 4

BASELINE CHARACTERIZATION STUDY RESULTS

An extensive baseline evaluation of the MCLB paint spray booths was performed in the Fall of 1993 to collect relevant process operating and emissions data used to properly design the recirculation/partition flow system, and to develop a pre-modification data set for subsequent comparison to data collected after modifications are completed. The results of this Baseline Study are summarized in Section 4.1. A summary of the recirculation calculations derived from the Baseline Study data and a general discussion regarding the overall flow rate reductions projected for each booth is provided in Section 4.2.

To ascertain whether or not Booth 1 operating characteristics had changed during the two year interval between the Baseline Study (Fall, 1993) and the booth modification activities, (Fall, 1995) a second Booth 1 characterization test was performed in the Fall of 1995 immediately prior to initiating booth modification activities. The results of the Pre-retrofit Characterization are summarized briefly in Section 4.3.

4.1 BASELINE STUDY RESULTS AND CONCLUSIONS

The Baseline Study was performed in the Fall of 1993; the objective of this study was to gather sufficient MCLB paint booth process operating data to project a reasonable and safe partitioned recirculation system. As indicated in Section 2, the parameters necessary to derive the partition height and the resulting recirculation rate include:

- Solid and vapor phase hazardous constituent concentration profiles at the exhaust face
- Particulate collection efficiency of the exhaust filter
- Vapor phase hazardous constituent release rates from the paint gun
- Paint booth volumetric flow rates

The Baseline Study characterized each of these parameters for Booths 1 and 2. As discussed in Section 2, Booth 3 design parameters were developed from engineering estimates because Booth 3 involved new construction. In Booths 1 and 2, hazardous constituent concentration measurements were also collected in the vicinity of the paint booth operator outside of the supplied-air respirator (personal protection equipment [PPE]). The objective of the painter vicinity tests was to obtain general air quality data in the areas in which the painter operates and assess the performance of the existing ventilation system in providing adequately safe working conditions.

The test matrix developed and implemented for the Baseline Study is summarized in Table 1. The Baseline Study results are briefly summarized in Sections 4.1.1 and 4.1.3. Detailed information relating to the sampling and analysis methods are summarized in Appendices A and B, respectively. Tabulated results of these sampling and analysis efforts are provided in Appendix C.

4.1.1 Booth 1 Baseline Study Test Results and Assumptions Employed in Partition Height Calculations

The constituent concentration profile results and painter vicinity data obtained from the Booth 1 source testing activities are summarized in Table 2. These concentration profile results were derived from exhaust filter face measurements and were used to define the parameter "X" in Equation 7. The exhaust duct flow rate and concentration measurement results used to define the Booth 1 recirculation rates are summarized in Table 3. From these results, the following assumptions were made to derive the input data for the Booth 1 recirculation/flow partition calculations (defined by Equation 7):

1) The maximum organic concentrations measured in the Booth 1 exhaust ducts were used for the organic mass release rate parameter.

2) The maximum zinc and total chromium measurement results were used for the inorganic compound concentrations; all chromium was assumed to be in the trivalent form.

3) The worst case results (highest detection limit) for hexamethylene diisocyanate (HDI) measured in the Booth 1 exhaust ducts were used for the HDI release rate parameter.

4) A volume flow rate of 962 m^3/min (34,000 cfm) is required in Booth 1 to maintain compliance with the 100 fpm minimum velocity requirement mandated by OSHA. However, the Baseline Study data indicate that Booth 1 exceeded this minimum flow rate by a significant margin (Table 3). It was therefore concluded that variable frequency drive (VFD) fans could safely reduce Booth 1 flow rates while maintaining compliance with the minimum ventilation requirements mandated by OSHA.

The initial Booth 1 recirculation/flow partition calculation results indicated that the optimal partition height was 2.68 meters (8.8 feet). However, during the detailed design phase (discussed in Section 5), it was decided that the Booth 1 ventilation system would operate more efficiently if an extra row of filters was added to the Booth 1 exhaust face. The optimal partition height yielding and OSHA Factor of 0.65 was then re-calculated at 2.65 meters (8.7 feet).

Table 1. Test Matrix for Baseline Study.

	Objective	Location	Parameter	Sampling Method
Booth 1	Determine stratification	Exhaust faces	Metals Isocyanates Speciated organics Particulate Flow rate	NIOSH 7300[8] OSHA 42[9] NIOSH 1300[10] NIOSH 500[11] Anemometer
	Determine exhaust concentrations	Exhaust ducts	Metals Isocyanates Speciated organics Total organics Particulate Flow rate	EPA Method 0060[12] NIOSH 5521[13] NIOSH 1300[10] EPA Method 25A[14] NIOSH 500[11] Anemometer
	Establish OSHA Factor in the vicinity of the paint booth operators	Vicinity of paint booth operators	Metals Isocyanates Speciated organics Particulate	NIOSH 7300[8] NIOSH 5521[13] NIOSH 1300[10] NIOSH 500[11]
	Compare collection efficiency of existing filtration system to the high performance filtration system.	Exhaust face with standard filters	Particulate at face Particulate in ducts Flow rate	NIOSH 500[11] EPA Method 5[15] EPA Method 2[16]
		Exhaust face with high performance filters	Particulate at face Particulate in ducts Flow rate	NIOSH 500[11] EPA Method 5[15] EPA Method 2[16]
Booth 2	Determine stratification	Exhaust faces	Metals Speciated organics Particulate Flow rate	NIOSH 7300[8] NIOSH 1300[10] NIOSH 500[11] Anemometer
	Determine exhaust concentrations	Exhaust ducts	Metals Speciated organics Total organics Flow rate	NIOSH 7300[8] NIOSH 1300[10] EPA Method 25A[14] Anemometer
	Establish OSHA Factor in the vicinity of the paint booth operators	Vicinity of paint booth operators	Metals Speciated organics Particulate	NIOSH 7300[8] NIOSH 1300[10] NIOSH 500[11]

1 The Baseline Study QAPjP refers to this method as the EPA Draft Method 29 Multi-Metals Sampling Procedure. In the time interval since the Baseline Study was completed, EPA finalized the draft method and now refers to it as Method 0060. The name change is reflected in this Table.

Table 2. Baseline Study Average Concentration Profile and Painter Vicinity Test Results for Booth 1 (unless indicated, all units are mg/m^3).

Height m (feet)	MEK	Ethyl-benzene	Xylenes	n-Butyl acetate	MIAK	Toluene	n-Butyl alcohol[1]	Hexyl acetate	PGMEA[1]	Total Chrome[2]	Zinc	HDI
3.9 (12.8)	2.2	0.7	3.0	2.6	28	0.9	0.06	0.3	0.2	0.007	0.12	0.0008
2.9 (9.5)	6.2	3.2	13	11	120	2.5	0.08	2.0	0.7	0.022	0.29	0.0020
2.4 (7.8)	7.7	3.9	17	14	170	3.2	0.07	2.8	1.3	0.031	0.46	0.0039
1.85 (6.1)	8.7	4.8	20	17	190	3.6	0.07	2.9	1.2	0.049	0.71	0.0050
1.4 (4.5)	10.2	5.9	25	21	270	4.3	0.16	4.1	1.1	0.052	0.82	0.0062
0.33 (1.1)	7.6	4.2	19	16	200	3.2	0.07	3.2	1.0	0.032	0.50	0.0039
Painter Vicinity[3] (avg)	16.9	10.2	47	39	400	8.2	0.11	6.2	1.1	0.0087	0.013	0.0040

[1] These compounds were measured at or below the method detection limit, thus to ensure conservative results in the recirculation/flow partition calculations, the detection level concentration was assumed.

[2] As indicated in Section 2, Booth 1 is used only for topcoat applications, and therefore only trivalent chromium is present in Booth 1.

[3] These results are averaged over all the Booth 1 painter vicinity test data collected. These results correspond to an average OSHA Factor of 1.3, with an OSHA Factor range of 1.0 to 1.6.

Table 3. Exhaust Duct Constituent Concentration and Flow Rate Data Obtained from Booth 1 Baseline Study.

Parameter	North Duct Concentrations (mg/m^3)	South Duct Concentrations (mg/m^3)
MEK	4.0	5.2
Ethylbenzene	3.3	3.0
Xylenes	17	9.6
n-Butyl acetate	13	7.7
MIAK	95	110
Toluene	2.1	2.6
n-Butyl alcohol[1]	0.09	0.04
Hexyl acetate	2.2	3.3
PGMEA	1.3	0.74
Total Chromium	0.00	0.00056
Zinc	0.037	0.063
HDI [1]	7.14	7.14
Flow Rate m^3/min (cfm)	1,367 - 1,625 (48,266 - 57,394)[2]	

1 The concentrations measured were essentially at the method detection limit, thus this limit was employed in the recirculation/flow partition calculation.

2 The Booth 1 exhaust flow rate tended to decrease throughout the test as a result of the exhaust filters gradually loading up with paint overspray particulate. To maintain compliance with OSHA requirements mandated in 29 CFR 1910, the minimum Booth 1 volume flow rate required is 963 m^3/min (34,000 cfm), thus these flow rates significantly exceed the levels mandated by OSHA.

4.1.2 Booth 2 Baseline Study Test Results and Assumptions Employed in Partition Height Calculations

The constituent concentration profile results and painter vicinity data obtained from the Booth 2 source testing activities are summarized in Table 4. These concentration profile face results were derived from exhaust filter face measurements and were used to define the parameter "X" in Equation 7. The exhaust duct flow rate and concentration measurement results that were used to define the Booth 2 recirculation rates are summarized in Table 5. As discussed in Section 2, the configuration of the Booth 2 exhaust system did not lend itself to accurate flow rate or isokinetic sampling, thus the flow rate data reported in Table 5 were derived from anemometer measurements taken at the exhaust face. Similarly, the metal concentration values assumed in the Booth 2 recirculation/flow partition calculations were derived from the exhaust face chromium concentration profile. From these results, the following assumptions were made to derive the input data for the Booth 2 recirculation/flow partition calculations:

1) The maximum organic concentrations measured in the Booth 2 exhaust ducts were used for the organic mass release rate parameter.

2) Based on the Booth 2 measurement results and observations made during the painting activities, it was determined that substantially more than half of the total chromium released in Booth 2 exists in the less toxic trivalent form. To derive more conservative results for the Booth 2 recirculation/flow partition calculation, it was therefore assumed that one half of the Booth 2 total chromium is in the hexavalent state, and one half is in the trivalent state.

3) A 99-percent filtration efficiency (by weight) was assumed for the advanced filtration system.

4) The ratio of zinc to hexavalent chromium concentration in Booth 2 is equal to the ratio measured in Booth 1 during the single wash primer test. This is a reasonable assumption, because zinc is present only in the wash primer; it is not a topcoat component.

5) The HDI to MIAK mass ratio measured for Booth 1 was employed to estimate the Booth 2 exhaust duct HDI concentrations for the recirculation/flow partition calculation.

The results reported in Tables 4 and 5 were coupled with engineering estimates and operating data to derive the input data for the Booth 2 recirculation/flow partition calculations. Moreover, only one painter typically operates in Booth 2, yet two painters were operating in Booth 2 during the exhaust face and exhaust duct sampling activities. Taking into consideration all of these issues, the optimal Booth 2 partition height yielding an OSHA Factor of 0.5 was calculated at 2.04 meters (6.7 feet). Moreover, because this partition height was determined assuming that 2 painters operate in the booth, it ensures extremely conservative operation of the recirculation system, and a safe operating environment for the worker.

Booth 2 was originally constructed in an open face configuration such that the paint booth operators were positioned outside of the enclosure during paint application. To ensure adequate ventilation air around the painter operating outside the booth, the volume flow through an open face booth is typically much higher than is required for an enclosed booth. It was recognized that one of the major benefits of modifying and enclosing Booth 2

Table 4. Baseline Study Average Concentration Profile Results for Booth 2 (unless indicated, all units are mg/m^3).

Height m (feet)	MEK	Ethyl Benzene	Xylenes	n-Butyl Acetate	MIAK	Toluene	n-Butyl Alcohol	Hexyl Acetate	PGMEA	Chrome[1]
2.7 (9.0)	2.1	0.21	0.57	0.54	4.6	2.4	5.4	0.15	0.03	0.039
2.1 (7.0)	5.6	0.64	2.5	0.28	18	4.4	6.7	1.7	0.21	
1.7 (5.7)	11	1.6	6.2	7.2	44	12	21	4.0	0.6	0.12
1.3 (4.3)	18	2.8	11	12	76	18	28	7.5	1.2	0.22
0.9 (3.0)	18	2.6	9.7	11	76	18	28	8.5	1.1	0.17
0.3 (1.0)	352	1.8	8.2	14	35	22	26	12	0.09	

1 The chromium measurements were taken during the second test series conducted under the Baseline Study (see Section 2). These measurements were taken at the following heights: 8.75 ft., 6.25 ft., 3.75 ft., and 1.25 ft.

Table 5. Exhaust Duct Constituent Concentration and Flow Rate Data Obtained from Booth 2 Baseline Study.

Parameter	North Duct (mg/m^3)	South Duct (mg/m^3)
MEK	3.0	8.5
Ethyl benzene	0.19	1.7
Xylenes	0.89	6.3
n-Butyl acetate	0.54	5.8
MIAK	6.3	59
Toluene	6.2	3.1
n-Butyl alcohol[1]	7.2	0.08
Hexyl acetate	2.3	1.6
PGMEA[1]	0.04	0.04
Flow Rate[2] m^3/min (cfm)	1,435 - 1,922 (50,700 - 67,900)	

1 The concentrations measured were essentially at the method detection limit, thus this limit was employed in the recirculation/flow partition calculation.

2 The Booth 2 exhaust ducts were not adequately configured to enable accurate flow rate measurements or isokinetic sampling. The flow rate values reported here were derived from anemometer data collected at the exhaust face. Note also that the Booth 2 flow rates tended to decrease throughout the Baseline Study as a result of the exhaust filters gradually loading up with paint overspray particulate.

for recirculation was that the overall flow rate through the booth would be significantly reduced; this is because the minimum flow rate required by OSHA after enclosing Booth 2 is 906 m^3/min (32,000 cfm) as opposed to the 1,678 m^3/min (59,300 cfm) average determined for Booth 2 in the open face configuration (see Table 5).

It was further hypothesized that the overall Booth 2 ventilation characteristics and quality of the air in the painter vicinity would improve, because the painter would operate in a fully ventilated area (e.g. the air flow rate in the vicinity of the painter would be a consistent 100 fpm). As such, the ventilation air in the reconfigured booth would be more effective at moving contaminants away from the paint booth operator. To test this hypothesis, some constituent concentration samples in the vicinity of the Booth 2 painters were collected during the Baseline Study. The results of these measurement activities are provided in Table 6, which summarizes three sets of total chromium measurement results and two sets of sets of organic concentration data. As discussed in detail in Section 6, the Table 6 results were compared with similar test data collected during the Technology Demonstration Study; the results of this comparison clearly indicate that the quality of ventilation air in the painter vicinity was significantly improved by enclosing Booth 2 and improving the ventilation system.

Table 6. Constituent Concentrations in Booth 2 Painter Vicinity.

	Constituent	Test 1	Test 2	Test 3	Average
Metals	Total Chromium	0.084	0.106	0.024[1]	0.095
Organics	MEK	6.6	4.2		5.4
	Ethylbenzene	0.76	0.04		0.4
	Total Xylenes	2.9	0.22		0.026
	Butyl acetate	3.8	0.16		1.9
	MIAK	19	1.2		10
	Toluene	2.5	3.3		2.9
	n-Butyl alcohol	< 0.06	3.9		1.9

1 The Test 3 measurement was taken in the vicinity of the painter applying the primer, which contains hexavalent chromium. The Test 1 and 2 samples were collected in the vicinity of the painter applying topcoat, which contains trivalent chromium. Note that the chromium concentration in the vicinity of the painter applying primer is significantly lower than the concentrations in the vicinity of the painter applying topcoat; these results indicate that trivalent chromium comprises the bulk of the total chromium present in Booth 2.

4.1.3 Booth 3 Profile and Emission Rate Estimates Employed in Partition Height Calculations

It was not possible to perform a detailed evaluation of Booth 3 because the booth was not fully functional at the time of the Baseline Study. Thus engineering estimates of the exhaust face constituent concentration profiles and exhaust duct constituent concentrations were developed to derive appropriate input data for the recirculation/flow partition calculations. These estimates were developed from booth configuration considerations, process operating information, and the source test results obtained for Booths 1 and 2. The following information was employed to develop the estimated profile illustrated in Figure 12 and establish appropriate partition height calculation input data:

1) The total Booth 3 coating usage was projected to be one eighth to one quarter of Booth 2 usage.

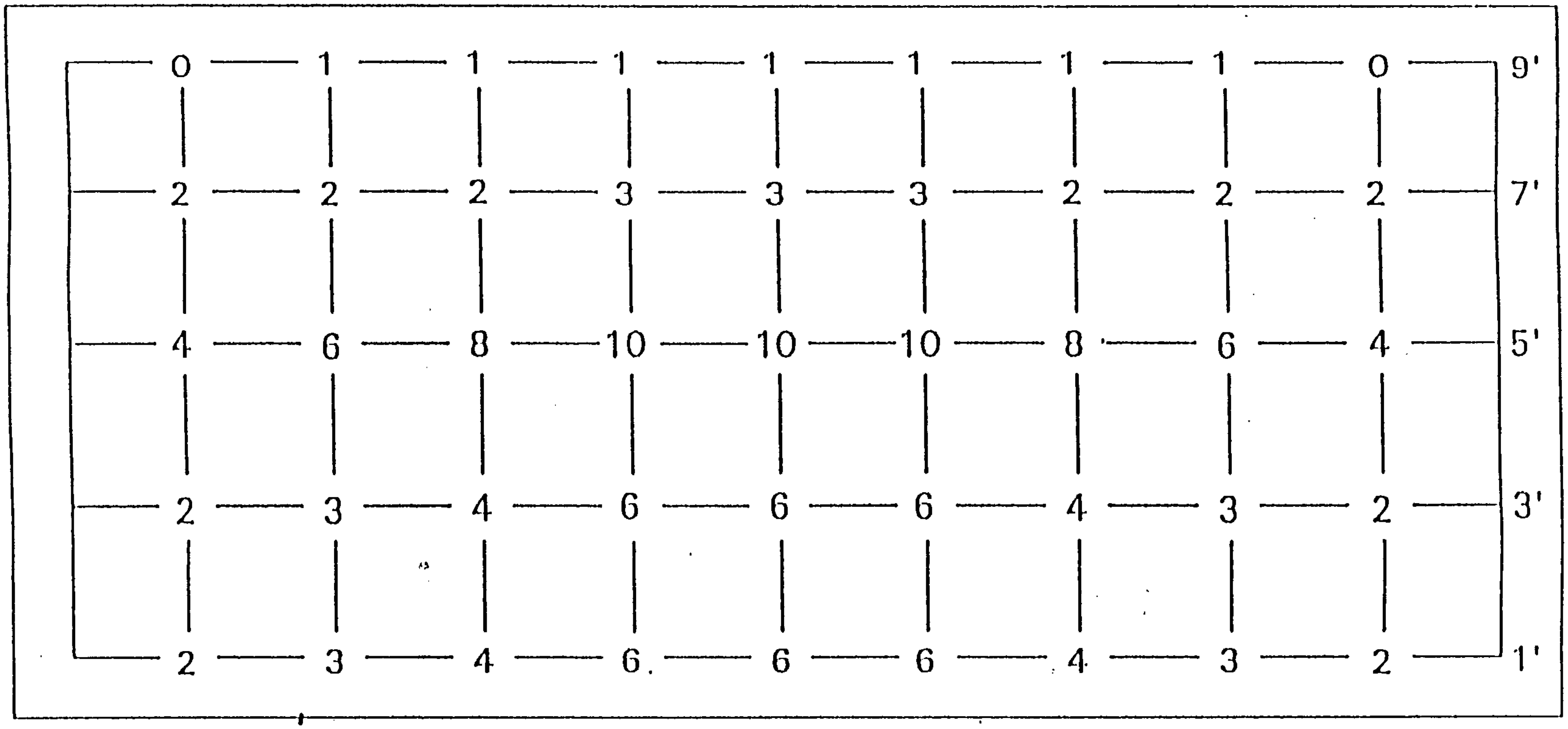


Figure 11. Estimated Booth 3 Constituent Concentration Profile (note, except for those indicating height in feet, numbers indicated are non-dimensional and should be considered in terms of relative concentration levels).

2) A maximum of 25 pallets of equipment may be coated per day.

3) Three pallets could be placed in Booth 3 per paint event. Wash primer, epoxy primer, and topcoat will be applied to all three pallets sequentially.

4) No more than one paint gun may operate in Booth 3 at any given time.

5) The estimated Booth 3 constituent emission rates are one-half the levels determined for Booth 2. This is extremely conservative, particularly because only one painter operates in Booth 3 at a time. Furthermore, MCLB projects that the Booth 3 daily coating usage will be much lower than the Booth 2 daily coating usage; therefore it is anticipated that Booth 3 instantaneous coating usage rates will be lower as well.

Based on these parameters, the optimal Booth 3 partition height yielding an OSHA Factor of 0.5 was calculated at 2.04 meters (6.7 feet).

4.2 BASELINE STUDY DESIGN RECOMMENDATIONS AND CONCLUSIONS

The data collected from Baseline Study were reduced and used as inputs to the mathematical model developed in accordance with the equations presented in Section 2 to derive a safe and efficient partition height and recirculation rate. The results of this mathematical analysis indicated that the exhaust volume flow rate from the MCLB paint booths could be safely reduced by a significant margin. Baseline Study results also proved very useful in developing the recirculation/flow partitioning system design, because the data indicated limitations in the existing (single pass) booth configurations and other ventilation system parameters that could be altered or otherwise optimized to further reduce the exhaust flow rate vented to the APCS.

4.2.1 System Design Enhancements/Constraints Identified From the Baseline Study

Upon review of the Baseline Study results, it was noted that the recirculation/flow partitioning system design should incorporate the following elements to reduce the exhaust flow rate to the APCS down to the lowest possible level and/or ensure a safe working environment:

1) The booth exhaust flow rate to the APCS is linearly dependent on the total booth volume flow, and therefore is also dependent on the linear velocity maintained in the booth. By reducing the linear flow rate through the booth to a constant 100 fpm (in accordance with OSHA regulations codified 29 CFR 1910.94)[5], a corresponding reduction in the exhaust flow rate can be realized, which in turn can contribute significantly to achieving the overall flow reduction goal. A constant flow rate through the booth can only be maintained through the use of a flow adjustment system such as that provided by variable frequency drive fans (VFDs). Thus it was concluded

that the recirculation/flow partitioning system design required VFD fans, rather than fixed drive fans that are commonly installed in most paint spray booths.

2) The Baseline Study results indicated that the Booth 2 volume flow rate was significantly higher than is typically encountered in booths of similar cross-sectional areas. The excessive flow rate was attributed to the open face configuration of Booth 2 in which the paint booth operator typically stood well outside of the booth enclosure. The booth ventilation system for this configuration was therefore designed to pull a sufficient volume of air *through* the booth to ensure that the 100 fpm linear velocity required by OSHA is maintained *outside* of the booth (where the painter stood). As is typical for open-faced booths, the exhaust fans in Booth 2 were drawing approximately twice the flow volume required by OSHA if the operator was actually located inside (rather than outside) the booth area. It was therefore concluded that enclosing Booth 2 would result in a significant reduction in the Booth 2 volume flow rate, which correspondingly would reduce the exhaust flow rate vented to the APCS.

3) A key system design criteria that provided an input to the mathematical recirculation analysis is that the exhaust filter system installed on the booths must be capable of achieving 99% collection efficiency. This is particularly true for Booths 2 and 3, in which primers containing hexavalent chrome are routinely applied.

4) In addition, the flow rate reductions were projected based on an OSHA Factor of 0.65 for Booth 1, and 0.5 for Booths 2 and 3 in the recirculation duct upstream of where the fresh make-up air is brought in. By projecting the recirculation rate such that the requisite action level is achieved prior to dilution by the fresh make-up air, the design ensures that the actual booth intake air OSHA Factor will be far less than 0.5 (In fact, calculations suggest that the actual intake air OSHA Factor will be less than 0.3).

4.2.2 Baseline Study Conclusions and Projected Flow Reductions

The results of the mathematical analysis developed from the Baseline Study data and the design criteria described above indicated that the exhaust flow rate vented from the MCLB paint booths could be significantly reduced through a combination of recirculation/flow partitioning and booth ventilation system optimization. The flow rate reductions that were projected from the Baseline Study and system design optimization effort are summarized in Table 7. Key conclusions derived from the baseline study include the following:

1) Measurements collected at the booth exhaust faces indicated the presence of constituent stratification, thereby conclusively demonstrating the applicability of recirculation/flow partitioning to the MCLB paint booths. These Baseline Study data therefore clearly indicate that, for the MCLB booths, the flow reduction which may be achieved using flow partitioning and recirculation is greater than the reduction achievable via simple recirculation.

2) The presence of hexavalent chromium in the coatings applied in Booths 2 and 3 contributed significantly to the flow reduction projections derived from the mathematical analysis. As such, it was concluded that the exhaust filters installed as part of the retrofit activities must achieve the highest possible filtration efficiency. As indicated in Section 4.1.2, the calculations assumed 99%, which should be considered the minimum acceptable filtration efficiency.

3) The Booth 1 Baseline Study data indicate that the high coating usage rate, coupled with the organic coating constituents which are present, seem to have the greatest impact on the Booth 1 partition height calculations.

As indicated in Table 7, the total flow rate from all three booths that was projected based on the mathematical model is 1,541 m^3/min (54,400 cfm). However, the capacity of the APCS is limited to 1,273 m^3/min (45,000 cfm), thus to achieve this exhaust flow rate, it was necessary to place an additional constraint on the MCLB ventilation system that limits Booths 2 and 3 to sequential operation. Thus, it was decided to design and integrate the booth ventilation systems such that Booth 1 could operate at any time, and Booths 2 and 3 could only operate sequentially. The primary reason for this additional operating constraint is that the MCLB booth partition height calculations were driven to a large extent by the conservative position taken by the Marine Corps regarding the recirculation duct OSHA Factor limits (note item 4 indicated in Section 4.2.1).

Table 7. Summary of Partition Height Calculation Results and Corresponding Flow Rate Reductions Projected from Baseline Study.

Booth	Partition Height meters (feet)	Projected OSHA Factor	Initial Booth Exhaust Flow Rate[1] m^3/min (cfm)	Final Booth Exhaust Flow Rate[2] m^3/min (cfm)
1	2.7 (8.9)	0.65	1,500 (53,000)	566 (20,000)
2	2.0 (6.7)	0.5	1,784 (63,000)	581 (20,500)
3	2.0 (6.7)	0.5	779[3] (27,500)	394 (13,900)

1 Prior to any modifications to the Booth or the ventilation system.

2 Projected exhaust flow rate vented to APCS after modification. The flow rates employed in the final design are discussed in Section 5.

3 The Booth 3 initial flow rate value was projected based on booth configuration information and corresponding ventilation system estimates assuming 125 fpm linear velocity.

4.2.3 General Comments on Recirculation with Respect to OSHA Design Mandates

The OSHA safety compliance requirements codified in 29 CFR 1910.1000 mandate that engineering controls be implemented whenever feasible to minimize worker exposure to hazardous compounds.[7] When such controls do not fully achieve compliance, protective equipment must be used to maintain worker exposure below the established safety levels. As discussed in Sections 4.1.1 and 4.1.2, the Baseline Study results indicate that the Booth 1 and 2 ventilation systems provided flow rates that greatly exceeded the 100 fpm flow rate requirements mandated in 29 CFR 1910. 94 and 107, and were therefore designed with the maximum level of engineering controls possible.

However, the Booth 1 painter vicinity data summarized in Table 2 indicate that, despite the significant level of engineering controls provided by the excessively high volume flow rates, the OSHA Factor conditions in the vicinity of the paint booth operators still exceeded unity. From the Baseline Study results, it appears that the use of engineering controls on the MCLB booths as they were originally configured was insufficient for maintaining acceptable working conditions, and that the use of PPE was therefore required under original, high flow rate, single-pass (non-recirculating) conditions. This is an important distinction, because it clearly indicates that PPE is required irrespective of whether or not recirculation is employed, thus recirculation does not inherently require the implementation of PPE measures as well.

4.3 RESULTS OF PRE-RETROFIT CHARACTERIZATION STUDY

A Pre-Retrofit Characterization of Booth 1 was performed in the Fall of 1995 to assess the changes in Booth 1 operating conditions that may have occurred in the intervening two years since the Baseline Study was completed. The Pre-Retrofit Characterization targeted key parameters that impact Booth 1 recirculation calculations, such as constituent stratification profiles and flow rates. Sufficient data were collected for this test series to ensure that, if significant changes in the recirculation parameters were noted, corrected recirculation calculations could be developed. The two critical measurements performed in the Pre-Retrofit Characterization were exhaust flow rate (presented in Section 4.3.1) and particulate stratification (discussed in Section 4.3.2) Details related to the Pre-Retrofit Characterization are provided in Appendix E, which contains the a summary of the data from that study.

4.3.1 Flow Rate Variations

The Booth 1 exhaust stacks are configured such that some cyclonic flow exists at the flow rate measurement location. Therefore, the flow rate data from both test series were corrected for cyclonic flow to the maximum extent possible. The results of a comparative analysis of the Booth 1 flow rates measured during the Baseline Study and the Pre-Retrofit Characterization are summarized in Table 8. The percent difference between the average flow rates measured during the two test series is less than 10%, which indicates that Booth 1 operations did not changed significantly in the two years following completion of the Baseline Study.

Table 8. Exhaust Flow Rate Data Comparative Analysis Results.

	Baseline Study m^3/min (ft^3/min_{actual})			Pre-Retrofit Characterization m^3/min (ft^3/min_{actual})		
Test	North	South	Total	North	South	Total
1	826 (29,183)	826 (29,182)	1,652 (58,365)	825 (29,118)	804 (28,392)	1,629 (57,510)
2	833 (29,423)	854 (30,167)	1,687 (59,590)	752 (26,553)	733 (25,869)	1,385 (52,422)
3	833 (29,402)	788 (27,827)	1,621(57,229)	730 (25,788)	727 (25,664)	1,457 (51,452)
4	838 (29,575)	816 (28,797)	1,654 (58,372)	695 (24,530)	751 (26,526)	1,446 (51,056)
Average:			1,654 (58,389)	Average:		1,504 (53,110)
Difference: 9%						

4.3.2 Particulate Concentration Profile

A key factor considered during in the Phase 1 partition height calculations was the hazardous constituent concentration profile at the exhaust face. Therefore, an objective of the Pre-Retrofit Study was to assess whether or not the exhaust face concentration profile had changed; particular emphasis was placed on the percent of the material found below the selected partition height. The calculations derived from the Baseline Study results indicated that the partition height should be located between the third and fourth row of filters at the north and south exhaust faces. Therefore, the analysis compared the percent of particulate found below each of these heights measured during the Baseline Study to the same values obtained from the Pre-Retrofit Study. The results of this comparative analysis are summarized in Table 9.

By inspection of the relative standard deviation data reported in Table 9 for the Pre-Retrofit Characterization, it may be deduced that the repeatability of these results is very high. This is also true for the Baseline Study results obtained at the north exhaust face, thus the data from the two test series collected at the north exhaust face are representative and therefore comparable. However, the Baseline Study south face data indicate poor repeatability, thus a comparative analysis of the Baseline Study and Pre-Retrofit Characterization data sets obtained for the south face may not provide a particularly reliable measure of variability.

As indicated in Table 9, Booth 1 particulate stratification at the key sampling locations bracketing the partition height location did not change significantly in the time since the Baseline Study was completed. In fact, the minor difference that is noted indicates that a higher particulate settling rate occurred during the Pre-Retrofit Characterization. Because this higher settling rate will only make the constituent concentrations in the recirculation ducts lower (assuming the partition height is not adjusted), it would in turn would yield a more conservative recirculation system (characterized by a lower recirculation duct OSHA Factor). Thus it was decided not to adjust the partition height based on this small difference.

Table 9. Particulate Stratification Data Comparative Analysis Results.

	% Particulate Below Row Centerpoint			
	North		South	
Pre-Retrofit Study	Row 3	Row 4	Row 3	Row 4
Test 1	71	57	80	74
Test 2	73	60	80	74
Test 3	72	56	83	76
Test 4	76	62	80	72
Average	73	59	81	74
Relative standard deviation (%)	2.9	4.7	2.4	2.2
Baseline Study				
Test 1	65	50	84	68
Test 2	67	53	67	51
Average	66	52	60	76
Relative percent difference (%)	5.8	3.0	28	22
Comparison: Baseline Study data vs. Pre-Retrofit Study data (Percent Difference [%])	9.5	12	26	3.0

SECTION 5

PAINT BOOTH MODIFICATION DESIGN ELEMENTS

The MCLB paint booth/APCS facility modification efforts completed under Phase II of the EPA/USMC Technology Demonstration Program entailed coordination of several key system design, integration, and operation management activities. At the initial stages of the Program, it was recognized that implementing standard industry practices in the design phase was crucial for facilitating technology transfer upon completion, as well as simplifying system integration to the greatest extent possible. Thus sheet metal, structure, and ductwork design and installation activities were executed with this goal. However, the following system elements did require a certain level of customization:

- Constant flow rates through each booth: To minimize the exhaust flow rates from each booth, yet ensure that the booth operates in compliance with the minimum flow rate requirements mandated under 29 CFR 1910.94, the booth ventilation systems were designed to operate at a constant flow rate, irrespective of the condition (e.g. particulate loading) of the exhaust filter system.[5]

- Maximum performance of exhaust filter system: It was necessary to install a high performance exhaust filtration system to minimize the deleterious effects of particulate overspray on the APCS, as well as minimize the hexavalent chromium concentrations in the recirculation duct.

- Coordinate paint booth/APCS system integration and interlocked operations: Properly integrating paint booth and APCS operation via operational sequencing to minimize system interrupts and reduce operator inconvenience was a key consideration throughout the Phase II effort.

- Develop an efficient, fully integrated safety monitoring system - The purpose of the safety monitoring system is to ensure compliance with applicable OSHA exposure standards without limiting booth operating schedules or process flexibility.

These issues were of primary importance in developing an efficient and properly integrated MCLB paint booth/APCS system, and are therefore discussed in detail in this section.

5.1 VENTILATION SYSTEM FLOW RATE CONSIDERATIONS

At the inception of the EPA/USMC Demonstration Program, it was recognized that minimizing the exhaust flow rates to the control device was the primary driving force for recirculation. As the Program proceeded beyond the source evaluation efforts of the Baseline Study (Phase I) to system design and installation (Phase II), it became evident that all potential flow reduction strategies should be investigated to maximize the economic benefits of the ventilation system retrofit activities. The key system options considered in this investigation are discussed in this subsection.

5.1.1 Advantages of Flow Control

Irrespective of recirculation considerations, booth ventilation rates should be controlled within set limits for several reasons. For instance, typical paint booth ventilation systems are designed with fixed drive fans that are rated sufficiently high to ensure that the OSHA mandated 100 fpm requirement is met even under severe system operating conditions such as when the exhaust and/or intake filters are heavily loaded with overspray particulate. Thus, fixed drive fans are therefore typically sized with a large safety margin, which correspondingly produced excessively high flow rates under "clean filter" conditions. While this approach ensures compliance with applicable health and safety standards under all operating conditions, it also increases the capital, installation, and operating costs of an air pollution control system (APCS), because the capacity of the device must be sufficiently large to process the high flow rates generated under "clean filter " conditions. Therefore, accurately controlling the booth ventilation rates to continuously maintain the 100 fpm velocity has the beneficial effect of reducing air pollution emission control costs.

A second reason for using recirculation and exhaust duct flow control is that it minimizes the fan speed to the lowest safe level, and therefore also minimizes the electricity usage rate. Thus flow control actively promotes cost effective ventilation system operation.

A third reason for controlling flow rates in recirculation/flow-partition systems is to ensure proper and safe operation. As discussed in Section 2, flow partitioning takes advantage of constituent stratification patterns that typically occur in paint booths to increase the recirculation rate to the greatest extent possible. The ventilation air that passes to the APCS therefore contains higher levels of overspray particulate, thus the filters through which the controlled exhaust stream passes tend to become loaded more quickly than the recirculation stream exhaust filters. This in turn causes the pressure drop across the exhaust stream filters to increase more rapidly than the pressure drop across the recirculation stream filters. Unless the flow rate in the recirculation and exhaust ducts are controlled, the increased exhaust filter pressure drop will cause air flow pattern migration from the exhaust stream (below the partition) to the recirculation stream (above the partition). This would disturb the normal overspray stratification pattern, and potentially cause an increased concentration of hazardous constituents in the recirculation stream. Flow control prevents an imbalance in exhaust flow through the filters above and below the partition.

5.1.2 Flow Control System Employed on MCLB Paint Booths

The flow rate through each booth is controlled with a feedback loop composed of a flow measurement probe, a transmitter, a process controller, and a variable frequency drive (VFD) equipped fan motor. The probe is located in the duct and senses the flow, then sends a pneumatic signal to the flow transmitter. The transmitter measures the signal and relays a flow proportional electrical signal to the process controller which compares it to the desired or setpoint flow. The controller then decides which way the flow needs to change to maintain the setpoint flow and communicates this electrically to the variable frequency drive, which directly controls the fan motor speed.

To reduce costs, one feedback loop controls each booth recirculation system, which is served by 2 discrete ducts, motors, and blowers. Each recirculation duct is served by a pair of flow probes oriented at right angles and which are plumbed to a single transmitter that feeds one process controller and one VFD. Each VFD controls 2 motors running at identical speeds. To ensure accurate flow, the recirculation ducts on each booth have identical configurations and components, and equal length pneumatic lines are used to join the flow probes to the transmitters.

Flow measurement is achieved using pitot grid array probes that are manufactured specifically for HVAC and process flow applications. These probes deliver a signal proportional to the square of the flow. Two probes are installed within each duct to reduce error attributed to cyclonic flow induced by elbows, fans and other disturbances. Each flow probe pair is connected in parallel to a pressure transmitter. Measurement errors are minimized by using high performance pressure transmitters that typically have a combined error of less than 0.1 percent of full scale.

The transmitters employed are the "smart sensor" type; each is equipped with a calibration data table that is stored on the sensor by the manufacturer and which supports field configuring. Errors for these transmitters are typically expressed as a percentage of the configured upper range, which produces substantially lower errors than transmitters having error rates expressed as a percentage of full range. An additional feature of the transmitters installed on the MCLB paint booths is built-in temperature detection and correction capability. By using these transmitters, flow measurement deviations are estimated at less than 2 percent.

The flow controller, chosen for its accuracy and operational flexibility, is an important component of the feedback control loop. The controller receives a signal from the transmitter, calculates the process error and generates a correction in its signal to the VFD. Of all components in the feedback control loop, the flow controller requires the greatest effort to trim and configure to the system operation. Loop tuning, which is required to provide smooth flow corrections without process overshoot or undershoot, can be a long laborious process. To reduce loop tuning efforts, automatic (self tuning) controllers were installed on the MCLB paint booths; this capability enabled the system programmer to quickly establish estimated values for the proportional, integral, and derivative (PID) settings (which define the controller response characteristics). After the approximate settings were defined, the desired characteristics were manually adjusted. Final PID settings were established after the booths were connected to the APCS by trimming the booth system responses to match the APCS induced draft fan characteristics.

Although the controllers were built with many options, one proved to be absolutely necessary. An input filter for electronically smoothing the signal from the pressure transmitter was invaluable for stabilizing the flow signal, which (at low pressure levels [<996 Pa (.04 inch w.c.)] tended to cyclically deviate from the true value.

In addition, the flow controllers have the capability to accept a remote signal that adjusts the controller setpoint. Although this feature was not used for the MCLB installation, it may be useful in more complex applications for handling flow effects of multiple (>5) booths that continuously cycle on and off and which are difficult to accommodate with a single control device.

The VFD components were selected to be consistent with the APCS drives. Each drive accepts a 4-20 mA signal from the controller. Each VFD is equipped with a number of diagnostic messages on the front panel and many registers for customizing. A readout in Hz enables the user to monitor fan speed as a function of fan flow.

5.2 SAFETY MONITORING SYSTEM

Every effort was made to design and install the MCLB booths such that, even under high coating usage (worst case) conditions, the hazardous constituent concentrations conform with the constraints established by Equation 2 in the recirculation dust upstream of where the fresh make-up air is introduced. A recirculation duct monitoring system was also designed and installed as an added safety feature. The safety system employees an FTIR to continuously monitor the recirculation stream organic concentrations (specific information relating to the FTIR system operation is provided in Section 2). This system assesses the quality of the recirculation air as it exits the paint booth on a real-time basis. Booth 1 was equipped with a dedicated safety monitoring system, and Booths 2 and 3 share a single monitoring system. This configuration was selected because Booth 1 must be capable of full operation at all times, whereas Booths 2 and 3 were designed to operate sequentially.

Each safety monitoring system is programmed with two alarm setpoints, or action levels, which modify the booth operation to reduce recirculation stream constituent concentrations. If the recirculation duct organic concentrations measured by the FTIR exceed the first action level, the paint delivery system is shut down, which immediately curtails coating delivery to the paint gun, and stops the release of hazardous constituents. The paint delivery system remains in the off mode until concentrations in the recirculation duct drop below the established set point. If for some reason the concentration continues to increase to the second action level (such as if a large quantity of paint is spilled in the booth, or high VOC levels flash of the workpiece), the booth control system activates dampers to convert the booth to single-pass operation. Such action instantly reduces the in-booth hazardous constituent concentrations. This alarm is latched, meaning that the alarm remains in effect until a supervisor resolves its cause and then resets the alarm. For the second action level as well as the first, the paint delivery system remains in the off mode until concentrations in the recirculation duct drop below the established set point.

It is anticipated that repeated excursions at the higher setpoint level will eventually be eliminated through changes in painter practices. Typical practices that can result in excursions include 1) pointing spray gun up toward the recirculation duct unnecessarily; 2) mixing paint with the fans off for an extended period, thus contributing to solvent vapor build-up in the booth before turning on the fans. After a short learning period for the painters the second level VOC alarm, conversion to single pass, should rarely if ever, be executed.

5.3 HIGH-PERFORMANCE PARTICULATE FILTRATION REQUIREMENTS

The coating operations in Booth 2 and 3 employ small quantities of a wash primer that contains hexavalent chromium for which, as indicated previously, a very low PEL has been established. The Booth 2 and 3 partition height calculations were influenced to a great extent by the potential presence of hexavalent chrome in the overspray that is directed to the recirculation duct, thus it was deemed appropriate to employ a filtration system that achieves the highest level of particulate control possible.

A 3-stage, high performance filtration system was selected for the MCLB application to minimize the solid phase hazardous compound concentrations in the recirculation duct. This decision was reached after a series of tests to determine characteristics such as pressure drop vs. paint loading rates for various coating materials and included tests with samples of the coatings used at Barstow.

Typical paint booth filter systems that achieve moderate filtration efficiencies are designed with single stage media such as fiberglass or kraft paper that have clean pressure drop readings of less than 49.8 Pa (0.2 inch w.c.), and which are replaced when the pressure differential across the media reaches 249 Pa (1 inch w.c.). However, high-efficiency, multi-stage filters tend to have relatively higher clean pressure-drop readings, and are also somewhat more expensive than traditional filter systems. As such, there is an economic incentive to drive the filters to a reasonably high pressure drop prior to replacement.

However, establishing a reasonable filter life cycle involves the consideration of several related factors. For instance, less frequent filter replacements require higher pressure differentials which in turn require higher fan and motor capacities as well as sturdier, heavier exhaust plenums, ducting, and dampers. One of the first tasks executed under the Phase II effort was to establish the limits of the MCLB paint booth exhaust plenums, as well as the selected 3-stage high efficiency filter system. The results of this evaluation indicated that the plenums are capable of withstanding a 622.5 Pa (2.5 inch w.c.) pressure drop, whereas the filters can easily handle a 17.4 Pa (.7 inch w.c.) or more pressure drop.

The operating life of each stage of the-3 stage filter system varies not only as a function of the filter material, but also as a function of other qualitative and quantitative painting parameters.They include such workplace characteristics as workpiece configuration, aerosol size distributions, coating transfer efficiency and dropout, and operator habits, etc. To establish the replacement frequency of each of the filter stages in the MCLB paint booths, two representative filter elements were selected (one above the partition in the recirculation zone, and one below the partition in the exhaust zone), and pressure differential gages were installed across each stage of these representative elements. The elements were selected to reasonably represent the median particulate loading level in each of the two zones. By installing a static pressure probe between stages 1 and 2 and one between stages 2 and 3 and referencing these to booth and plenum pressures, respectively, three discrete pressure signals are available from each representative element. The probes are connected to manometer gages mounted on the exterior of the booth, thus providing a means of measuring the pressure differential across each stage. These gages provide information for determining whether the first, second, or third stage needs replacing when the overall pressure exceeds 2.0 inch w.c.

Clean filter pressure drop is directly proportional to the linear face velocity through the filter. Therefore, controlling the flow rate through each booth produces the added benefit of reducing the clean pressure drop insofar as possible. For booths 2 and 3, the face velocities through the exhaust filters is 134 fpm, which corresponds to a clean filter pressure differential of approximately 0.5 inch w.c. across all three stages. The original Booth 1 exhaust face was configured such that, even with the flow rate reductions achievable by flow control, a 200 fpm face velocity would be generated after the retrofit modification. This was considered too high to achieve reasonable filter replacement intervals, thus the exhaust system was redesigned to accommodate an additional row of filters. This successfully reduced the linear face velocity through the Booth 1 exhaust filters to 167 fpm, which corresponds to a clean filter pressure differential 0.87 inch w.c.

For each booth, the pressure gages provide input to the booth control panel, and notifies the operator of impending filter replacement requirements via a 2-level warning system. The first level is triggered at a 2.0 inch w.c. pressure drop, and notifies the operator to schedule a filter change. The second level, which occurs at 2.5 inch w.c., disables the booth fans, thereby maintaining a reasonable pressure differential in the plenums and ductwork. This 0.5 inch margin was provided in an effort to reasonably extend filter life and minimize operating costs.

5.4 FINAL FLOW RATES

As discussed in Section 4, the results of the Baseline Study indicated that significant flow reductions could be achieved for the MCLB paint booths. The initial, projected, and actual booth exhaust flow rates achieved are summarized in Table 10. The initial volume flow rate data and the flow reductions projected from the Baseline Study results are discussed in detail in Section 4. The data presented in Table 10 in the Final Configuration column reflect actual operating conditions that currently exist and which were established as a result of the Phase II retrofit efforts (described in detail above).

Table 10. Summary of Volume Flow Rate Reductions Achieved for MCLB Paint Booths

Booth	Initial Volume Flow Rate m^3/min (cfm)	Projected from Baseline Study[1]		Final Configuration		Overall Percent Flow Reduction Achieved
		Volume Flow m^3/min (cfm)	Exhaust Flow m^3/min (cfm)	VolumeFlow m^3/min (cfm)	Exhaust Flow m^3/m (cfm)	
1	1,500 (53,000)	1,019 (36,000)	566 (20,000)	962 (34,000)	572 (20,210)	62%
2	1,783 (63,000)	906 (32,000)	580 (20,500)	906 (32,000)	604 (21,330)	66%
3	778 (27,500)	623 (22,000)	393 (13,900)	623 (22,000)	415 (14,660)	47%
Total	4,061 (143,500)	2,547 (90,000)	1,539 (54,400)	2,490 (88,000)	1,176 (41,540)[2]	71%[2]

1 Details provided in Section 4.

2 The APCS installed at the Barstow facility has a maximum rated capacity of 1274.4 m^3/min (45,000 cfm), therefore Booths 2 and 3 were configured for sequential operation only. For this reason, the maximum volumetric flow rate vented to the APCS does not exceed 1,176 m^3/min (41,540 cfm). However the macimum reduction capability is 1274.4 m^3/min (45,000 cfm).

The significant flow reduction achieved in the MCLB paint booth retrofit efforts is attributed to the following design factors:

1) FLOW CONTROL By using the VFDs to control air flows, a constant flow rate is maintained in each booth, which ensures compliance with OSHA requirements while minimizing exhaust flow rates. 32% of the flow reduction achieved is attributed to the flow control feature.

2) RECIRCULATION/FLOW-PARTITIONING Through installation and operation of recirculation/ flow-partitioning, the exhaust flow rate to the APCS was reduced by an additional 31%. Note that the level of flow reduction achieved by recirculation/flow partitioning was limited primarily by the conservative EPA/MCLB decision to

establish large safety margin for the recirculation duct OSHA Factor. Greater flow reductions may be achieved via recirculation for facilities that either employ more stringent protective equipment, or do not adopt an approach that is not quite so conservative.

3) BOOTH 2 ENCLOSURE As discussed in Section 4, Booth 2 was originally configured as an open face booth, and therefore operated at a significantly higher flow rate than is necessary for a fully enclosed booth of similar size. By enclosing Booth 2, the flow rate vented to the APCS was reduced by an additional 23%.

4) FLOW MANAGEMENT By alternating the operating schedules for Booths 2 and 3, the volumetric flow rate vented to the APCS was reduced an additional 14%. The sequential operation of Booths 2 and 3 is controlled from a single interface panel. Although each booth is internally equipped with full operation capabilities, the circuitry is designed such that only one booth can be run at a time. The operating booth is selected via a front panel switch, which is locked for supervisor control. The safety monitor is devoted to whichever booth is operating, and the sample inlet direction is controlled with a three-way valve connected to the panel mounted switch.

5.5 PAINT BOOTH/APCS SYSTEM INTEGRATION REQUIREMENTS

The MCLB paint booth operating schedules are frequently demanding and generally variable. The two booth areas, Area 11 (Booths 2 and 3) and Area 18 (Booth 1) are managed by different supervisors. Booths 2 and 3 are designed for sequential operation (i.e. these booths cannot be operated simultaneously) due to flow capacity of the APCS. Given the process constraints and area management structure, the importance of adequately linking booth ventilation systems with APCS operation was apparent from the initial stages of Phase II. To develop the necessary system coordination procedures and handshake signals between the booths and the APCS, various startup and operation strategies were identified through a detailed "what if" analysis.

The startup strategy was developed based on the premise that the booths and the APCS form an integrated process, thus all painting operations rely on proper functioning of the APCS. Booth operators must be able to detect at a glance whether the APCS is available for service, or is down for maintenance. After this is determined, and the start button is pressed, startup becomes a series of automatically executed steps that include several system condition tests. The booth ventilation system and APCS operations are activated only after these checks are satisfactorily completed to ensure simultaneous, smooth, and safe system integration. The following summarizes the integrated system sequence of operation:

1) The "APCS Ready" signal, sent from the APCS control network, indicates the availability of the APCS for booth service. The "APCS Ready" light on each booth

control panel is illuminated when this signal is received. The booths can not be started until this signal is received.

2) If the "Start" button on the control panel is pressed and no fan overload conditions are sensed, the variable frequency drives (VFDs) power up and the "Start Sequence Enable" light is illuminated. At this stage, booth fans remain immobile.

3) When the "Start Permissive" signal is received from the APCS and the indicator light is illuminated, the recirculation fans are sent a "Run" (forward) command. The "Start Permissive" signal is controlled by the APCS network to properly coordinate APCS operation with booth exhaust fan activation.

4) The exhaust duct dampers also open when the "Start Permissive" signal is received by the booth control panel. When system is shut down, the exhaust dampers close after a time delay.

5) Fan speed is locally controlled by a feedback loop containing a pitot array velocity probe, a pressure transmitter, a process controller, and a VFD. A separate velocity probe is provided in each recirculation duct; for each booth, these probes share a common transmitter, process controller, and VFD drive. The controller is programmable and is capable of remote setpoint control should this be required for additional control via the APCS network.

6) In the event that a high pressure differential (2.0 inch w.c.) across the exhaust filter is detected, both a filter maintenance warning light and an audible alarm signal are activated.

7) In the event that the highest level pressure differential (2.5 inch w.c.) across the exhaust filter is detected, the booth system is shut down, the VFD is disconnected from the power sources, a filter shutdown indicator is lit, and both an audible alarm and a visible beacon are activated.

8) If the recirculation VFD is operating properly, the "Recirculation Fans Running" light is illuminated.

9) If the recirculation VFD is running and the "Exhaust Damper Limit Switch" is closed, then the exhaust VFD is started.

10) If the exhaust VFD is operating properly, the "Exhaust Fan Running" light is illuminated.

11) If normal VOC levels are present and a personnel access door is opened, a timer starts. If door is not shut within the time setting (approximately 1 minute), a solenoid valve shuts off paint flow.

12) A high VOC level triggers the "High Solvent Concentration Level 1" light. This light

is switched via the safety monitor, and paint supply is shut off. The monitor system is designed to automatically clear this condition once VOC levels return to normal. This strategy was devised so that only minimum production delays are experienced.

13) A maximum VOC level triggers the "High Solvent Concentration Level 2" event in which the monitor latches, the paint air supply is shut off, and the recirculation air is vented to the outside (which converts the booth ventilation system to single-pass operation). The alarm controller also activates a siren, a flashing beacon, and a lighted alarm indicator. The alarm is latched and may be cleared only by manual interface with the safety monitor. Only authorized personnel have access to the monitor to clear the signal; this allows a review of the conditions that initiated the alarm.

14) For diagnostic purposes, a number of signals are relayed to the APCS control computer for storage and historical trends. These signals include:

- Exhaust flow rate
- Recirculation flow rate
- Booth temperature
- Exhaust filter pressure drop
- Recirculation filter pressure drop
- Booth in single pass mode
- Booth emergency stop

15) An additional control signal was provided to prevent low flow rate conditions caused by loose drive belts. The APCS computer compares the flow rate signals that are received from an on-line booth. If the flow rate is below the established setpoint by 20 percent or more, it engages a "low flow" alarm on the booth. This ensures that the booths always operate in compliance with the 100 fpm (30.5 m/min) linear velocity mandated under 29 CFR 1910.94 for spray booth operation.[5]

16) If a booth control panel has power, no alarms are engaged, and compressed air is available, the emergency stack damper is closed, the recirculation dampers are open, and the booths proceed to operate in recirculation mode. If a booth panel requires powering down for maintenance, the dampers must be placed in "maintenance mode" via manual valves to force them closed.

17) If the "fire suppression alarm" is triggered, power to the booths is shut off, and dampers adjust to their "fail open" conditions. The fire suppression panel controls its own audible and visible alarms. In all other respects, the fire suppression system is independent of the operation of the booths.

SECTION 6

TECHNOLOGY DEMONSTRATION STUDY RESULTS

Following the Phase II design, fabrication, and installation of the spray booths, Phase III of the program including system testing and evaluation activities was initiated. The objective of the Phase III effort was to determine if the recirculation/flow partition systems installed in a production environment behaves mechanically, and functionally as predicted. Thus, it was necessary to confirm that the constituent concentrations in the recirculation duct are below the established safety level, and that recirculation has little impact on constituent concentrations in the vicinity of the paint booth operator. Vicinity sampling results are particularly important, as they provide an indication of the operational compliance status with respect to OSHA exposure requirements. Supplemental data pertaining to vapor and solid phase concentration profiles at the exhaust face of each booth were also collected in the event that adjustments in the partition height was required at a later date. The test matrix that was developed and implemented for the Phase III Demonstration Study is summarized in Table 11. The results of these tests are provided and discussed in this Section.

6.1 HAZARDOUS CONSTITUENT CONCENTRATIONS MEASURED UPSTREAM OF FRESH MAKEUP AIR INTAKE IN THE RECIRCULATION DUCTS

6.1.1 Measurement Objective and Results

As discussed in detail in Section 4, the results of the Phase I Baseline Characterization Study were used to estimate the appropriate partition heights and corresponding recirculation rates for each of the three MCLB paint booths. These estimates were developed based on the premise that the concentrations in the recirculation duct upstream of the fresh make-up air intake must conform with the OSHA Factor restriction imposed by Equation 2. Correspondingly, the objective of the recirculation duct measurements described here was to confirm whether or not these partition height/recirculation rate estimates were correct. This was accomplished by determining the constituent concentrations (and corresponding OSHA Factors) in the recirculation duct upstream of the fresh make-up air intake. Details relating to the sampling and analysis procedures employed for these measurements are summarized in Appendices A and B, respectively.

The results of the recirculation duct concentration measurements and OSHA Factor calculations for Booths 1, 2 and 3 are summarized in Tables 12 through 14. The hexavalent chrome data reported in Tables 13 and 14 have been blank-corrected, as well as the HDI results reported for Booths 1 and 2. Details pertaining to these analytical correction procedures are included in the Quality Assurance/Quality Control (QA/QC) discussion provided in Section 9. More detailed information relating to the OSHA Factor calculations for each of the recirculation duct sampling events is provided in Appendix D.

Table 11. Test Matrix for Demonstration Study.

	Objective	Location	Parameter	Sampling Method
Booth 1	Determine recirculation duct concentrations	Recirculation ducts	Metals Isocyanates Speciated organics Total organics Flow rate	EPA Method 0060[12] EPA Method 0061[17] EPA Draft Method[18] NIOSH 1300[10] EPA Method 25A[14] EPA Method 2[16]
	Establish OSHA Factor in the vicinity of the paint booth operators	Vicinity of paint booth operators	Metals Isocyanates Speciated organics	NIOSH 7300[8] OSHA 42[7] NIOSH 1300[10]
	Determine exhaust face concentration profile	Exhaust faces	Metals Speciated organics	NIOSH 7300[8] NIOSH 1300[10]
Booth 2	Determine recirculation duct concentrations	Recirculation ducts	Metals Isocyanates Speciated organics Total organics Phosphoric Acid Flow rate	EPA Method 0061[17] EPA Draft Method[18] NIOSH 1300[10] EPA Method 25A[16] NIOSH 7903[18] EPA Method 2[16]
	Establish OSHA Factor in the vicinity of the paint booth operators	Vicinity of paint booth operators	Metals Isocyanates Speciated organics Phosphoric acid	NIOSH 7300[8] OSHA 42[7] NIOSH 1300[10] NIOSH 7903[18]
	Determine exhaust face concentration profile	Exhaust faces	Metals Speciated organics	NIOSH 7300[8] NIOSH 1300[10]
Booth 3	Determine recirculation duct concentrations	Recirculation ducts	Metals Isocyanates Speciated organics Total organics Phosphoric acid Flow rate	EPA Method 0061[17] EPA Draft Method[18] NIOSH 1300[10] EPA Method 25A[16] NIOSH 7903[18] EPA Method 2[16]
	Establish OSHA Factor in the vicinity of the paint booth operators	Vicinity of paint booth operators	Metals Isocyanates Speciated organics Phosphoric acid	NIOSH 7300[8] OSHA 42[7] NIOSH 1300[10] NIOSH 7903[18]
	Determine exhaust face concentration profile	Exhaust faces	Metals Speciated organics	NIOSH 7300[8] NIOSH 1300[10]

Table 12. Booth 1 Recirculation Duct Constituent Sampling Results.

	Test 1		Test 2		Test 3		Test 4		Test 5		Test 6	
	North	South	North	South	North	South	North	South	North	South	North	South
Concentrations (mg/m^3)												
Trivalent chromium	0.0042	0.0046	0.0142	0.0050	ND	0.0075	0.003	0.0039	0.0045	0.0059	0.0022	0.0047
HDI	0.0015	0.0014	0.0015	0.0015	0.0015	0.0014	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015
Methyl ethyl ketone	18	28	13	27	16	21	13	18	7.9	11	1.8	11
Ethyl acetate	0.26	0.30	0.21	0.26	0.32	0.23	0.2	0.24	0.18	0.18	0.26	0.25
Methyl isobutyl ketone	33	50	23	50	31	40	28	47	33	48	7.2	39
Toluene	41	61	29	63	38	50	28	44	29	42	8.7	47
Butyl acetate	20	30	14	31	17	22	12	20	11	17	3.4	19
Methyl isoamyl ketone	22	35	16	38	4.8	0.23	3	5	1.3	2.1	0.42	2.5
Ethyl benzene	19	29	13	30	17	23	12	21	14	20	4.2	23
Total xylenes	100	150	69	158	90	121	64	110	73	110	22	120
Trimethyl benzene	4.3	6.3	2.9	7.1	3.5	6.3	2.9	4.7	2.9	4.4	0.94	4.9
Hexyl acetate	6.5	9.5	4.6	11	5.2	7.4	4	6.6	2.4	3.7	0.8	4.5
OSHA Factor upstream of fresh make-up air intake	0.76		0.71		0.60		0.53		0.52		0.40	
OSHA Factor in ventilation air introduced to Booth 1	0.31		0.29		0.25		0.22		0.21		0.16	

Table 13. Booth 2 Recirculation Duct Constituent Sampling Results.

	Test 1		Test 2		Test 3		Test 4		Test 5		Test 6	
	North	South	North	South	North	South	North	South	North	South	North	South
Concentrations (mg/m^3)												
HDI	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015
Phosphoric acid	0.0203	0.026	0.027	0.03	0.026	0.029	0.026	0.027	0.026	0.026	0.026	0.025
Hexavalent Chromium	0.0011	0.0004	5.4E-5	5.4E-5	5.6E-5	7.0E-5	0.0002	0.0014	3.8E-4	2.8E-5	1.3E-5	5.3E-5
Methyl ethyl ketone	15	12	8.4	8	14	13	19	9.3	25.6	17	27	16
Ethyl acetate	0.12	0.11	0.13	0.13	0.13	0.48	0.38	0.13	0.18	0.22	0.34	0.32
n-Butanol	5.1	5.1	3.3	6	5.3	7.4	12	7.8	7.6	6.0	19	6.8
Methyl isobutyl ketone	12	8.1	7	8.1	11	15	15	7.9	15	8.7	18	8.3
Toluene	16	12	9.4	14	14	19	19	12	22	14	32	16
Butyl acetate	10	6.6	4.8	5.5	30	39	39	20	14	8	19	8.7
Methyl isoamyl ketone	0.12	0.11	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Ethyl benzene	5.9	4.0	3.5	4	3.5	4.6	4.5	2.4	7.2	4.1	9.2	4.1
Total xylenes	30	21	18	21	24	31	30	16	37	21	47	21
Trimethyl benzene	4.8	3.5	2.8	3.5	4.1	5.1	5.4	3.1	6.1	3.5	8.8	3.7
Hexyl acetate	7	4.9	3.2	3.5	5.6	6.4	6	3.2	8.3	4.4	12	5.2
OSHA Factor upstream of fresh make-up air intake	1.07		0.28		0.41		1.07		0.68		0.50	
OSHA Factor in ventilation air introduced to Booth 2	0.28		0.07		0.11		0.29		0.18		0.14	

Table 14. Booth 3 Recirculation Duct Constituent Sampling Results

	Test 1		Test 2		Test 3		Test 4		Test 5		Test 6	
	East	West	East	West	East	West	East	West	East	West	East	West
Concentrations (mg/m^3)												
HDI	0.0022	0.0017	0.0025	0.0022	0.022	0.0022	0.0025	0.0029	0.0024	0.0027	0.0015	0.0019
Phosphoric acid	0.021	0.021	0.024	0.024	0.024	0.025	0.025	0.025	0.023	0.027	0.021	0.027
Hexavalent chromium	0.0004	5.1E-5	0.0001	5.1E-5	0.0002	5.0E-5	5.4-E5	9.2E-5	5.4E-5	4.8E-5	0.0001	4.7E-5
Methyl ethyl ketone	2.4	2.1	2.6	2.3	3.9	2.4	3.2	0.3	6.6	5.6	6.9	5.6
Ethyl acetate	0.15	0.23	0.12	0.25	0.25	0.25	0.13	0.23	0.13	0.33	0.20	0.34
n-Butanol	0.83	0.6	2.2	1.2	0.83	0.65	0.95	0.39	1.6	0.88	0.80	0.89
Methyl isobutyl ketone	0.57	0.48	1.1	0.95	1.6	1.0	1.6	0.13	2.0	1.3	0.87	1.3
Toluene	1.1	1.6	2.5	3.4	4.5	7.4	5.2	2.8	6.1	8.6	3.1	8.7
Butyl acetate	0.58	0.5	1	0.89	1.4	0.95	1.4	0.13	1.2	0.81	0.63	0.82
Methyl isoamyl ketone	0.1	0.11	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.13
Ethyl benzene	0.27	0.23	0.57	0.48	0.81	0.55	0.82	0.13	1.2	0.9	0.67	0.91
Total xylenes	1.4	1.2	3.0	2.5	4.3	3.0	4.3	0.13	6.7	4.9	3.4	3.1
Trimethyl benzene	0.69	0.41	0.64	0.54	0.69	0.5	0.77	0.26	0.59	0.45	0.33	0.46
Hexyl acetate	0.1	0.58	0.85	0.72	0.12	0.83	1.3	0.13	1.0	0.72	0.34	0.73
OSHA Factor upstream of make-up air intake	0.31		0.20		0.25		0.20		0.20		0.19	
OSHA Factor in ventilation air introduced to Booth 3	0.11		0.07		0.09		0.07		0.07		0.07	

The coating usages recorded during each test are indicated in Table 15. Note that, because the test results were intended to reflect maximum coating usage rates for worst case (highest OSHA Factor) conditions, the paint application rates recorded are much higher than typically occur at the MCLB facility. There was some concern that perhaps the Booth 2 test conditions during the recirculation test series were excessive, thus additional coating usage data which reflect typical Booth 2 operations were also collected. This "standard coating usage rate" data for Booth 2 are also summarized in Table 15.

6.1.2 Implications of Recirculation Duct Sampling Results

As indicated in Tables 12 through 14, the quality of the respirable air introduced into the MCLB paint booths as determined from the recirculation duct sampling results conforms with the health and safety requirements mandated by OSHA and codified in 29 CFR 1910.1000.[7] Additional conclusions from Tables 12 through 14 results include the following:

- Despite the fact that a high efficiency, 3-stage particulate filtration system was installed on all the booths, there were still traces of hexavalent chrome measured in the booth 2 and 3 exhaust streams. Because hexavalent chrome can be a major contributor to the OSHA Factor summation equation (ranging from 15 to 87 percent), the presence of this compound has a significant impact on the magnitude of the OSHA Factors reported in Tables 13 and 14. The filter manufacturer claims that the presence of hexavalent chrome is due to leakage around the filter frame (at the point of attachment to the third stage of the filter) and is currently exploring design changes. The fact remains that hexavalent chrome was measured in the recirculation ducts, and therefore did impact the Booth 2 and 3 OSHA Factor results. [*Note: Metal samples from the Booth 2 and 3 recirculation ducts were collected in accordance with EPA Method 0061 for hexavalent chrome. Metal samples in the Booth 1 recirculation ducts were collected in accordance with EPA Method 0060 for total chrome.* Hexavalent chrome in not used in booth 1.]

- The source of hexavalent chrome in the CARC paint system is the wash primer material, which is typically used in small quantities in Booths 2 and 3. As noted in Section 6.1, a high wash primer usage rate was imposed for the Booth 2 recirculation tests to ensure that booth 2 results represented worst case conditions. The paint usage data reported in Table 15 indicate that the average wash primer usage during the 1 hour recirculation duct tests was 17 kg, however typical booth 2 production levels require only 2.3 kg of wash primer per hour of operation. Thus, the booth 2 recirculation test results indicate that the 0.5 OSHA Factor target level in the recirculation duct upstream of where it is diluted with fresh make-up air will only be slightly exceeded (to 0.67), even when the throughput rate is seven times higher than typical production levels. Moreover, due to the dilution effects of the fresh make up air that is mixed with the recirculated air, the quality of the paint booth intake air (comprised of recirculation air + fresh make-up air) does not exceed the target 0.5 OSHA Factor.

Table 15. Paint Usage Rates Recorded during Painter Vicinity OSHA Factor Measurements.

Location	Condition		Painter 1	Painter 2	Total
Booth 1 Both painters apply topcoat + thinner only	Single-Pass Operation	Test 1	21.33 kg	26.15 kg	46.61 kg
		Test 2	25.28 kg	22.98 kg	49.13 kg
		Test 3	19.94 kg	18.32 kg	38.26 kg
		Average	22.3 kg		44.67 kg
	Recirculation Operation	Test 1	28.29 kg	20.67 kg	48.96 kg
		Test 2	22.79 kg	31.00 kg	53.79 kg
		Test 3	28.36 kg	26.13 kg	54.67 kg
		Test 4	20.33 kg	24.55 kg	44.88 kg
		Test 5	26.23 kg	29.47 kg	55.70 kg
		Test 6	15.90 kg	31.06 kg	46.96 kg
		Average	25.41 kg		50.87 kg
Booth 2 Painter 1: primer only Painter 2: topcoat + thinner	Single-Pass Operation	Test 1	3.76 kg	22.00 kg	25.76 kg
		Test 2	4.39 kg	46.35 kg	50.74 kg
		Test 3	14.59 kg	24.76 kg	39.35 kg
		Average	7.58 kg	31.04 kg	38.62 kg
	Recirculation Operation	Test 1	17.27 kg	20.43 kg	37.7 kg
		Test 2	12.29 kg	30.64 kg	42.93 kg
		Test 3	19.97 kg	17.66 kg	37.63 kg
		Test 4	23.04 kg	35.35 kg	58.39 kg
		Test 5	14.20 kg	13.36 kg	27.56 kg
		Test 6	15.36 kg	20.43 kg	35.79 kg
		Average	17.02	22.98 kg	40.00 kg
Booth 2 Coating Usage in a Typical 2-Hour Painting Cycle (i.e. typical 2 hour operation)			Wash Primer Usage: 4.6 kg / 2-hrs	Topcoat Usage: 11.39 kg / 2-hrs	
Booth 3 Painter 1: primer use Painter 2: topcoat + thinner use	Single-Pass Operation	Test 1	2.70 kg	7.07 kg	9.77 kg
		Test 2	4.06 kg	7.48 kg	11.54 kg
		Test 3	5.16 kg	2.73 kg	7.89 kg
		Average	3.97 kg	5.76 kg	9.73 kg
Note: only one painter is present in booth 3; the painter continuously shifts from primer to topcoat application	Recirculation Operation	Test 1	6.15 kg	6.29 kg	12.44 kg
		Test 2	6.91 kg	4.71 kg	11.62 kg
		Test 3	6.15 kg	4.71 kg	10.86 kg
		Test 4	8.05 kg	4.71 kg	12.76 kg
		Test 5	4.61 kg	7.67 kg	12.28 kg
		Test 6	4.61 kg	7.64 kg	12.25 kg
		Average	6.08 kg	5.96 kg	12.04 kg

- The goal of maintaining hazardous concentrations in the recirculation duct at a location upstream of the fresh makeup air intake near the level established by Equation 2 was met for 12 of the 17 individual measurements. The average OSHA Factor measured in the Booth 1 recirculation ducts prior to mixing with the fresh make-up air was 0.59, which is slightly above the 0.5 target value. The calculated OSHA Factor is further reduced to 0.24 at the booth intake due to dilution by the fresh make-up air. Note however that the high production throughput under which the Booth 1 recirculation duct measurements were collected represent extreme, worst-case conditions which are atypical for this facility. Thus the OSHA Factor in the recirculation duct under normal operating conditions will remain well below the 0.5 setpoint level, and the quality of the Booth 1 intake air determined from the recirculation duct data will remain below 0.25.

- As indicated in the results presented in Table 14, it appears that the assumptions employed to estimate the proper partition height for Booth 3 were conservative. Recall that the objective for the Booth 3 design was to achieve an OSHA Factor of 0.5 in the recirculation duct; however, the OSHA Factors obtained from the Booth 3 recirculation duct measurements are somewhat lower.

- It is important to note that the OSHA PELs employed to derive the recirculation duct and dilution stream OSHA Factors reported in Tables 12 through 14 are 8 hour TWAs. Thus, the results are conservative since the OSHA Factor results assumes that the paint booth operators apply paint in the booths for 8 hours per day which is not the case. The typical painting intervals (the hours per day that paint is actually sprayed) do not exceed 4-5 hours per day. Therefore, actual recirculation duct and dilution stream OSHA Factors are at least 25% lower than those reported in Tables 12 through 14.

The recirculation duct and dilution stream OSHA Factors reported in Tables 12 through 14, coupled with the safety margins implicit in their derivation, clearly indicate that the MCLB recirculation/flow partition systems operate well within the health and safety limits mandated by OSHA under 29 CFR 1910.1000.[7]

6.2 EXHAUST FACE CONSTITUENT CONCENTRATION PROFILE RESULTS

The partition heights and recirculation rates were determined for each booth using conservative assumptions regarding hazardous constituent concentrations in the recirculation stream. The initial design criteria specified that the recirculated concentrations conform with the Equation 2 summation rule <u>upstream</u> of where the recirculation concentrations are diluted by fresh make-up air. The resulting ventilation systems that were installed create working conditions that conform with OSHA health and safety limits by a wide margin. If, in the future, MCLB staff members elect to re-evaluate this particular design criteron, and perhaps alter one or more of the booths to increase the recirculation rate, it will be necessary to recalculate the to the solid and vapor phase compound concentration profiles for each exhaust face. Thus, these data will be required in the event that MCLB subsequently modifies the booth recirculation systems in any way.

In an effort to provide supplemental information to MCLB and thereby facilitate future system modification activities, a key effort under the Phase III Demonstration Study was to profile the solid and vapor phase constituent concentrations across the exhaust face of each booth. These profile measurements provide relative concentration data for metal and organic vapor compounds at various heights across the exhaust filter for each booth. The test parameters were developed based on the assumption that metal and organic concentration measurements would provide representative solid and vapor phase profiles, respectively.

Results of the aggregate metal concentration measurements as a function of height for Booths 1, 2 and 3 are indicated in Tables 16 through 18, respectively, and the total organic concentration results are summarized in Tables 19 through 21, respectively. The metal and organic data are also presented graphically Figures 12 through 14. The graphs defines the basis for determining the percentage of pollutant that must be removed in the partition stream and the corresponding partition height. These data can therefore be directly applied as inputs to Equation 7 to develop alternative partition height scenarios. Note that Tables 16 through 21 provide summary information only; detailed information relating to the actual constituent concentrations measured at each location are provided in Appendix D.

6.3 HAZARDOUS CONSTITUENT CONCENTRATIONS IN THE VICINITY OF THE PAINT BOOTH OPERATOR

6.3.1 Measurement Objective and Results

In typical paint spray operations, the pattern created by the spray nozzle coupled with the target configuration and the booth air flow dynamics tend to combine in such a way that the painter frequently operates in a "cloud" of overspray particulate and solvent vapor.[8] As such, the hazardous constituent concentrations generated by non-recirculating booths in the immediate vicinity of the painter often exceed the OSHA Factor level defined by Equation 1 in Section 2. To ensure that the impact of recirculation on the constituent concentrations in the painter vicinity is negligible (i.e., recirculation does not contribute to this "cloud effect"), the paint booth partition heights were selected to maintain the quality of respirable air well below the safety limits established by OSHA. As indicated in the results summarized in Section 6.2, the partition heights and recirculation rates successfully maintain the concentrations in the intake air well below these limits.

To conclusively demonstrate the negligible impact of recirculation on the working environment in the paint booth, samples were collected in each booth in the vicinity of the paint booth operators. Two sets of measurements were collected for each booth in separate test series. In the first series, samples were collected in the vicinity of the painter while the booth operated in single-pass mode (without recirculation) to establish booth operating conditions created by the cloud effect in the vicinity of the painter in the absence of recirculation. For the second test in single-pass mode (without recirculation) to establish booth operating conditions created by the cloud effect in the vicinity of the painter in the absence of recirculation. For the second test series performed after booth modifications were completed, constituent concentration measurements were again collected in the vicinity of the painter while the booth was operated in recirculation mode.

For each test series, three sets of samples were collected for each class of compound measured. It was not possible to collect all the samples required for each booth in a single sampling run, thus for each booth, the three data sets were collected over six painting cycles. To provide a means of effectively correlating these results, the amount of coating used during each sampling event was also measured; these data are summarized in Table 15.

The painter vicinity test results obtained from the single-pass operating mode for Booths 1, 2, and 3 are presented in Tables 22, 23, and 24, respectively. Similar data obtained from the recirculating operating mode for Booths 1, 2, and 3 are presented in Tables 25, 26, and 27, respectively. Each table summarizes the painter vicinity concentrations measured during the single-pass mode and recirculation mode tests, and the corresponding painter vicinity OSHA Factor which was derived from Equation 1. Note that the OSHA Factor derived in this way does not in any way reflect the painter's actual exposure during the sampling event.

The data input to the summation equation were collected *outside* the respirator hood in the vicinity of the painter's breathing zone, and therefore do not include the protection factor provided by the personal protection equipment worn by the operator during painting. To estimate the OSHA Factor related to the painter's exposure, the value determined for the painter vicinity OSHA Factor was divided by the respirator protection factor assigned in accordance with OSHA guidelines. Note that, because the painters operating in Booth 1 often wear cartridge-type respirators (which are assigned a protection factor of 10) rather than hooded air-line respirators (which are assigned a protection factor of 25), both of these factors are reflected in Tables 22 and 25.

In comparing the Booth 2 painter vicinity chromium concentration results from the Baseline Study (provided in Section 4) to the painter vicinity chromium results obtained from the Technology Demonstration Study, it becomes immediately apparent that the Booth 2 modifications significantly reduced painter vicinity metal concentrations. As indicated in Table 5, the average painter vicinity chrome concentration prior to the Booth 2 modifications ranges from 0.024 mg/m^3- 0.106 mg/m^3, with an average of 0.095 mg/m^3. Similar results from the Technology Demonstration Study indicate that the Booth 2 painter vicinity total chrome concentration ranges from 0.002 mg/m^3 to 0.022 mg/m^3, and averages 0.0073 mg/m^3.

This data conclusively demonstrates that the Booth 2 modifications significantly enhanced the ventilation system performance, and greatly improved the working conditions in the booth in terms of the health and safety requirements mandated by OSHA. These enhancements are doubtlessly due to the combined effect of enclosing Booth 2 and using the VFDs to create a consistent and uniform flow profile within the booth.

Table 16. Booth 1 Average Chrome Concentrations at Specific Exhaust Face Heights.

Height m (ft)	Test 1 (mg/m^3)	Test 2 (mg/m^3)	Test 3 (mg/m^3)	Average (mg/m^3)
4.4 (14.4)	0.0067	0.0030	0.0064	0.0054
3.9 (12.7)	0.060	0.0047	0.011	0.025
3.3 (11.0)	0.016	0.0062	0.020	0.014
2.8 (9.3)	0.040	0.021	0.0091	0.023
2.3 (7.6)	0.051	0.013	0.055	0.040
1.8 (5.9)	0.056	0.017	0.022	0.032
1.3 (4.2)	0.082	0.0078	0.023	0.038
0.76 (2.5)	0.054	0.0069	2.1	0.72
0.024 (0.8)	0.024	0.0025	0.012	0.013

Table 17. Booth 2 Average Chrome Concentrations at Specific Exhaust Face Heights.

Height m (ft)	Test 1 (mg/m^3)	Test 2 (mg/m^3)	Test 3 (mg/m^3)	Average (mg/m^3)
2.8 (9.3)	0.013	0.013	0.014	0.013
2.3 (7.6)	0.017	0.018	0.022	0.019
1.8 (5.9)	0.022	0.044	0.021	0.029
1.3 (4.2)	0.037	0.067	0.051	0.052
0.76 (2.5)	0.032	0.067	0.055	0.051
0.024 (0.8)	0.030	0.086	0.094	0.070

Table 18. Booth 3 Average Chrome Concentrations at Specific Exhaust Face Heights.

Height m (ft)	Test 1 (mg/m^3)	Test 2 (mg/m^3)	Test 3 (mg/m^3)	Average (mg/m^3)
2.8 (9.3)	0.0019	0.0090	0.0034	0.0047
2.3 (7.6)	0.011	0.039	0.025	0.025
1.8 (5.9)	0.049	0.085	0.044	0.059
1.3 (4.2)	0.15	0.15	0.088	0.13
0.76 (2.5)	0.17	0.14	0.062	0.12
0.024 (0.8)	0.076	0.063	0.056	0.065

Table 19. Booth 1 Average Organic Concentrations at Specific Exhaust Face Heights.

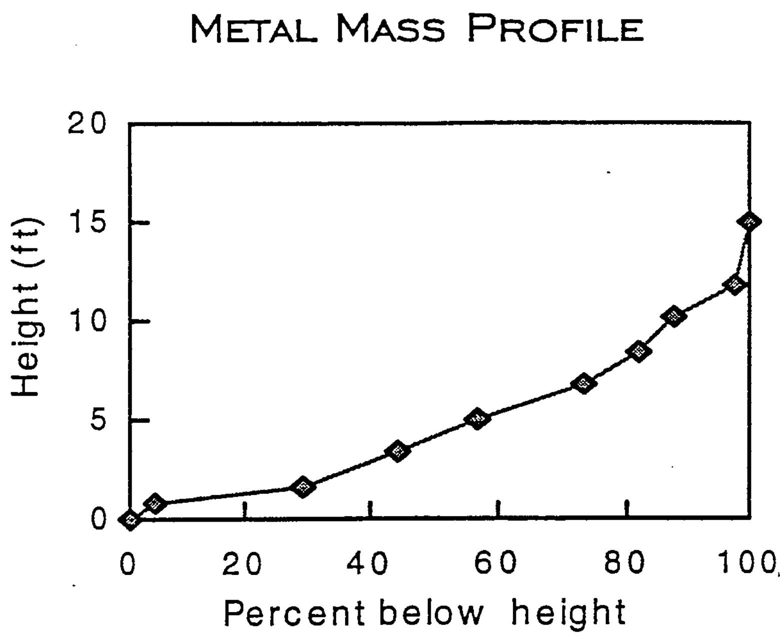
Height m (ft)	Test 1 (mg/m^3)	Test 2 (mg/m^3)	Test 3 (mg/m^3)	Average (mg/m^3)
4.4 (14.4)	210	190	180	190
3.9 (12.7)	240	290	240	260
3.3 (11.0)	310	360	290	320
2.8 (9.3)	360	370	260	330
2.3 (7.6)	400	440	340	390
1.8 (5.9)	400	470	340	400
1.3 (4.2)	450	350	300	370
0.76 (2.5)	360	370	300	340
0.024 (0.8)	200	150	170	170

Table 20. Booth 2 Average Organic Concentrations at Specific Exhaust Face Heights.

Height m (ft)	Test 1 (mg/m^3)	Test 2 (mg/m^3)	Test 3 (mg/m^3)	Average (mg/m^3)
2.8 (9.3)	74	44	87	68
2.3 (7.6)	87	64	120	90
1.8 (5.9)	99	100	160	120
1.3 (4.2)	170	120	170	150
0.76 (2.5)	130	120	170	140
0.024 (0.8)	150	160	230	180

Table 21. Booth 3 Average Organic Concentrations at Specific Exhaust Face Heights.

Height m (ft)	Test 1 (mg/m^3)	Test 2 (mg/m^3)	Test 3 (mg/m^3)	Average (mg/m^3)
2.8 (9.3)	13	18	15	15
2.3 (7.6)	23	31	27	27
1.8 (5.9)	43	67	62	57
1.3 (4.2)	89	170	160	140
0.76 (2.5)	68	120	130	110
0.024 (0.8)	51	180	150	130



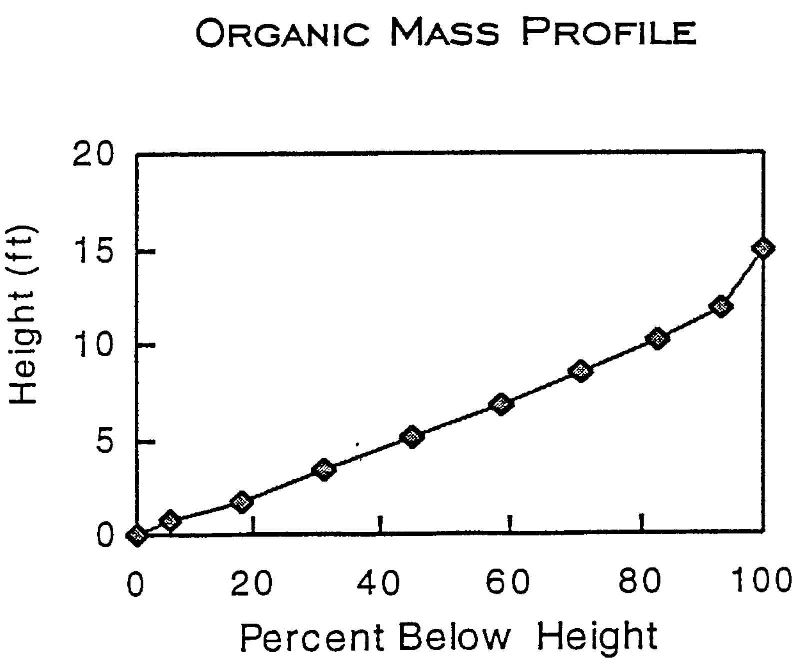
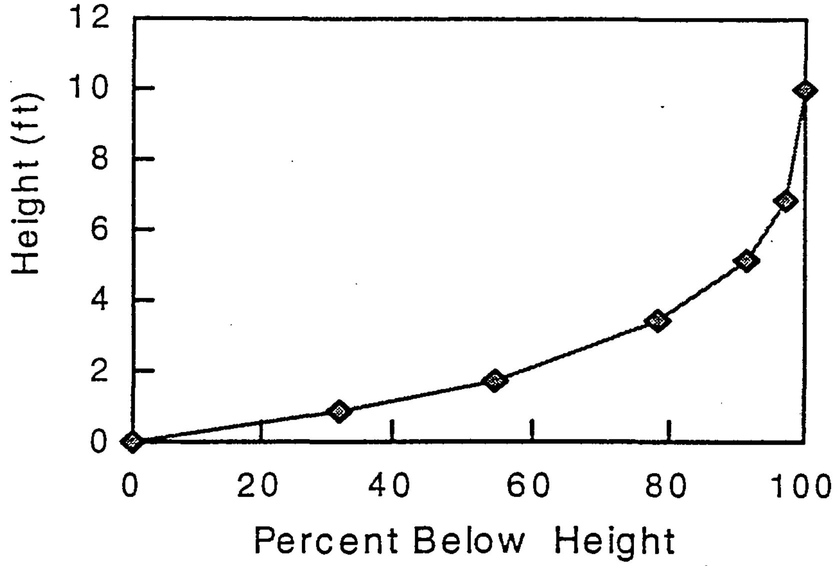


Figure 12. Cumulative Distribution of Metal and Organic Constituents at Various Heights Across the Exhaust Face for Booth 1, (to ensure conservative results, one outlying data point was omitted from the average results obtained to derive the metals graph).

METAL MASS PROFILE



ORGANIC MASS PROFILE

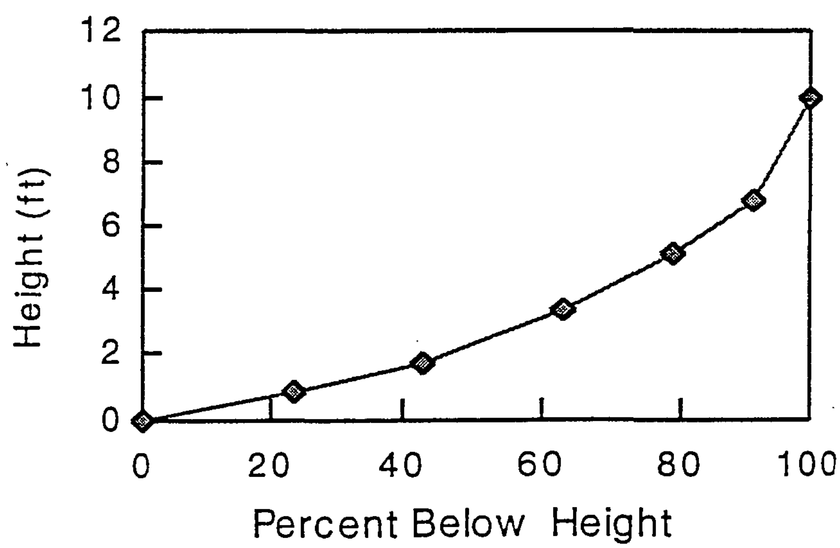
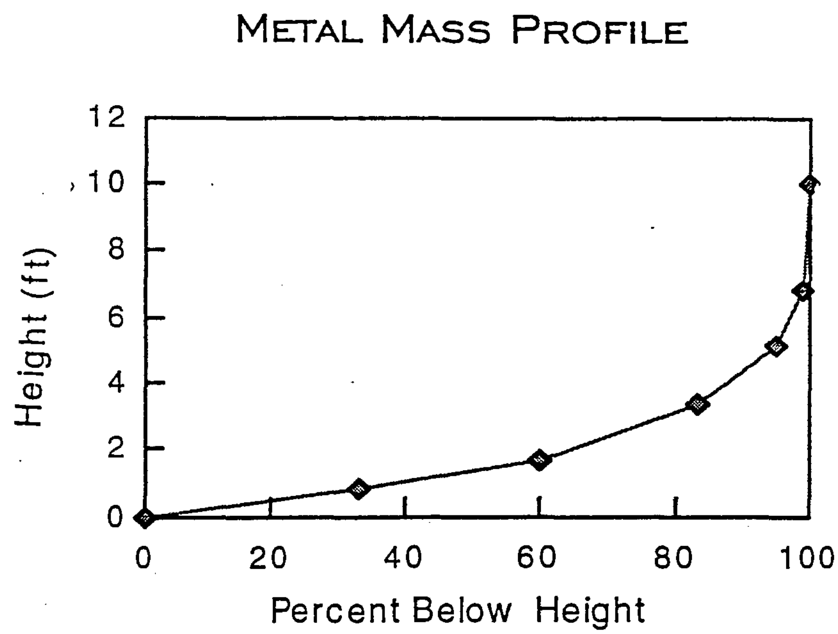


Figure 13. Cumulative Distribution of Metal and Organic Constituents at Various Heights Across the Exhaust Face for Booth 2.



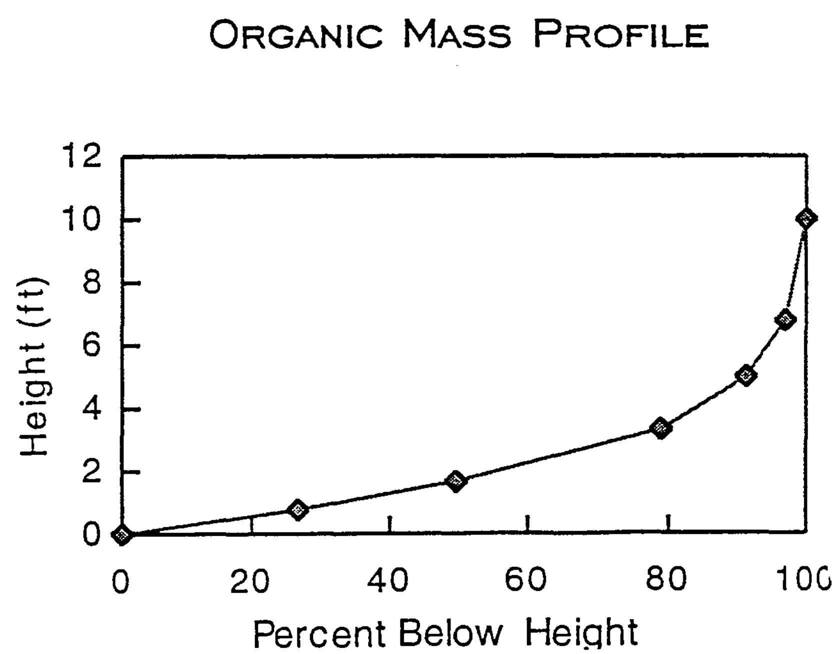


Figure 14. Cumulative Distribution of Metal and Organic Constituents at Various Heights Across the Exhaust Face for Booth 3.

Table 22. Booth 1 Painter Vicinity Measurements in Single-Pass Mode.

	Test 1		Test 2		Test 3		Average	
	Painter	Painter	Painter	Painter	Painter	Painter	Painter	Painter
Constituent Concentrations (mg/m^3)								
Trivalent chromium	0.065	0.028	0.098	0.012	0.058	0.009	0.074	0.016
Hexamethylene diisocyanate	0.035	0.018	0.0054	0.011	0.025	0.014	0.022	0.015
Methyl ethyl ketone	60	37	42	ND[1]	100	57	68	45
Ethyl acetate	0.25	0.33	0.24	ND	0.39	0.34	0.29	0.34
Methyl isobutyl ketone	130	58	83	ND	240	120	150	87
Toluene	140	71	86	ND	250	120	160	96
Butyl acetate	71	36	41	ND	80	48	64	42
Methyl isoamyl ketone	260	130	140	ND	160	100	190	120
Ethyl benzene	50	31	35	ND	73	44	53	38
Total xylenes	290	152	190	ND	490	250	320	200
Trimethyl benzene	12	6.7	8.5	ND	13	9.5	11	8.1
Hexyl acetate	15	7.9	10	ND	17	13	14	11
OSHA Factor outside respirator	3.3	1.7	1.7	1.7[2]	3.8	2.0	2.9	1.8
Calculated painter OSHA Factor (assigned protection factor of 10)	0.33	0.17	0.17	0.17	0.38	0.20	0.29	0.18
Calculated painter OSHA Factor (assigned protection factor of 25)	0.13	0.068	0.068	0.068	0.15	0.08	0.12	0.072

1 ND = No data; sample lost due to field sampling error.

2 The OSHA Factor reported here was derived from the organics data collected for the other painter at the same time.

Table 23. Booth 2 Painter Vicinity Measurements in Single-Pass Mode.

	Test 1		Test 2		Test 3		Average	
	Painter	Painter	Painter	Painter	Painter	Painter	Painter	Painter
Constituent Concentrations (mg/m^3)								
Hexavalent chromium	0.0035	0.0042	0.0060	0.0046	0.0012	0.0019	0.0030	0.0040
Phosphoric acid	0.016	0.016	0.017	0.017	0.014	0.014	0.016	0.016
Hexamethylene diisocyanate	0.0012	0.0030	0.0013	0.0091	0.0011	0.0059	0.0010	0.0060
Methyl ethyl ketone	4.2	5.6	5.2	6.8	5.5	16	5.0	9.5
Ethyl acetate	0.63	0.23	0.16	0.16	0.30	0.53	0.31	0.25
n-Butanol	7.4	2.4	8.3	0.18	4.9	0.68	6.9	1.1
Methyl isobutyl ketone	1.5	13	3.1	11	1.7	3.5	2.1	9.2
Toluene	2.4	12	3.6	11	1.8	4.1	2.6	9.0
Butyl acetate	0.56	4.2	1.6	4.5	0.99	1.4	1.1	3.4
Methyl isoamyl ketone	0.15	0.15	0.16	0.16	0.13	0.13	0.15	0.15
Ethyl benzene	0.60	5.4	1.5	4.5	1.1	1.4	1.1	3.8
Total xylenes	3.1	27	8.1	23	6.3	7.0	5.8	19
Trimethyl benzene	1.4	1.6	1.9	1.6	1.6	0.44	1.6	1.2
Hexyl acetate	0.20	1.0	0.94	1.7	0.72	0.46	0.62	1.1
OSHA Factor outside respirator	3.6	4.5	5.8	5.0	1.3	2.2	3.6	3.9
Calculated painter OSHA Factor (assigned protection factor of 25)	0.14	0.18	0.23	0.20	0.052	0.088	0.14	0.16

Note: This table assumes that hexavalent chrome comprises one-half of the chrome measured in the vicinity of the painter.

Table 24. Booth 3 Painter Vicinity Measurements in Single-Pass Mode.

	Test 1 Painter	Test 2 Painter	Test 3 Painter	Average Painter
Constituent Concentrations				
(mg/m^3)	0.014	0.0039	0.010	0.009
Hexavalent chromium	0.014	0.015	0.015	0.015
Phosphoric acid	0.001	0.001	0.001	0.001
Hexamethylene diisocyanate	20	65	59	48
Methyl ethyl ketone	0.13	0.20	0.58	0.30
Ethyl acetate	3.4	4.6	4.1	4.0
n-Butanol	5.2	7.2	4.8	5.7
Methyl isobutyl ketone	7.5	9.9	5.8	7.7
Toluene	4.1	5.4	2.4	4.0
Butyl acetate	0.13	0.14	0.14	0.14
Methyl isoamyl ketone	2.3	3.2	2.1	2.5
Ethyl benzene	12	16.	11	13
Total xylenes	1.7	1.5	1.4	1.5
Trimethyl benzene	2.4	2.9	1.3	2.2
Hexyl acetate				
OSHA Factor outside respirator	14	4.2	10	9.4
Calculated painter OSHA Factor (assigned protection factor of 25)	0.55	0.17	0.41	0.38

Note: This table assumes that hexavalent chrome comprises one-half of the chrome measured in the vicinity of the painter.

Table 25. Booth 1 Painter Vicinity Measurements in Recirculation Mode.

	Test 1		Test 2		Test 3		Average	
	Painter	Painter	Painter	Painter	Painter	Painter	Painter	Painter
Constituent Concentrations (mg/m^3)								
Trivalent chromium	0.006	0.035	0.037	0.013	0.0036	0.048	0.016	0.032
Hexamethylene diisocyanate	0.026	0.013	0.0089	0.021	0.034	0.023	0.023	0.019
Methyl ethyl ketone	17	65	31	44	66	57	38	55
Ethyl acetate	0.22	0.24	0.23	0.23	0.34	0.26	0.26	0.24
Methyl isobutyl ketone	44	160 [E]	150 [E]	190	220	210	140	190
Toluene	41	150 [E]	140 [E]	190	270	220	150	190
Butyl acetate	18	62 [E]	48 [E]	67	92	76	53	68
Methyl isoamyl ketone	2.0	23	3.3 [E]	8.2	9.7	12	5.0	14
Ethyl benzene	18	65 [E]	59 [E]	75	110	89	62	76
Total xylenes	94	340 [E]	310 [E]	410	600	480	340	410
Trimethyl benzene	3.7	13	11	13	20	15	12	14
Hexyl acetate	5.5	16	7.9	11	17	13	10	13
OSHA Factor outside respirator	1.3	2.4	2.0	2.8	4.0	3.3	2.4	2.8
Calculated painter OSHA Factor (assigned protection factor of 10)	0.13	0.24	0.19	0.28	0.40	0.33	0.24	0.28
Calculated painter OSHA Factor (assigned protection factor of 25)	0.052	0.096	0.076	0.112	0.16	0.13	0.096	0.112

[E] Value estimated from chromatograph results

Table 26. Booth 2 Painter Vicinity Measurements in Recirculation Mode.

	Test 1		Test 2		Test 3		Average	
	Painter	Painter	Painter	Painter	Painter	Painter	Painter	Painter
Constituent Concentrations								
(mg/m^3)	0.0012	0.0048	0.0024	0.011	0.0012	0.0014	0.0016	0.0057
Hexavalent chromium	0.012	0.012	0.014	0.015	0.014	0.014	0.013	0.014
Phosphoric acid	0.0010	0.0011	0.0011	0.0061	0.0011	0.0046	0.011	0.0039
Hexamethylene diisocyanate	6.6	36	4.1	13	4.1	29	4.9	26
Methyl ethyl ketone	0.11	0.73	0.13	0.14	0.21	0.16	0.15	0.34
Ethyl acetate	7.6	3.8	7.9	2.2	6.7	3.2	7.4	3.1
n-Butanol	2.7	21	3.2	8.3	2.8	20	2.9	16
Methyl isobutyl ketone	4.5	32	6.3	11	3.7	26	4.8	23
Toluene	2.5	16	2.5	5.1	8.0	45	4.3	22
Butyl acetate	0.11	0.14	0.13	0.14	0.13	0.13	0.12	0.14
Methyl isoamyl ketone	1.5	9.4	1.8	3.6	0.97	5.2	1.4	6.1
Ethyl benzene	8.1	52	9.9	18	6.8	33	8.3	34
Total xylenes	2.6	6.1	2.9	2.0	2.2	4.4	2.6	4.2
Trimethyl benzene	2.5	9.0	2.1	2.5	1.9	6.2	2.2	5.9
Hexyl acetate								
OSHA Factor outside respirator	1.4	5.2	2.6	11	1.5	1.8	1.9	6.1
Calculated painter OSHA Factor (assigned protection factor of 25)	0.056	0.21	0.10	0.44	0.060	0.072	0.076	0.24

Note: This table assumes that hexavalent chrome comprises one-half of the chrome measured in the vicinity of the painter.

Table 27. Booth 3 Painter Vicinity Measurements in Recirculation Mode.

	Test 1 Painter	Test 2 Painter	Test 3 Painter	Average Painter
Constituent Concentrations				
(mg/m^3)	0.014	0.0019	0.0021	0.0060
Hexavalent chromium	0.013	0.013	0.012	0.013
Phosphoric acid	0.00085	0.00085	0.00085	0.00085
Hexamethylene diisocyanate	ND[1]	41	110	76
Methyl ethyl ketone	ND	0.16	0.31	0.24
Ethyl acetate	ND	3.9	5.8	4.9
n-Butanol	ND	5.8	4.3	5.1
Methyl isobutyl ketone	ND	11	8.7	9.9
Toluene	ND	3.1	2.6	2.9
Butyl acetate	ND	0.13	0.13	0.13
Methyl isoamyl ketone	ND	2.8	2.0	2.4
Ethyl benzene	ND	14	10	12
Total xylenes	ND	1.8	1.4	1.6
Trimethyl benzene	ND	1.7	1.0	1.4
Hexyl acetate				
Resulting OSHA Factor	14	2.1	2.4	6.1
Calculated Painter OSHA Factor (assigned protection factor of 25)	0.54	0.084	0.096	0.24

[1]ND = No data; sample lost due to field sampling error. The OSHA Factor reported here was derived only from the non-organic painter vicinity sampling data. It is believed that the organic concentration in the vicinity of the painter in Booth 2 is small, thus lack of organic data for this result should not impact the results repored herein.

Note: This table assumes that hexavalent chrome comprises one-half of the chrome measured in the vicinity of the painter.

6.3.2 Implications of Painter Vicinity Sampling Results.

From the results reported in Tables 22 through 27, it is immediately apparent that recirculation does not have a discernable impact on the painter vicinity concentrations. This premise was confirmed via statistical analysis to determine the data precision for each test event. The precision (or variability) of the measurement provides a means of discerning and quantifying recirculation impacts.

The results of this precision analysis are summarized in Table 28; note that the term "variability range" is defined as the interval occurring within one standard deviation of the average value. For Booths 1 and 3, the OSHA Factor variability range under single pass (non-recirculating) conditions is virtually the same as the OSHA Factor range occurring under recirculating conditions.

The Booth 2 results under the recirculation condition indicate slightly increased average and range values, however this can be traced to the OSHA Factor value of 11 measured in the vicinity of Painter 2 during Test 2. This value is significantly higher than any other measurements collected in Booth 2. No additional data exist to explain this measurement such as observation, however, if we consider this individual result to be a data outlier, the Booth 2 OSHA Factor under recirculating conditions is much lower than under single-pass operation. It is possible that the painter inadvertently applied paint obliquely to the sample cassette used to derive this particular result.

Because the differences measured for the single-pass and recirculation conditions fall within the measurement variability range, it is reasonable to conclude that recirculation has little or no measurable impact on the constituent concentrations in the vicinity of the painter. The data further indicates that the "cloud effect" is the principal contributor to the painter exposure level. This confirms similar findings reported previously at other painting facilities.[19]

Several operational issues immediately become apparent in reviewing the results presented in Tables 22 through 27. First, it appears that organic and inorganic constituent concentrations in the vicinity of the Booth 1 painters under recirculating and non-recirculating conditions are much higher than the concentrations found in the vicinity of the painters in Booths 2 and 3. This difference stems from the fact that Booth 1 is a vehicle booth in which the painters move around large equipment (armored personnel vehicles [APVs], Humvees, etc.) and workpieces that are painted. Under these conditions, the painters frequently paint either against or across the ventilation airflow, thus overspray particulate and solvent vapors often surround them in a heavy cloud. Furthermore, the painters in Booth 1 often paint in the confined space underneath the vehicles, or are located downwind of painted vehicle sections from which organic vapors are released as the coating dries (e.g. flash-off). It is likely that these factors contribute heavily to the organic concentrations in the vicinity of the painter, and therefore contribute to the OSHA Factor results reported in Tables 22 and 25. Conversely, the painters in Booths 2 and 3 tend to remain upwind of the target workpiece, and therefore do not become so surrounded by the overspray cloud or paint drying fumes.

Table 28. Precision Analysis of Painter Vicinity OSHA Factor Measurements.

Condition	Test	Booth 1 Painter 1	Booth 1 Painter 2	Booth 2 Painter 1	Booth 2 Painter 2	Booth 3 Painter
Single-Pass Mode	Test 1	3.3	1.7	3.6	4.5	13
	Test 2	1.7	1.7[1]	5.8	5.0	4.2
	Test 3	3.8	2.0	1.3	2.2	10
	Average (painter 1&2)	2.4		3.7		9.1
	Standard Deviation	0.86		1.6		3.7
	Variability Range[2]	1.5 - 3.2		2.2 - 5.3		5.4 - 12.7
Recirculation Mode	Test 1	1.3	2.4	1.4	5.2	13[3]
	Test 2	1.9	2.8	2.6	11	2.1
	Test 3	3.9	3.3	1.5	1.8	2.4
	Average (painter 1&2)	2.6		3.9		5.8
	Standard Deviation	0.86		3.4		5.1
	Variability Range[2]	1.7 - 3.5		0.5 - 7.3		0.76-10.9
	Booth 2 Average Without Outlier			2.5		
	Booth 2 Standard Deviation Without Outlier			1.4		
	Booth 2 Variability Range Without Outlier			1.1 - 3.9		

1 The OSHA Factor was derived from organics data collected for the other painter - See Table 22.
2 Range is defined as the interval that is within one standard deviation of the average value.
3 The OSHA Factor reported here was derived only from the non-organic painter vicinity sampling data. It is believed that the organic concentration in the vicinity of the painter in Booth 2 is small, thus lack of organic data for this result should not impact the results reported herein - See Table 27.

It is not intuitively obvious why the Booth 1 OSHA Factor is generally lower than the OSHA Factors determined for Booths 2 and 3, especially because the painter vicinity concentrations are much higher. As indicated in Equation 1, the OSHA Factor is derived from two parameters; the concentration of a particular constituent as well as the specific PEL for that constituent. The OSHA Factor results reported for Booths 2 and 3 are somewhat higher than the results reported for Booth 1, which indicates the presence of one or more compounds having relatively low PELs which are in the coatings used in Booths 2 and 3 , and not present in Booth 1. As indicated in Section 3, Booth 1 is used for topcoat applications only, thus only the trivalent form of chromium is present in Booth 1. However, a wash primer material containing hexavalent chromium is applied in Booths 2 and 3, and the PEL for hexavalent chrome is much lower than the PEL for any other compound present, thus it has a major impact on the OSHA Factors indicated for Booths 2 and 3.

It is easily surmised from these results that the impact of recirculation on the quality of the ventilation air surrounding the paint booth operators is relatively imperceptible. The fact that the total coating usage rates (Table 15) for each booth during the recirculation tests are consistently higher than the usage rates recorded during the single-pass tests further substantiates this conclusion. Finally it should be noted that the OSHA PELs employed to derive the painter vicinity OSHA Factors reported in Tables 22 through 27 are 8 hour TWAs, thus the OSHA Factor results assume that the paint booth operators apply paint in the booths for 8 hours per day. Of course, typical painting intervals (the hours per day that paint is actually sprayed) do not exceed 4-5 hours a day (if that much). Therefore, actual painter vicinity OSHA Factors are at least 25% lower than those reported in Tables 22 through 27.

6.4 COMPARISON OF FTIR RESULTS TO NIOSH 1300 SPECIATED ORGANIC DATA AND FID RESULTS

The results of the NIOSH 1300 speciated organic concentration measurements and the EPA Method 25A data collected in the recirculation ducts during the Technology Demonstration Study were compared against preliminary FTIR data to enhance the FTIR spectral analysis software, and evaluate the results of the FTIR measurements.[10,14] The results of this comparison for Booths 1, 2, and 3 are indicated in Tables 29, 30, and 31, respectively. The following procedures were employed to perform this analysis:

1) For each test, the NIOSH 1300 speciated data collected in each of the two recirculation ducts were reconciled with the volumetric flow rates measured in these ducts and then averaged to derive a single, representative recirculation stream concentration value for each constituent.

2) For each test, the instantaneous FID results measured (via EPA Method 25A) in each recirculation duct were averaged to derive a single concentration value that represents the organic carbon concentration measured in each exhaust duct. The calculated concentration value was then reconciled to obtain a single, representative recirculation duct organic concentration value for each test.

3) During each test, a continuous sample gas stream was extracted from each recirculation duct; these sample streams were combined and then passed through the FTIR sample cell. The FTIR operated continuously throughout each test, thus the results obtained for each constituent were averaged over the sampling period to obtain a single, representative recirculation stream concentration value from the FTIR results.

4) The results of Steps 1 through 3 were compared to assess the overall performance of the FTIR system.

Table 29. FTIR - NIOSH 1300 Comparison Summary for Booth 1 Recirculation Duct Samples.

	Organics 3 (mg/m^3)		Organics 4 (mg/m^3)		Organics 6 (mg/m^3)	
Compound	FTIR	NIOSH	FTIR	NIOSH	FTIR	NIOSH
Butyl + Hexyl acetates	57	26	78	21	66	14
MEK	16	19	17	16	9	6
MIAK + MIBK	95	39	135	42	132	24
Ethyl benzene	40	20	67	17	53	14
Xylenes	115	105	173	87	186	71
Toluene	50	44	72	36	74	28
Total Carbon	613	427	902	368	872	271
Total Carbon from FID measurement	399		434		438	

The FTIR spectral analysis software installed on the MCLB paint booths was developed specifically for this application. It is evident from the data presented in Tables 29 through 31 that, in instances where there is disagreement between the FTIR results and the NIOSH 1300 results, the FTIR consistently yields higher concentrations. This in fact increases the safety factor inherent in the monitoring system, because the FTIR has a tendency to over predict the constituent concentrations. Thus, if the FTIR system detects concentrations in the recirculation duct that exceed the established setpoint, it is likely that the actual concentrations in the recirculation duct are somewhat lower.

In actuality, it is anticipated that the concentrations measured by the FTIR systems that were installed at MCLB actually provide more realistic and representative data than it appears in Tables 29 through 31. This conclusion is drawn from a number of factors, including:

- The FTIR spectral data collected during the Technology Demonstration Study were taken at a one-half wave number ($0.5\ cm^{-1}$) resolution. However, to reduce processing time and increase the signal to noise ratio, the FTIR systems installed on the MCLB paint booths are set at one wavenumber ($1\ cm^{-1}$) resolution, and $0.5\ cm^{-1}$ analysis software was developed accordingly. In analyzing the $0.5\ cm^{-1}$ spectral results reported in Tables 29 through 31, the data were first deresolved prior to analysis with the $1\ cm^{-1}$ resolution software. This reduces the spectral match in the analysis module, and therefore had an impact on the results presented in Tables 29 through 31.

Table 30. FTIR - NIOSH 1300 Comparison Summary for Booth 2 Recirculation Duct Samples

	Organics 1 (mg/m^3)		Organics 2 (mg/m^3)		Organics 4 (mg/m^3)		Organics 6 (mg/m^3)	
Compound	FTIR	NIOSH	FTIR	NIOSH	FTIR	NIOSH	FTIR	NIOSH
Butyl + Hexyl acetates	55	16	30	8	90	35	88	23
n-Butyl alcohol	12	3	16	5	10	10	37	13
MEK	45	39	32	8	22	14	158	9
MIAK + MIBK	31	12	17	8	45	11	15	13
Ethyl benzene	2	3	0	4	8	3	2	7
Xylenes	63	17	48	20	56	23	91	34
Toluene	28	12	21	12	30	16	52	24
Total Carbon	368	153	258	104	405	170	664	214
Total Carbon from FID measurement	137		110		183		212	

Table 31. FTIR - NIOSH 1300 Comparison Summary for Booth 3 Recirculation Duct Samples.

	Organics 1 (mg/m^3)		Organics 2 (mg/m^3)		Organics 3 (mg/m^3)		Organics 4 (mg/m^3)		Organics 5 (mg/m^3)	
Compound	FTIR	NIOSH	FTIR	NIOSH	FTIR	NIOSH	FTIR	NIOSH	FTIR	NIOSH
Butyl + Hexyl acetates	9	3	13	2	12	1	8	2	4	2
n-Butyl alcohol	2	1	14	2	11	1	1	1	6	1
MEK	0	2	14	2	33	3	0	2	35	2
MIAK + MIBK	41	1	16	1	0	1	15	1	2	2
Ethyl benzene	0	0	0	1	0	1	0	0	0	1
Xylenes	19	1	21	3	19	4	11	2	15	6
Toluene	7	1	11	3	29	6	7	4	13	7
Total Carbon	127	14	137	21	164	28	67	18	114	41
Total Carbon from FID measurement	15		38		45		39		54	

- In the FTIR sampling portion of the Technology Demonstration Study, the air sample collected during background spectra sample runs were probably not given the level of conditioning and handling that is required to obtain precise results. This is because the FTIR sampling system was not set up in the final configuration, thus "field test" conditions occurred. Proper conditioning of background sample air is important because moisture and residual organics will impact the analytical results. An improved background system was developed for the FTIRs installed at MCLB.

The FTIR systems installed at MCLB were programed to perform the OSHA Summation Rule calculation (Equation 1 in Section 2) on a continuous basis for each set of speciated organic data that are collected. The TWA values programmed into the FTIR software to perform this calculation are summarized in Table 32. Most of the TWA values are OSHA 8-hour PELs. However, because the FTIR sample stream is extracted upstream of where the fresh make-up air is brought into each booth, and because the FTIR operates on a continuous basis (and therefore provides virtually instantaneous notification of excessive recirculation duct concentrations), it was considered reasonable to program the FTIR with ACGIH 15 minute STEL values for select compounds such as MEK. As indicated from an inspection of Tables 29 through 31, all of the organic concentration results are well below the established OSHA levels.

Table 32. TWA Levels Programmed into the FTIR OSHA Additive Rule Calculation.

Compound	TWA Setpoint		TWA Source
	ppm	mg/m^3	
Ethyl benzene	100	435	OSHA PEL
IPA	400	980	OSHA PEL
MEK (2-butanone)	300	590	ACGIH STEL
MIAK (5 methyl-2-hexanone)	100	475	OSHA PEL
MIBK (hexone)	100	410	OSHA PEL
PGMEA	100		Note 1
Toluene	200	766	OSHA PEL
Butyl acetate	150	710	OSHA PEL
Hexyl acetate	50	300	OSHA PEL
Xylenes	100	435	OSHA PEL
n-Butanol	100	300	OSHA PEL

1 No value specified by OSHA, ACGIH, or NIOSH. Thus, the 100 ppm OSHA PEL for ethylene glycol monoethyl ether acetate (EGEEA) and propylene glycol monomethyl ether (PGME) was substituted.

Since completing the Technology Demonstration Study in December, 1995, the FTIR systems installed at MCLB have found multiple applications as ventilation system evaluation and diagnostic tools, in addition to the safety monitoring application originally envisioned. As a result of these system diagnostic/evaluation efforts, several interesting operating characteristics were identified,as follows:

- The use of new coatings was detected through these FTIR system diagnostic exercises. These coatings were identified because the FTIR provides speciated concentration data, thus anomalies with respect to solvent mixtures or unanticipated results are noted from the FTIR data. The potential impact of these coating reformulations is being assessed.

- Significant variability in the technical skill and paint application habits of individual paint booth operators was noted when the Booth 2 FTIR repeatedly measured high concentration excursions that triggered the ventilation system to convert to single pass operation under seemingly "typical" painting circumstances. Upon inspection, it was found that the FTIR system correctly responded to excursions created by ineffective painter habits. It was further noted that the individual operating in Booth 2 when these excursions occurred tended to use significantly more coating material and solvents than most painters that typically operate in Booth 2. As a result of these observations, Barstow MCLB is contemplating the need for increased painter training with respect to coating application and housekeeping procedures. The need for painter training does not in any way reflect on the inherently safe recirculation system; rather the training will serve to avoid nuisance interruptions that are the result of easily preventable events generated by inefficient painter habits.

- To minimize migration of hazardous constituents from the high concentration zones of the booth into the recirculation stream, it is necessary to adequately seal the filter elements located at the partition level.

SECTION 7

ECONOMIC BENEFITS OF RECIRCULATION AND OTHER FLOW REDUCTION STRATEGIES

As indicated in Section 2, the cost to install and operate a typical VOC emission control system is directly related to the volume flow rate processed by the device, thus reducing the process exhaust flow rate will also reduce system costs. Moreover, VOC emission control systems typically achieve a destruction efficiency of 95% or better, irrespective of the volume flow rate that is processed. The key advantage of recirculation and the other ventilation system enhancements installed on the MCLB paint booths is in achieving the flow reduction necessary to decrease APCS installation/operating costs without sacrificing system performance in terms of destruction efficiency and pollution prevention. However, it is recognized that the economic advantages inherent in these flow reduction strategies are realized only if the ventilation system design and installation costs are significantly offset by reductions in the installation and operating costs associated with the VOC emission control system. This section summarizes the results of a detailed economic analysis which demonstrates the economic benefits of recirculation and the other flow reduction strategies implemented at the Barstow MCLB facility. The three key parameters considered for this economic analysis are as follows:

- System exhaust flow rates .
- VOC emission control system configurations.
- Paint booth retrofit and VOC emission control system installation and operating costs.

7.1 EXHAUST FLOW RATES

The process exhaust flow rate is a key parameter because it provides the basis for establishing the cost savings accrued from recirculation and the other ventilation system modifications discussed in Section 5. For this analysis, three different flow rates are considered:

Initial Configuration of Booths - The cost of controlling VOC emissions from the booths in their initial single pass configuration provides the baseline for this analysis. As indicated in Section 3, the initial exhaust flow rate was 4,064 m^3/min (143,500 cfm).

Final Configuration of Booths - The final exhaust flow rate achieved after booth modifications were complete is 1,176 m^3/m (41,450 cfm). This flow reduction is attributed to several factors, including recirculation/flow partitioning, VFD fans, and interlocking operations such that Booth 1 may be operated any time, and Booths 2 and 3 operate sequentially. The 1,176 m^3/min flow rate (41,450 cfm) is the combined exhaust from Booth 1 (572 m^3/min [20,120 cfm] and Booth 2 (604 m^3/min [21,330 cfm]).

Initial Configuration of Booths 1 and 2 - In the final configuration, the maximum exhaust flow rate occurs when Booths 1 and 2 are operated simultaneously. It is therefore appropriate to perform an emission control cost comparison for Booths 1 and 2 in their original configuration (at 3,285 m^3/min [116,000 cfm]) and in their final configuration (1,174 m^3/min [41,450 cfm]).

The results of the economic analyses summarized in tabular form below were developed based on these exhaust flow rate parameters.

7.2 VOC EMISSION CONTROL SYSTEMS

There are many different types of VOC emission control systems that may be employed to control emissions from military paint spray booths. The fact that the installation and operating costs of these systems vary significantly must also be taken into consideration to develop an accurate and representative economic comparison. Two different VOC emission control technologies are included in the economic analysis to give a spectrum of viable emission control options and costs.

Regenerative Thermal Oxidizer (RTO): This systems achieves a very high thermal efficiency (up to 95%) compared to standard thermal oxidizer systems. This significantly reduces the fuel demand and the corresponding operating costs.

Rotor Concentrator/Recuperative Oxidizer (rotor/recup): This system employs a two step flow reduction process in which an adsorption rotor (zeolyte, carbon fiber, or other material) collects and concentrates the solvent vapor. The collected organics are continuously desorbed from the rotor and vented to a recuperative oxidizer. The rotor concentrator typically achieves a 10:1 volume flow reduction, which reduces both the size and the fuel demand of the recuperative oxidizer.

7.3 PAINT BOOTH RETROFIT AND EMISSION CONTROL COST PARAMETERS

Although there are many equipment vendors that manufacture and install both RTOs and rotor/recup systems, it was not necessary or feasible to solicit cost estimates from each manufacturer and develop aggregate cost projections for the three flow rate scenarios considered in this economic evaluation (see Section 7.1). Moreover, the objective of this economic analysis is to demonstrate that recirculation/flow partitioning and the other ventilation system modifications implemented on the MCLB paint booths significantly reduce VOC emission controls costs. To achieve this objective, it is necessary only to present control cost data that reasonably represent the spectrum of candidate emission control options. To develop the economic analysis results, representative system installation and operating cost data were obtained from the following sources:

OAQPS Control Cost Manual: The Control Cost Manual was developed by EPA's Office of Air Quality Planning and Standards (OAQPS) to provide facilities that face air pollution control requirements with guidance and background information regarding various emission control options.[20] Data pertaining to RTO system installation and operating costs were obtained from this manual and employed in the cost evaluation. In addition to RTO system costs, the OAQPS Control Cost Manual was also used to estimate costs for site preparation and other logistics such as foundation construction, utilities, startup, etc. The RTO system capital cost data provided in the manual are in 1989 dollars, thus supplemental data pertaining to escalation indexes (also provided by OAQPS) were employed to convert the capital cost data to 1995 dollars.

Paint Booth Retrofit Contractor - Paint booth system retrofit design, installation, and operating cost estimates were supplied by Acurex Environmental Corporation. Acurex Environmental was the prime contractor responsible for planning and implementing all booth retrofit activities, and is therefore capable of providing accurate and representative estimates for system retrofit costs.

VOC Emission Control Vendor Cost Quotes - Two equipment vendors were contacted and provided system capital, installation, and operating cost data for the three flow rate scenarios considered in this evaluation. One provided supplemental data pertaining to RTO system economics, and the second provided cost data pertaining to rotor/recup systems.

7.4 COST ANALYSIS RESULTS

An Equivalent Uniform Annual Cash Flow (EUAC) analysis was performed in accordance with cost analysis procedures defined in Chapter 2 of the OAQPS Control Cost Manual.[20] The analysis assumes a twelve year life for the control systems and provides an average annualized cost for the system. The recirculation/patrition modification to the spray booths were shown to produce an immediate cost savings benefit.

The installation and operating EUAC cost analysis results for the three VOC emission control systems considered were completed for three flow scenarioes: 41,450 cfm, 116,000 cfm, and 143,500 cfm, Tables 33, 34, and 35, respectively. Supplemental information employed to derive these cost estimates are summarized in footnotes to each table. The results of the EUAC comparison are summarized in Table 36, and clearly indicates the significant economic benefit of installing the recirculation/partition flow system and making the other system adjustments described in Section 5.

The cost comparison evaluation was performed in accordance with the EUAC procedures and assumes a 12 year equipment life, and an 8% interest rate. As shown in the summary Table 36 the lower system capital and installation costs incurred for the integrated recirculation/VOC emission control system result in immediate cost benefits. For example, the EUAC analysis result for installing and operating a rotor/recup system to control emissions from Booths 1 and 2 without recirculation (i.e., a flow rate of 116,000 cfm, and paint booth retrofit costs of $0) is

$476,260 annualized cost over the twelve year life of the system. However, the result for operating the rotor/recup system to control emissions from Booths 1 and 2 modified with recirculation (i.e., a flow rate of 41,450 cfm and booth modification costs of $350,000) is $308,540 annualized cost over the twelve year period . Over the twelve year period, a $2,019,120 cost savings is realized due to the recirculation/partition booth modification. This represents a 35% reduction in annualized EUAC costs, as well as a 25% reduction in capital/installation costs and 53% reduction in system operating costs.

Table 33. Emission Control System Installation/Operating Costs at 1,176 m^3/min (41.450 cfm).

INITIAL CAPITAL AND INSTALLATION COSTS - 41,450 cfm, Booths 1 & 2 operated after retrofit (Booth 3 retrofit costs not included)

Purchased APCS Equipment Cost	RTO - OAQPS data (2)	RTO Vendor data	Rotor/Recup Vendor data
Control equipment capital cost	$810,414 (1)	$503,425 (5)	$800,000 (5)
Auxilliary equipment	$50,000 (3)	$50,000 (3)	$50,000 (3)
Sales tax (5%) (1)	$43,021	$27,671	$42,500
Freight	$34,417 (4%) (1)	$34,417 (OAQPS Value)	$34,000 (5)
Total APCS purchase equipment cos	$937,852	$615,513	$926,500
Direct APCS Installation Costs			
Foundation & Supports (4%) (1)	$37,514 (4%) (1)	$37,514 (OAQPS Value)	$41,400 (5)
Handling & Erection (5%) (1)	$46,893 (5%) (1)	$26,500 (5)	$51,800 (5)
Electrical & Piping (5%) (1)	$46,893 (5%) (1)	$46,893 (OAQPS Value)	$51,800 (5)
Insulation (.05%) (1)	$4,689 (0.05%) (1)	$4,689 (OAQPS Value)	$5,200 (5)
Total Direct APCS Installation Cost	$135,989	$115,596	$150,200
Indirect APCS Installation Costs			
Engineering	$37,514 (4%) (1)	$13,428 (5)	$225,000 (5)
Construction/field expenses	$18,757 (2%) (1)	(included)	(included)
Contractors fees	$46,893 (5%) (1)	(included)	(included)
Start-up	$18,757 (2%) (1)	$18,757 (OAQPS Value)	$20,700 (5)
Performance test	$9,379 (1%) (1)	$9,379 (OAQPS Value)	$10,400 (5)
Contingencies	$28,136 (3%) (1)	$20,950 (5)	$31,000 (5)
Total indirect APCS installation cost	$159,435	$82,514	$287,100
Paint booth retrofit cost (4):	$350,000	$350,000	$350,000
TOTAL INSTALLATED COST:	$1,583,275	$1,143,623	$1,713,800

(1) Unless otherwise specified, the factors were taken from the OAQPS Manual

(2) OAQPS Manual RTO capital cost assumptions include:

- Costs reported are 1st quarter 1989 dollars; conversion data from OAQPS manual supplements
- Formula: $ = (2.204 X 10E5) + 11.57Q
- Results: 1989 $ 1995 $

  $699,977 $810,414

(3) Auxiliary equipment is monitoring system

(4) Paint booth installation data from Acurex Environmental Design Group

(5) Manufacturers' estimated cost

OPERATING COSTS (1)

	RTO - OAQPS data (2) (3)				RTO Vendor (2)				Rotor/Recup Vendor (8)(10)			
APCS			$/hr	$/yr			$/hr	$/yr			$/hr	$/yr
Electricity (4)	136	kW (3)	$8.15	$24,442	113	kW (8)	$6.78	$20,340	65	kW (8)	$4	$11,700
Natural gas (5)	3.97	MBtu/hr	$15.88	$59,700	3.97	MBtu/hr (8	$15.88	$54,005	2.04	MBtu/hr (8	$8	$42,840
Maintenance (6)	4	hr/wk	$20.00	$4,000	4	hr/wk	$20.00	$4,000	4	hr/wk	$20	$4,000
Miscellaneous	$5,000	$/yr		$5,000	$5,000	$/yr		$5,000	$7,500	$/yr (8)		$7,500
												$0
Paint Booths												
Maintenance labor (6)(	8	hr/wk	$20.00	$8,000	8	hr/wk	$20.00	$8,000	8	hr/wk	$20.00	$8,000
Electricity (4) (9)	39.4	kW	$2.36	$7,092	39.4	kW	$2.36	$7,092	39.4	kW	$2.36	$7,092
TOTAL ANNUAL OPERATING COST:				$108,234				$98,437				$81,132

(1) Booths operate 10 hours/day, 6 days/week, 50 weeks/year

(2) RTO Vendor assumptions for standard and startup operations:

RTO operates at 95% thermal efficiency 10 hrs/day
RTO operates additional 45 min/day @ full fire (6.7 MBTu/hr) 5 days per week
RTO operates additional 1 hr/day @ full fire (6.7 MBTu/hr) 1 day per week
[last two items adds anual n.g. cost factor of ($/MBtu*6.7M Btu/hr)*50*[(5*45/60) + 1]

OAQPS Manual Assumptions for standard and start-up operations:

RTO operates at 95% thermal efficiency 10 hrs/day
RTO operates additional 1.5 hour per day @ full fire (6.7 MBTu/hr)

(3) Additional OAQPS Manual assumptions:

14 inch pressure drop through system
fan/motor efficiency is 50% (e)
electricity calculated from the formula: 1.14E-4*Q*dp/e

(4) Electricity is $0.06/kWhr

(5) The following assumptions apply to all control systems data sets:

Natural gas is $4/Mbtu
Oxidizer operated at 1650F
Heat capacity of air is 0.255 Btu/lbF, density is 0.0739 lb/scf
Intake air is at an average temperature of 70F
There is no fuel value in exhaust gas

(6) Maintenance labor is $20/hr

(7) Maintenance items such as filter replacement are the same for recirculating & non-recirculating booths and are therefore not included

(8) Manufacturers' estimate

(9) Paint booth operating data from Acurex Environmental energy audit/estimate: Booths 1 & 2 operated simultaneously in final configuration

Table 34. Emission Control System Installation/Operating Costs at 3,285 m^3/min (116,000 cfm).

INITIAL CAPITAL AND INSTALLATION COSTS - 116,000 cfm, Booths 1 & 2 only in their original configuration

	RTO - OAQPS data (2)	RTO Vendor data	Rotor/Recup Vendor data
Purchased APCS Equipment Cost			
Control equipment capital	$1,309,045 (1)	$1,213,200 (5)	$1,320,000
Auxiliary equipment	$50,000 (3)	$50,000 (3)	$50,000 (3)
Sales tax (5%) (1)	$92,952	$63,160	$68,500
Freight	$74,362 (4%)(1)	$74,362 (OAQPS Value)	$54,800
Total APCS capital cost	$2,026,359	$1,400,722	$1,493,300
Direct APCS Installation Costs			
Foundation & Supports	$81,054 (4%)(1)	$81,054 (OAQPS Value)	$59,732
Handling & Erection	$101,318 (5%)(1)	$60,200 (5)	$74,665
Electrical & Piping	$101,318 (5%)(1)	$101,318 (OAQPS Value)	$74,665
Insulation (.05%) (1)	$10,132 (0.05%)(1)	$10,132 (OAQPS Value)	$7,467
Total Direct APCS Installation Cost	$293,822	$252,704	$216,529
Indirect APCS Installation Costs			
Engineering	$81,054 (4%) (1)	$26,785 (5)	$480,000 (5)
Construction/field expenses	$40,527 (2%) (1)	(included)	(included)
Contractors fees	$101,318 (5%) (1)	(included)	(included)
Start-up	$40,527 (2%) (1)	$40,527 (OAQPS Value)	$29,866
Performance test	$20,264 (1%) (1)	$20,264 (OAQPS Value)	$14,933
Contingencies	$60,791 (3%) (1)	$41,300 (5)	$44,799
Total indirect APCS installation cost	$344,481	$128,876	$569,598
Paint booth retrofit cost (4):	$0	$0	$0
TOTAL INSTALLATED COST:	$2,564,662	$1,782,302	$2,279,427

(1) Unless otherwise specified, the factors were taken from the OAQPS Manual
(2) OAQPS Manual RTO capital cost assumptions include:
- Costs reported are 1st quarter 1989 dollars; conversion data from OAQPS manual supplements
- Formula: $ = (2.204 X 10E5) + 11.57Q
- Results: 1989 $ 1995 $
  $1,562,520 $1,309,045

(3) Auxiliary equipment is monitoring system
(4) Paint booth installation data from Acurex Environmental Design Group
(5) Manufacturers' estimate for system cost.

OPERATING COSTS (1)

	RTO - OAQPS data (2) (3)				RTO Vendor (2)				Rotor/Recup Vendor (3)(10)			
APCS			$/hr	$/yr			$/hr	$/yr			$/hr	$/yr
Electricity (4)	380	kW (3)	$22.80	$68,403	282	kW (8)	$16.92	$50,760	168	kW (8)	$10	$30,225
Natural gas (5)	10.4	MBtu/hr	$41.45	$154,488	10.50	MBtu/hr (8	$42.01	$145,138	4.95	MBtu/hr (8	$20	$103,950
Maintenance (6)	4	hr/wk	$20.00	$4,000	4	hr/wk	$20	$4,000	4	hr/wk	$20	$4,000
Miscellaneous	$10,000	$/yr		$10,000	$10,000	$/yr		$10,000	$10,000	$/yr		$10,000
Paint Booths												
Maintenance labor (6)(7)	8	hr/wk	$20.00	$8,000	8	hr/wk	$20	$8,000	8	hr/wk	$20	$8,000
Electricity (4) (9)	97.9	kW	$5.87	$17,622	97.9	kW	$6	$17,622	97.9	kW	$6	$17,622
TOTAL ANNUAL OPERATING COST:				$262,513				$235,520				$173,797

(1) Booths operate 10 hours/day, 6 days/week, 50 weeks/year
(2) RTO Assumptions for standard and startup operations:
  RTO operates at 95% thermal efficiency 10 hrs/day
  RTO operates additional 45 min/day @ full fire (20.1 MBtu/hr) 5 days per week
  RTO operates additional 1 hour/day@ full fire (20.1 MBTu/hr) 1day per week
  [last two items adds anual n.g. cost factor of ($/Btu*20.1 Btu/hr)*50/0.05*[(5*45/60) + 1]
 OAQPS Assumptions for standard and startup conditions
  RTO operates at 95% thermal efficiency 10 hrs/day
  RTO operates additional 1.5 hr per day @ full fire (20.1 MBtu/hr)
(3) Additional OAQPS Manual assumptions:
  14 inch pressure drop through system
  fan/motor efficiency is 50% (e)
  electricity calculated from the formula: 1.14E-4*Q*dp/e
(4) Electricity is $0.06/kWhr
(5) The following assumptions apply to all control systems data sets:
  Natural gas is $4/Mbtu
  Oxidizer operated at 1650F
  Heat capacity of air is 0.255 Btu/lbF; density is 0.0739 lb/scf
  Intake air is at an average temperature of 70F
  There is no fuel value in exhaust gas
(6) Maintenance labor is $20/hr
(7) Maintenance items such as filter replacement are the same for recirculating & non-recirculating booths and are therefore not included
(8) Manufacturers' estimate
(9) Paint booth operating data from Acurex Environmental energy audit/estimate: Booths 1 & 2 operated simultaneously in original configuration
(10) Rotor concentrator achieves a 10:1 volume reduction

Table 35. Emission Control System Installation/Operating Costs at 4,064 m^3/min (143,500 cfm).

INITIAL CAPITAL AND INSTALLATION COSTS - 143,500 cfm, Booths 1, 2, and 3 operated simultaneously in their original configuration

Purchased APCS Equipment Cost	RTO - OAQPS data (2)	RTO Vendor data	Rotor/Recup Vendor data
Control equipment capital	$2,177,419 (1)	$1,585,700 (5)	$1,600,000 (5)
Auxiliary equipment	$50,000 (3)	$50,000 (3)	$50,000 (3)
Sales tax (5%) (1)	$111,371	$81,785	$82,500
Freight	$89,097 (4%)(1)	$89,097 (OAQPS Value)	$66,000 (5)
Total APCS capital cost	$2,427,887	$1,806,582	$1,798,500
Direct APCS Installation Costs			
Foundation & Supports (4%) (1)	$97,115 (4%)(1)	$97,115 (OAQPS Value)	$71,940 (5)
Handling & Erection (5%) (1)	$121,394 (5%)(1)	$80,200 (5)	$89,925 (5)
Electrical & Piping (5%) (1)	$121,394 (5%)(1)	$121,394 (OAQPS Value)	$89,925 (5)
Insulation	$12,139 (0.05%)(1)	$12,139 (OAQPS Value)	$8,993 (5)
Total Direct APCS Installation Cost	$352,044	$310,848	$250,783
Indirect APCS Installation Costs			
Engineering	$97,115 (4%) (1)	$35,500 (5)	$430,000 (5)
Construction/field expenses	$48,558 (2%) (1)	(included)	(included)
Contractors fees	$121,394 (5%) (1)	(included)	(included)
Start-up (2%) (1)	$48,558 (2%) (1)	$48,558 (OAQPS Value)	$35,970 (5)
Performance test (1%) (1)	$24,279 (1%) (1)	$24,279 (OAQPS Value)	$17,985 (5)
Contingencies (3%) (1)	$72,837 (3%) (1)	$53,500 (5)	$53,955 (5)
Total indirect APCS installation cost	$412,741	$161,837	$537,910
Paint booth retrofit cost (4):	$0	$0	$0
TOTAL INSTALLATED COST:	$3,192,672	$2,279,267	$2,597,193

(1) Unless otherwise specified, the factors were taken from the OAQPS Manual
(2) OAQPS Manual RTO capital cost assumptions include:
- Costs reported are 1st quarter 1989 dollars; conversion data from OAQPS manual supplements
- Formula: $ = (2.204 X 10E5) + 11.57Q
- Results: 1989 $ 1995 $
  $1,880,695 $2,177,419

(3) Auxiliary equipment is monitoring system
(4) Paint booth installation data from Acurex Environmental Design Group
(5) Manufacturers' estimate for system cost.

OPERATING COSTS (1)

	RTO - OAQPS data (2) (3)				RTO Vendor (2)				Rotor/Recup Vendor (8)(10)			
APCS			$/hr	$/yr			$/hr	$/yr			$/hr	$/yr
Electricity (4)	470.1	kW	$28.21	$84,619	360	kW (8)	$21.60	$64,800	207	kW (8)	$12	$37,260
Natural gas (5)	12.8	MBtu/hr	$51.27	$191,314	13.11	MBtu/hr (8	$52.42	$181,022	6.40	MBtu/hr (8	$26	$134,400
Maintenance (6)	4	hr/wk	$20.00	$4,000	4	hr/wk	$20	$4,000	4	hr/wk	$20	$4,000
Miscellaneous	$15,000	$/yr		$15,000	$15,000	$/yr		$15,000	$20,000	$/yr		$20,000
Paint Booths												
Maintenance labor (6)(7)	8	hr/wk	$20.00	$8,000	8	hr/wk	$20.00	$8,000	8	hr/wk	$20.00	$8,000
Electricity (4) (9)	103.3	kW	$6.20	$18,594	103.3	kW	$6.20	$18,594	103.3	kW	$6.20	$18,594
TOTAL ANNUAL OPERATING COST:				$321,527				$291,416				$222,254

(1) Booths operate 10 hours/day, 6 days/week, 50 weeks/year
(2) RTO Assumptions for standard and startup operations:
RTO operates at 95% thermal efficiency 10 hrs/day
RTO operates additional 45 min/day @ full fire (25 MBtu/hr) 5 days per week
RTO operates additional 1 hour/day@ full fire (25 MBTu/hr) 1day per week
[last two items adds anual n.g. cost factor of ($/Btu*25 Btu/hr)*50/0.95*[(5*45/60) + 1]
OAQPS Assumptions for standard and startup conditions
RTO operates at 95% thermal efficiency 10 hrs/day
RTO operates additional 1.5 hr per day @ full fire (25 MBtu/hr)
(3) Additional OAQPS Manual assumptions:
14 inch pressure drop through system
fan/motor efficiency is 50% (e)
electricity calculated from the formula: 1.14E-4*Q*dp/e
(4) Electricity is $0.06/kWhr
(5) The following assumptions apply to all control systems data sets:
Natural gas is $4/Mbtu
Oxidizer operated at 1650F
Heat capacity of air is 0.255 Btu/lbF; density is 0.0739 lb/scf
Intake air is at an average temperature of 70F
There is no fuel value in exhaust gas
(6) Maintenance labor is $20/hr
(7) Maintenance items such as filter replacement are the same for recirculating & non-recirculating booths and are therefore not included
(8) Manufacturers' estimate
(9) Paint booth operating data from Acurex Environmental energy audit/estimate; Booths 1, 2 & 3 operated simultaneously in original configuration
(10) Rotor concentrator achieves a 10:1 volume reduction

Table 36. Summary of Cost Analysis Results Comparing Emission Control Costs With and Without Recirculation/Flow Partitioning.

Control Technology Cost Elements (assumes a 12 year equipment life)	Operating Scenario		
	1,176 m^3/min (41,450 cfm) Final Configuration (Booths 1 & 2 operating)	3,285 m^3/min (116,000 cfm) Initial Configuration (Booths 1 & 2 operating)	4,064 m^3/min (143,500 cfm) Initial Configuration (Booths 1, 2 & 3 operating)
Regenerative Thermal Oxidizer			
Paint Booth Modification Design and Installation Costs	$ 350,000	$ 0	$ 0
RTO System Capital and Installation Cost	$ 793,625	$1,782,300	$2,279,270
Booth + RTO System Annual Operating Costs	$ 98,437	$ 235,520	$ 291,420
Total System Equivalent Uniform Annual Cash Flow (EUAC)	$ 250,190	$ 473,000	$ 593,870
Rotor Concentrator/Recuperative Oxidizer			
Paint Booth Modification Design and Installation Costs	$ 350,000	$ 0	$ 0
Rotor/Recup System Capital and Installation Costs	$1,363,800	$2,279,400	$2,597,200
Booth + Rotor/Recup System Annual Operating Cost	$ 81,130	$ 173,790	$ 222,250
Total System Equivalent Uniform Annual Cash Flow (EUAC)	$ 308,540	$ 476,000	$ 566,880
OAQPS Control Cost Manual Estimate for Regenerative Thermal Oxidizer			
Paint Booth Modification Design & Installation Costs	$ 350,000	$ 0	$ 0
RTO System Capital and Installation Cost	$1,233,300	$2,664,660	$3,192,670
Booth + RTO System Annual Operating Costs	$ 108,230	$ 262,500	$ 321,500
Total System Equivalent Uniform Annual Cash Flow (EUAC)	$ 318,330	$ 616,100	$ 745,180

[1] Only the cost of retrofitting Booths 1 and 2 are included for this scenario.

SECTION 8

ENGINEERING CONCLUSIONS AND RECOMMENDATIONS

The data summarized in the preceding sections provide compelling evidence that recirculation/flow partitioning and other ventilation system enhancements provide a safe and efficient means of reducing VOC emission control costs for military paint spray booths.

8.1 PROGRAM CONCLUSIONS

The information collected for this spray booth recirculation technology demonstration program demonstrates the successful application of various innovative technologies at a high production maintenance facility and leads to the following conclusions:

- In non-recirculating booths, the presence of hazardous constituent compounds in the vicinity of the booth operators can be attributed to the air flow conditions in the booth, the target configuration, and the spray pattern created by the paint application system. The combination of these parameters tends to create a "cloud" of over spray particulate and solvent vapor, which often creates conditions in the vicinity of the painter in which the OSHA Factor exceeds unity. For this reason, booth operators should wear personal protective equipment (PPE) to ensure safe working conditions. The Phase III test data conclusively demonstrate that recirculation does not cause an increase in concentrations in this over spray "cloud," and therefore does not cause a deterioration of working conditions in the booth [details provided in Section 6].

- For paint booth ventilation systems where standard engineering and administrative controls as defined in 29 CFR 1910.1000[7] {i.e., a single pass ventilation system rated at >125 fpm (38.18 m/h) linear velocity, } are not sufficient to achieve compliance with worker exposure requirements. Personal protective equipment (PPE) should be employed to ensure safe working conditions. Moreover, as indicated in Section 6, recirculation in the MCLB paint booths does not have a measurable effect on the specific constituent concentrations in the worker vicinity. Test data indicate that the MCLB recirculation systems did not increase odor. Protective respiratory equipment was required prior to modifying the booths, and was still required after modification: details provided in Sections 4 and 6.

- The PPE systems currently employed in the MCLB paint booths have assigned protection factors of 10 (cartridge respirators) and 25 (hooded air-line respirators).

Reconciling protection factors with the constituent concentration data collected in the painter vicinity indicates that a safe working environment is provided in recirculation mode when the proper protective equipment is used [details provided in Section 6].

- All of the OSHA Factors reported herein were derived based on 8-hour OSHA PELs, thus the OSHA Factors assume that the paint booth operators apply paint in the booths for 8 hours per day. The typical MCLB painting intervals (the hours per 24 hour day that an individual is potentially exposed to paint fumes and over spray particulate) do not exceed 4-5 hours a day. Therefore, actual OSHA Factors exposures are at least 25% lower than those reported in Sections 4 and 6. This provides an additional safety margin to the MCLB results. This approach may be employed for any painting facility that operates on an 8 hour shift schedule to determine a safe and efficient recirculation system.

- The test results from the Phase III demonstration study clearly indicate that the partition height and corresponding recirculation rate projections determined from the Phase I baseline study were correctly estimated. The Booth 1 and 2 results demonstrate that an average OSHA Factor of approximately 0.5 was achieved *upstream* of the fresh make-up air intake; this insured that the quality of the booth intake air would be well below the 0.5 OSHA Factor target value. The Booth 3 results show that an OSHA Factor of much less than 0.5 is consistently achieved at this location. When the dilution effects of the fresh make-up air are taken into consideration, the intake air OSHA Factors calculated for all three booths conform with the limit imposed by Equation 1 by a margin of at least 40% [details provided in Section 6].

- As predicted a sufficient concentration gradient occurs at the MCLB paint booth exhaust faces thus warranting the efficient use of the recirculation/flow partition system. This is particularly true for Booths 2 and 3, which show a significant decrease in concentrations above the 7-8 foot level [details provided in Section 6].

- The use of VFD fans in a paint booth ventilation system provides a means of ensuring compliance with the 100 fpm minimum flow rate requirements mandated under 29 CFR 1910.94,[5] while simultaneously reducing ventilation system electrical usage to the lowest possible level. Paint booth ventilation systems are typically constructed using fixed-drive fans that are usually oversized to ensure adequate ventilation even if the exhaust filters are heavily laden. This not only generates excessive exhaust flows, but also creates an unnecessarily high electrical demand to operate the fans and other HVAC equipment. Using VFDs in a booth ventilation system provides numerous benefits, such as generating a consistent flow profile in the booth, reducing electricity usage, minimizing heating and air conditioning requirements, and reducing the capital, installation, and operating costs associated with both the VOC emission control systems and the spray booths [details provided in Section 5].

- The combined effects of enclosing Booth 2 and installing VFD fans successfully reduced the total chrome concentration in the vicinity of the paint booth operator by more than 80%. This decrease is doubtlessly due to the elimination of lateral flow patterns, inertial flow entrance losses, and inconsistent flow profiles commonly found in open or partially closed paint facilities equipped with fixed-drive fans.

- High performance particulate filtration systems are capable of reducing paint over spray particulate in the paint booth exhaust. However, the Phase III test results indicate the presence of trace levels of hexavalent chrome in the recirculation ducts downstream of the exhaust filters. It therefore appears that the 3-stage system may not achieve quite the filtration efficiency desired. The manufacturer maintains that the presence of hexavalent chrome detected in the recirculation duct is attributed to leakage around the third stage, and that future design changes will improve the filter sealing characteristics. Although the presence of hexavalent chrome impacts significantly to the OSHA Factors calculated for the Booth 2 and 3 recirculation ducts prior to addition of the dilution air, it is does not occur in sufficiently high concentrations to cause the calculated intake air to exceed the OSHA safety level established by Equation 2 [details provided in Section 6].

- To minimize plenum zone leakage and ensure separation between the high concentration air stream (vented to the APCS) and the low concentration air stream (recirculated back into the booth), an efficient seal around the partition within the plenum is necessary.

- A detailed ventilation system performance evaluation was performed over the 7 month period following the Phase III test. During this evaluation, tremendous variations were noted with respect to painter technique, ability, and coating usage. In several instances, some painting techniques cause unnecessary conversions to single-pass operation; this in turn cause booth operating delays. These techniques should be adjusted to reduce or eliminate delays.

- Multiple paint spray booths equipped with recirculation/flow partitioning and in high production environments can operate using most conventional or innovative APCS. The booth and APCS operations must are properly integrated [details provided in Section 5].

- An FTIR can be adapted and programmed to serve effectively as a safety monitor for paint booth recirculation system applications. The FTIR instrument has demonstrated short term success in obtaining accurate and reliable speciated organic concentration data. The long term applicability of FTIR instrumentation in this application is yet to be determined [details provided in Sections 2 and 6].

8.2 PROGRAM RECOMMENDATIONS

Several technology and system recommendations can be made based on the results obtained from the EPA/USMC Technology Demonstration Program, including:

- Industrial and military paint booth facilities should consider recirculation as an efficient means of reducing paint booth exhaust volume flow rates and achieving cost effective VOC emission control goals.

- To minimize worker exposure to hazardous constituent concentrations, facilities should furnish paint booth operators with PPE having the highest assigned protection factor that may be reasonably accommodated. For example, both cartridge respirators and hooded air-line respirators may be used in the MCLB booths, yet the hooded air-line respirator affords a higher level of protection than the cartridge type respirator. Use of the hooded air-line respirator should be actively encouraged.

- Although not required by OSHA, facilities that contemplate installing recirculation ventilation should consider including a safety monitoring system in the design. This would insure that excessive pollutant concentrations which exceed OSHA limits, do not occur in the recirculating stream intake air.

- A painter training program will reduce paint both operating delays, as well as enhance facility operating efficiencies by reducing facility labor and coating usage.

SECTION 9

SUMMARY OF QUALITY ASSURANCE/QUALITY CONTROL RESULTS

A number of quality assurance/quality control (QA/QC) procedures were implemented to assess the quality of the data collected during Phase I (Baseline Study) and Phase III (Demonstration Study) of the EPA/USMC Technology Demonstration Program. The overall results of the QA/QC efforts undertaken for this program are summarized in this section, along with a brief description of the data quality analysis procedures that were implemented. The following subsections briefly address the overall quality of data achieved, and provide highlights of principal QA/QC issues considered during the Baseline and Demonstration Studies. A separate subsection summarizes the results of a field audit performed under the direction of the EPA APPCD Quality Assurance Officer (QAO) during the Demonstration Study.

9.1 OVERALL DATA QUALITY AND CRITICAL MEASUREMENT QUALITY

Nearly all the objectives established for the Data Quality Indicators (DQI) were met for both the Baseline (Phase I) and the Technology Demonstration (Phase III) portions of the EPA/USMC Technology Demonstration Program. As indicated in the Technology Demonstration Study Quality Assurance Project Plan (QAPjP) submitted to the EPA QAO in August 1995, the most critical measurements in the EPA/USMC Program were the hazardous constituent concentrations in the recirculated stream. These data are necessary to demonstrate that, under high throughput (worst case) conditions, the calculated OSHA factor in the recirculated stream does not exceed 0.5. The DQI objectives specified for the recirculation duct measurements were selected to ensure an adequate safety margin in this calculation.

All of the recirculation duct measurement DQI objectives were met or exceeded with the exception of the accuracy level for hexamethylene diisocyanate (HDI). The results of a multi-level spike and recovery analysis for the EPA Draft Isocyanate sampling procedure indicated that a 125% recovery was achieved at the low concentration range (1.0 μg), but only 64% recovery was achieved at higher spikant concentrations (10 - 50 μg). Fortunately, the majority of the recirculation duct HDI concentrations were found at or below the detection level, thus the high spike/recovery factor is applicable to the field test results obtained. It may therefore be concluded that, despite the broad measurement accuracy range indicated by the spike/recovery results, the HDI levels measured in the recirculation ducts are perhaps overpredictive, which yields a more conservative (safe) OSHA Factor. In summary, all the QA/QC results obtained indicate that the recirculation/flow partition ventilation systems installed on the Barstow MCLB paint booths operate well within an acceptable margin of safety.

9.2 CALCULATION OF DATA QUALITY INDICATORS

The four data quality indicators that were considered in planning and executing the Baseline and Demonstration Studies were accuracy, precision, completeness and representativeness; the calculation procedures for each of these parameters are presented separately below.

9.2.1 Accuracy

Accuracy of the integrated samples is assessed by spiking a known quantity of the target analyte(s) onto clean sampling media, and subsequently analyzing the spiked samples along with the field samples to determine the percent recovery achieved. The percent recovery result provides a measure of the sampling bias which is introduced via sample handling and analysis. The percent recovery is calculated from the expression:

$$\%\ Recovery = \frac{Spiked\ Sample\ Result\ -\ Spiked\ Amount}{Spiked\ Amount} \times 100$$

In many cases, a multi-level spike/recovery analysis is performed in which replicate spike samples are prepared at several concentrations which represent the concentration range found in the field samples. For each spike level, the percent recovery for the replicate spike samples are averaged to derive the overall percent recovery at that particular spikant level.

The paint volatile content and density measurement accuracy is assessed by comparing the sample results to published values obtained from manufacturer data.

9.2.2 Precision

Precision is defined as the reproducibility of measured results. Method precision for the NIOSH and OSHA samples is assessed through the collection and analysis of side-by-side duplicate samples that are collected simultaneously. The relative percent difference between these duplicate results defines the precision limits, and is calculated from:

$$RPD = \frac{|X_1 - X_2|}{X_{avg}} \times 100$$

The dynamic nature of paint booth operations may cause poor reproducibility in some of the side-by-side sample results. It is therefore important that the overall sampling variability be characterized; this was accomplished for the Demonstration Study results by pooling the individual RPD values obtained for each measurement type to assess an overall RPD value. To establish how well this "pooled" RPD value represents actual measurement RPDs, the relative standard deviation is determined according to the following equation:

$$s_{RPD}^{2} = \Sigma \frac{(RPD_i - RPD_{avg})^2}{(n - 1)}$$

The precision of paint density and percent volatile measurements is determined from RPD results for duplicate samples. For continuous monitors; instrument precision is determined by periodically comparing zero, span, and reference gas response results.

9.2.3 Completeness

Completeness is defined as the ratio of the number of valid analytical results obtained to the number of samples required in the test matrix. Causes for not producing valid analytical results include sample loss from breakage, mis-identification of samples, or errors in the sample recovery or analysis procedures. Completeness is derived from the following equation:

$$\% C = \frac{\text{Number of Valid Analytical Results Obtained}}{\text{Total Number of Proposed Samples}} \times 100$$

9.2.4 Representativeness

The dynamic nature of the Barstow MCLB paint booth operations raises concerns over proper test planning, because the sampling must be performed in such a way as to preserve process representativeness. Moreover, it was important that the test results represent a relatively high throughput rate for the booths to ensure subsequent safe operation under worst case conditions. To achieve conservative and representative results, all the sampling events were carefully coordinated with facility operators, and detailed coating usage and throughput records were collected during each test series.

9.3 SUMMARY OF BASELINE STUDY QA/QC RESULTS

There were several sets of integrated and continuous sampling measurements collected during the Baseline Study completed in the Fall of 1993. Specific information relating to the sampling and analysis results are provided in Appendix C along with details pertaining to the data quality evaluation effort. A Baseline Study QA/QC assessment summary is provided in Table 37, which indicates the DQI objectives and results obtained for each measurement parameter. Measurement parameters that exceed the DQI objectives are indicated in boldface. The DQI objectives were taken from the Category III QAPjP which was submitted to and approved by the EPA QAO prior to initiating any test activities.

All of the DQI objectives established for the Baseline Study were met with the exception of OSHA 42 measurement precision. As indicated in Appendix A, OSHA 42 is an integrated isocyanate sampling procedure in which sample air is pulled through a small filter cassette. The duplicate samples that were collected to assess method precision were arranged in a side-by-side configuration to ensure replicate results insofar as possible. The variability noted in the OSHA 42 precision analysis is doubtlessly due to sample orientation; although considerable effort was expended to ensure that side-by-side samples were oriented identically, such a configuration was not always achievable. The difficulties associated with proper orientation of duplicate samples is also reflected in the relatively high precision results reported for the NIOSH 500 and NIOSH 7300 samples, which are collected in a manner similar to the OSHA 42 procedure.

At the inception of the Baseline Study, it was anticipated that a significant level of sample variability could occur for all the NIOSH and OSHA test methods. To counter the impact of sample variability, a large sample set was collected. The results of multiple exhaust face measurements from the Baseline Study indicate that constituent concentration profiles remain fairly consistent, thus it may be concluded that the test matrix contained adequate sample redundancy and test event repetitions to neutralize any effects of individual sample variability.

9.4 SUMMARY OF TECHNOLOGY DEMONSTRATION STUDY QA/QC RESULTS

Specific information relating to the sampling and analysis results obtained for the Demonstration Study are provided in Appendix D along with details pertaining to the data quality evaluation effort. A QA/QC assessment summary for the technology Demonstration Study is provided in Table 38, which indicates the DQI objective for each measurement parameter as well as the results obtained. The measurement parameters which exceed the DQI objectives are indicated in boldface. The DQI objectives were taken from the Category III QAPjP submitted to and approved by the EPA QAO prior to initiating any test activities.

All but two of the DQI objectives established for the Technology Demonstration Study were met. The fact that the NIOSH 7300 precision results fell outside of the DQI objective is attributed to sample orientation, which caused similar problems for the Baseline Study OSHA 42 sampling efforts. For the reasons mentioned in Section 9.3, it is assumed that the impact of the NIOSH 7300 precision results on overall program conclusions is negligible.

Table 37. Summary of Data Quality Achieved for the Phase I Baseline Study

Measurement Parameter	Measurement Method	Precision (RPD)		Accuracy [1] (%)		Completeness	
		Objective	Result	Objective	Result	Objective	Result
Particulate	NIOSH 500	< 35%	24%	NA	NA	> 90%	99%
	EPA Method 5	NA	NA	NA	NA	> 90%	96%
Metals	NIOSH 7300	< 35%	32.5%[2]	< ± 30%	- 7%	> 90%	97%
	EPA Method 0060	NA	NA	< ± 30%	19%	> 90%	100%
Organics	NIOSH 1300	< 35%	17%[3]	< ± 30%	8%[4]	> 90%	94%
	EPA Method 25A	< 20%	1%	< ± 20%	< 0.8%	> 90%	100%
Isocyanates	OSHA 42	< 35%	**45%**	< ± 30%	- 23%	> 90%	96%
	NIOSH 5521	< 35%	4%	< ± 30%	- 2%	> 90%	100%
Paints	Density	< 20%	ND[5]	< ± 30%	2.7%	> 90%	100%
	% Volatile	< 20%	6%	< ± 30%	5.0%	> 90%	100%
Air Flow	EPA Method 2	< 20%	2.9[6]	< ± 10%	**13%**	> 90%	100%
	Anemometer	<20%	5.0	< ± 40%	20%	> 90%	100%

1 Accuracy as a measure of method bias determined from percent recovery data.
2 Averaged over all compounds considered; actual average precision RPD for zinc and chrome ranged from 25% to 40%.
3 Averaged over all compounds considered; actual average precision RPD for all compounds ranged from 9% to 41%.
4 Averaged over all compounds considered; actual average method bias percentage for all compounds ranged from +7% to - 19%.
5 This analysis was not performed.
6 These results derived from Booth 1 data only, because Booth 2 flow rates could not be measured via EPA Method 2.

Table 38. Summary of Data Quality Achieved for the Phase II Technology Demonstration Study

Measurement Parameter	Measurement Method	Precision (RSD)		Accuracy (%)[1]		Completeness	
		Objective	Result	Objective	Result	Objective	Result
Metals	NIOSH 7300	< 40%	**57%**	< ± 30%	-13% to +2%[2]	> 90%	96%
	EPA Method 0060	NA	NA	< ± 30%	+2% to +9%[3]	> 90%	93%
	EPA 0061 (Cr^{+6})	NA	NA	< ± 50%	-3% to +3%[3]	> 90%	100%
Organics	NIOSH 1300	< 40%	18%	< ± 30%	Avg: -7%, Range: -49 to +3%[4]	> 90%	97%
	EPA Method 25A	<20%	0.7%	< ± 20%	0.7% - 8.9%	> 90%	100%
Phosphoric Acid	NIOSH 7903	< 40%	0%	< ± 30%	-28% to +1%[3]	> 90%	100%
Isocyanates	OSHA 42	< 40%	8%	< ± 30%	-27% to +20%[3]	> 90%	103%
	EPA Draft Method	NA	NA	< ± 30%	**-54% to +25%**[3]	> 90%	100%
Paints	Density	< 20%	1%	< ± 30%	± 3%	> 90%	100%
	% Volatile	< 20%	3%	< ± 30%	± 17%	> 90%	100%
Air Flow	EPA Method 2	< 20%	1.5%	< ± 40%	3% - 38%	> 90%	100%
	Anemometer	<20%	0.5%			> 90%	100%

1 Accuracy as a measure of method bias determined from percent recovery data.

2 Bias determined from spike/recovery of chrome only; range indicates results over various spikant levels.

3 Bias determined from spike/recovery; range indicates results over various spikant levels.

4 The percent recovery varied as a function of compound and spikant levels (three spikant levels were used). The percent recovery range for all the compounds except benzyl alcohol was 51% - 103% (average is 93%). The average recovery for benzyl alcohol was 21%, however this compound was never measured above the detection level in any samples, thus the low recovery factor has no impact on data quality.

The high variability in the spike/recovery results obtained for the EPA Draft Isocyanate Method provides compelling reasons to evaluate the overall success of this method in more detail. This is particularly appropriate in view of the fact that the method is still in draft form, thus the sampling and analysis procedures are not completely finalized. As indicated in Section 9-1, the impact of this variability on the overall results of the EPA/USMC Technology Demonstration Program is considered small, and in fact may indicate that the recirculation duct isocyanate results obtained are rather conservative. However, other issues of concern related to this method were noted during the sampling and analysis activities, including:

- Background Levels - The isocyanate train sampling solutions were prepared in the field by combining a pre-measured volume of reagent grade toluene with a pre-measured amount of reagent grade 1-(2-pyridyl)piperazine solution in accordance with the method requirements. The sample solutions were prepared fresh every 1-2 days, and in accordance with QAPjP requirements, train blank and solution blank samples were prepared for each booth test event. When the analytical results were reviewed, it was found that two-thirds of the Booth 1 field samples and all of the Booth 3 field and blank samples were at or below the method detection level. However, all the blank samples from Booths 1 and 2 indicated contamination at approximately 10 times the detection level, and similar amounts were measured in the field samples as well. The only HDI source at the facility is the topcoat material, yet the reagents and samples were stored far away from the paint storage area. Moreover, the use of isocyanates compounds is typically very specific and controlled, thus the presence of a second, unknown HDI source is unlikely. Because it is a relatively new method which has not yet found widespread use, little is known about potential interferents.

- Overall Poor Recovery Efficiencies - The multi-level isocyanate spike and recovery results indicate that reasonable recovery efficiencies are easily achieved at low spikant levels. However, the results obtained at higher spike levels (10 times over the detection limit) were not encouraging. No reason for the poor recovery efficiency could be found, but fortunately it does not appear to impact overall program results.

In planning the Demonstration Study tests, it was anticipated that the highest isocyanate concentrations would be found in the Booth 1 recirculation ducts, because Booth 1 is used exclusively for topcoat applications, and typically has a high topcoat usage rate. The fact that the first six recirculation duct sampling results from Booth 1 and of all the Booth 3 recirculation duct sampling results indicate that no isocyanates were present implies that 1) the isocyanates occur largely in the solid phase (in the polymeric form, rather than the monomeric form); and 2) the advanced filtration system effectively eliminates these solid phase isocyanates. The presence of HDI in half the Booth 1 recirculation duct samples and all of the Booth 2 recirculation duct samples at approximately the same levels measured in the blank samples raises concerns regarding contamination. As such, the recirculation duct OSHA Factors calculated for Booths 1 and 2 assume that the isocyanate concentrations are at the method detection limit.

9.5 EPA FIELD AUDIT RESULTS

During the technology Demonstration Study, the EPA Quality Assurance Office conducted a field audit. The EPA staff prepared several field spike samples that were submitted for analysis to the appropriate laboratory with the field samples that were collected. The analytical results that were obtained for the field spike samples as well as the standards that were also submitted are summarized in Tables 39 and 40. Both uncorrected and corrected field spike sample results are reported in Table 39. Please note the following:

1) The factors that were employed for the field spike corrections are indicated in Table 39; these factors were obtained from the multi-level spike and recovery study results provided in Appendix D. The appropriate recovery factor was identified based on the quantity measured in the spiked sample. For example, the results indicate that approximately 122 μg of MEK was spiked on the sample, thus the 81% average MEK recovery obtained for the 333 μg lab spike level was used for the correction factor.

2) For the NIOSH 1300 and NIOSH 7903 sampling activities, two sample tubes were placed in series to ensure 100% collection of the sampled constituents. The laboratory was instructed to analyze all front tubes, and further instructed to analyze the back tubes only if the front tube results indicated the possibility of breakthrough. To distinguish front tubes from back tubes, all the front tubes were denoted with the suffix "a", and back tubes were denoted with the suffix "b". Unfortunately, the EPA field spike samples were submitted with identification numbers that included the "a" and "b" suffixes, thus the laboratory only analyzed the field spike samples denote with an "a". This oversight was not recognized until nearly two months after the samples were submitted. Although the samples were then analyzed immediately, it is likely that the results obtained from these two field spike samples are skewed. EPA may therefore want to consider disregarding the results reported for the samples identified as B2PH4P1b and B2O4P1b.

3) The analytical laboratory did not measure the volume of the hexavalent chrome standard prior to analysis, thus the total mass found in the sample could not be reported. However, it is estimated the initial volume was approximately 9 - 10 ml.

4) The zinc standard was submitted with the hexavalent chrome standard to the laboratory performing the Booth 2 and 3 Method 0061 analyses. This is because zinc occurs only in combination with the hexavalent chrome found in the wash primer (which is used only in Booths 2 and 3), and not with the trivalent chrome found in the topcoat material (which is the only material applied in Booth 1). However, due to field sampling crew errors, the Method 0061 train fractions collected from the Booth 2 and 3 sampling efforts were not sufficiently recovered to allow analysis for total chrome and zinc, thus the Method 0061 analyses performed on the field samples did not include total chrome or zinc.

Table 39. Summary of EPA Field Spike and Analysis Results

Sampling Procedure	Sample #	Target Analyte	Uncorrected (μg)
EPA Method 0061	B2C10NR	Cr^{+6}	0.561
	B2C10SR	Cr^{+6}	0.369
EPA Method 0060	B1M10NR	Total Chrome	1.75
	B1M10SR	Total Chrome	1.96
NIOSH 7300	B2M4P1	Chrome Zinc	13.1 24.8
	B2M4P2	Chrome Zinc	9.14 2.41
OSHA 42	B2I4P1	HDI	< 0.06
	B2I4P2	HDI	0.19
EPA Draft Method	B2I10NR	HDI	16.2
	B2I10SR	HDI	14.9
NIOSH 7903	B2PH4P1a	Phosphoric Acid	9.87
	B2PH4P1b[1]	Phosphoric Acid	145
NIOSH 1300	B2O4P1a	MEK Ethyl acetate n-Butanol MIBK Toluene Butyl Acetate MIAK PGMEA Ethyl benzene Xylene TMB Hexyl Acetate Benzyl Alcohol	122 183 120 < 7.5 173 192 165 < 7.5 203 144 165 173 <7.5
	B2O4P1b[1]	MEK Ethyl acetate n-Butanol MIBK Toluene Butyl Acetate MIAK PGMEA Ethyl benzene Xylene TMB Hexyl Acetate Benzyl Alcohol	64.6 195 not reported < 7.5 175 102 111 < 7.5 215 150 170 183 < 7.5

[1] These tubes were not analyzed with original group of samples. See comments in text.

Table 40. Analytical Results of EPA Submitted Standards.

Method	Analyte	Analytical Results
EPA 0061	Hexavalent Chrome [1]	9.6 E+5 ug/L
EPA 0060	Total Chrome Zinc [2]	8.6 mg Not analyzed
EPA Draft Isocyanate	HDI	No results
NIOSH 7903	Phosphoric Acid	28.4 mg
NIOSH 1300	MEK Ethyl acetate n-Butanol MIBK Toluene Butyl Acetate MIAK PGMEA Ethyl benzene Xylene TMB Hexyl Acetate Benzyl Alcohol	10.31 mg 11.68 mg 11.62 mg < 7.5 μg 11.31 mg 11.94 mg < 7.5 μg 18.43 mg 12.62 mg 9.39 mg 11.2 mg 10.73 mg < 7.5 μg
EPA Method 25A	Propane	97 ppm

[1] See comment 3 section 9.5.

[2] See comment 4 section 9.5.

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