CALIFORNIA AIR RESOURCES BOARD INNOVATIVE CLEAN AIR TECHNOLOGY (ICAT) PROGRAM:

DYNAMICALLY OPTIMIZED RECIRCULATION COUPLED WITH FLUIDIZED BED ADSORPTION TO COST EFFECTIVELY CONTROL EMISSIONS FROM INDUSTRIAL COATING AND SOLVENT OPERATIONS

FINAL REPORT

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Prepared By
AIR QUALITY SPECIALISTS, INC.
4533 MacArthur Blvd., #564
Newport Beach, CA 92660

Jacqueline Ayer,
Principal Investigator &
Director of Engineering Operations

Prepared For
California Air Resources Board
California Environmental Protection Agency
The South Coast Air Quality Management District

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SECTION 1

BACKGROUND

The implementation of energy efficient, low cost strategies for controlling emissions of volatile organic compounds (VOCs) from industrial coating and solvent operations is a key objective of the California Air Resources Board (ARB). According to the 1995 Statewide Estimated Emission Report for California[1], coating and related industrial processes comprise the fourth largest stationary source category, and release 230 tons of organic compound emissions per day. However, add-on pollution controls for these sources have not historically been required due to the excessive costs that are incurred. Correspondingly, significant economic and environmental benefits can be derived by developing more cost effective pollution control strategies that are applicable to this source category. These strategies will enable ARB to meet regulatory needs pertaining to state and federal ozone attainment standards as well as air toxic exposure risk reduction provisions.

In the summer of 1996, Air Quality Specialists, Inc. (AQS) joined with Southern California Edison and Steelcase North America to demonstrate two innovative strategies for reducing emission controls costs from industrial coating operations; this demonstration program was conducted under the auspice of ARB's Innovative Clean Air Technology Program (ICAT) working in concert with the South Coast Air Quality Management District (SCAQMD). The two separate and distinct technologies that were evaluated under this project are:

Dynamic Recirculation - a ventilation system which enables a facility to reduce the size and cost of an add-on pollution control device up to 80% or more; and

Fluidized Bed Solvent Concentrator/Emission Control - a technology which highly concentrates VOC levels in process exhaust streams and therefore reduces equipment and energy requirements of the associated solvent recovery (or destruction) process.

These technologies were both installed at an office furniture production plant located in Tustin, CA and operated by Steelcase, North America (Steelcase). The Steelcase facility that served as the host site for this program continues to maintain and operate the equipment in the same manner as was used throughout the demonstration program described herein. This report summarizes the activities undertaken to successfully demonstrate the viability of both of these technologies; it describes the project objectives, approach, and the results obtained, and discusses how the project demonstration objectives were met. The data generated from this ICAT Program clearly demonstrate the potential for widespread implementation and commercialization of both the technologies that were evaluated.

1.1 PROJECT OBJECTIVES

The project objectives are:

1) Demonstrate that dynamic recirculation is a safe and effective means of reducing process exhaust flow rates to the lowest achievable level on a real time basis. This necessarily implies that the ventilation system control equipment can be successfully integrated with a continuously operated air quality monitor to provide an appropriate and safe work environment.
2) Explore the long term effectiveness of the fluidized bed concentrator system, and assess the economic viability of this technology in today's pollution control market.

1.2 PROJECT APPROACH

To achieve these goals in evaluating these technologies under the ICAT Program, AQS devised the following four-phase approach (described in detail in Section 2):

Phase 1 - Configure the dynamic recirculation ventilation system at the Steelcase facility and integrate operation of the system with the fluidized bed concentrator/emission control equipment supplied by Steelcase.

Phase 2 - Conduct a long term performance evaluation of the fluidized bed concentrator equipment and adsorber material, as well as a long term evaluation of the dynamic recirculation system; the results of these evaluations provide the basis for establishing overall technology viability and applicability.

Phase 3- Analyze the data collected in Phases 1 and 2, confirm and/or modify technology performance predictions, assess economic benefits of the technologies evaluated, develop the project report, and coordinate critical technology transfer activities among program principals.

Phase 4 - Establish and maintain project management controls, and coordinate overall technical program activities.

1.3 DESCRIPTION OF TECHNOLOGIES EVALUATED

The technologies evaluated under ICAT Project 95-347 are described separately below.

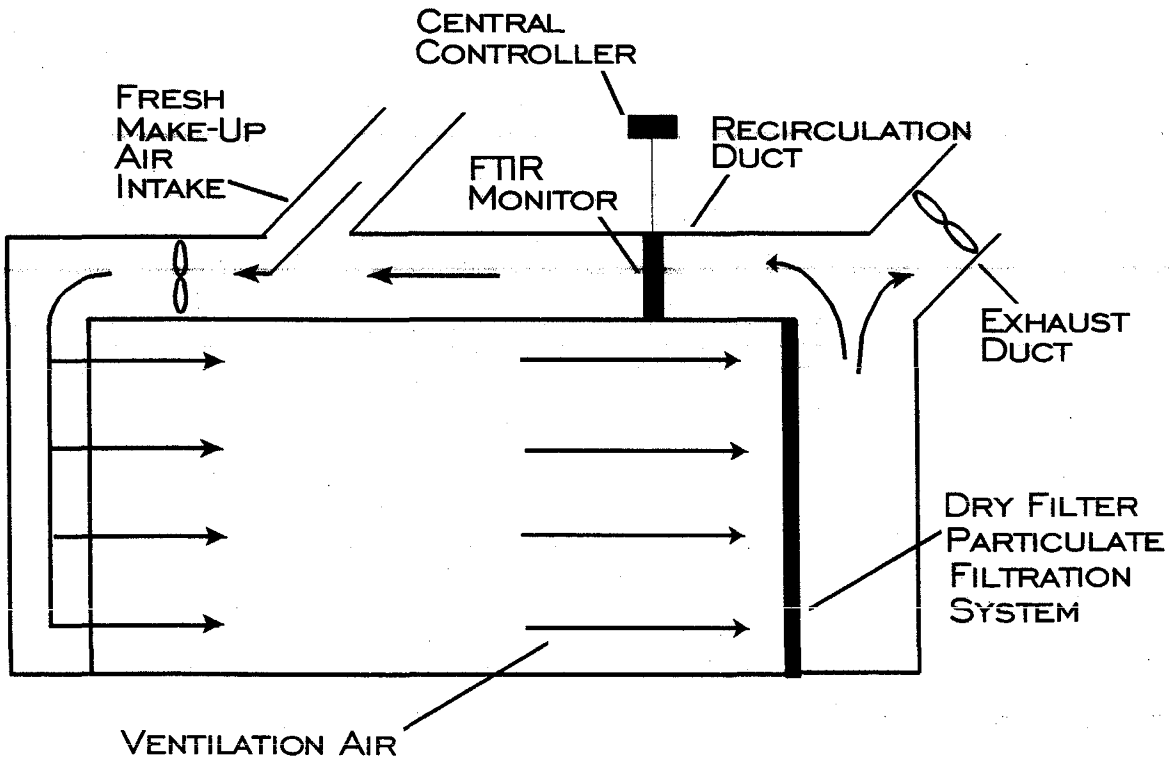
1.3.1 Dynamic Recirculation

Industrial coating operations are typically enclosed and ventilated by the introduction of clean air through an intake face; the ventilation air passes through the enclosure (removing solvent vapors and overspray particulate) and is then vented to atmosphere. This "single pass" ventilation mode generates high process exhaust flow rates as well as excessive heating, ventilation, and air conditioning (HVAC) costs. Moreover, add-on pollution control systems are sized and installed based on the process exhaust volume flow rate, thus single pass operation also results in high emission control equipment installation and operating costs. In fact, the installation of add-on controls for these sources has historically not been required due to excessive costs, thus development of an exhaust flow reduction strategy can provide considerable economic and environmental benefits.

Dynamic recirculation provides a safe and efficient means of reducing process exhaust flow rates. As indicated in the schematic diagram provided in Figure 1, dynamic recirculation employs a return air system to recirculate a portion of the exhaust air back into the booth; the remainder of the exhaust is vented to an air pollution control system. Prior to re-entering the booth, the recirculated air is mixed with fresh make-up air which is provided to replace the exhaust air vented to the control device. The recirculation rate that may be employed is limited by applicable health and safety standards; the hazardous compound concentrations in the respirable air of the enclosure cannot exceed established safety limits.

To ensure compliance with applicable safety limits, dynamic recirculation employs a continuous monitor to evaluate the quality of the air that is recirculated. Based on the monitor output, the dynamic recirculation central control system continually adjusts the exhaust and recirculation flow rates to optimize ventilation system operation. For example, when the paint application rate within the enclosure is reduced, the recirculation rate is increased and the exhaust flow rate is decreased. When painting resumes, the recirculation rate is reduced and the exhaust rate is increased. This dynamic mode of operation allows the facility to reduce the process exhaust flow rates to the lowest possible level and, correspondingly, reduce emission control and HVAC operating costs to the lowest possible level.

Figure 1. Schematic Diagram of a Dynamic Recirculation System



The key to successful operation of dynamic recirculation is a continuous monitor that provides accurate, real-time constituent concentrations data; innovations in the field of Fourier Transform Infrared (FTIR) analysis makes this technology ideal for the dynamic recirculation application. FTIR systems are capable of speciating and quantifying individual organic components in a mixture, and are well suited to organic constituents typically found in solvent-based coatings. The FTIR operating principal is based on the fact that each organic compound responds to infra-red light differently. As such, each compound can be identified and quantified based on its unique intra-red absorbance signature. The FTIR instrument scans the infra-red spectral region and records the absorbance as a function of wavenumber (1/wavelength), and a computer-based analytical algorithm converts the absorbance spectra into quantitative data. Prior to initiating the ICAT demonstration project, AQS compiled numerous reports and technical papers that confirm applicability of FTIR to the dynamic recirculation application [2,3].

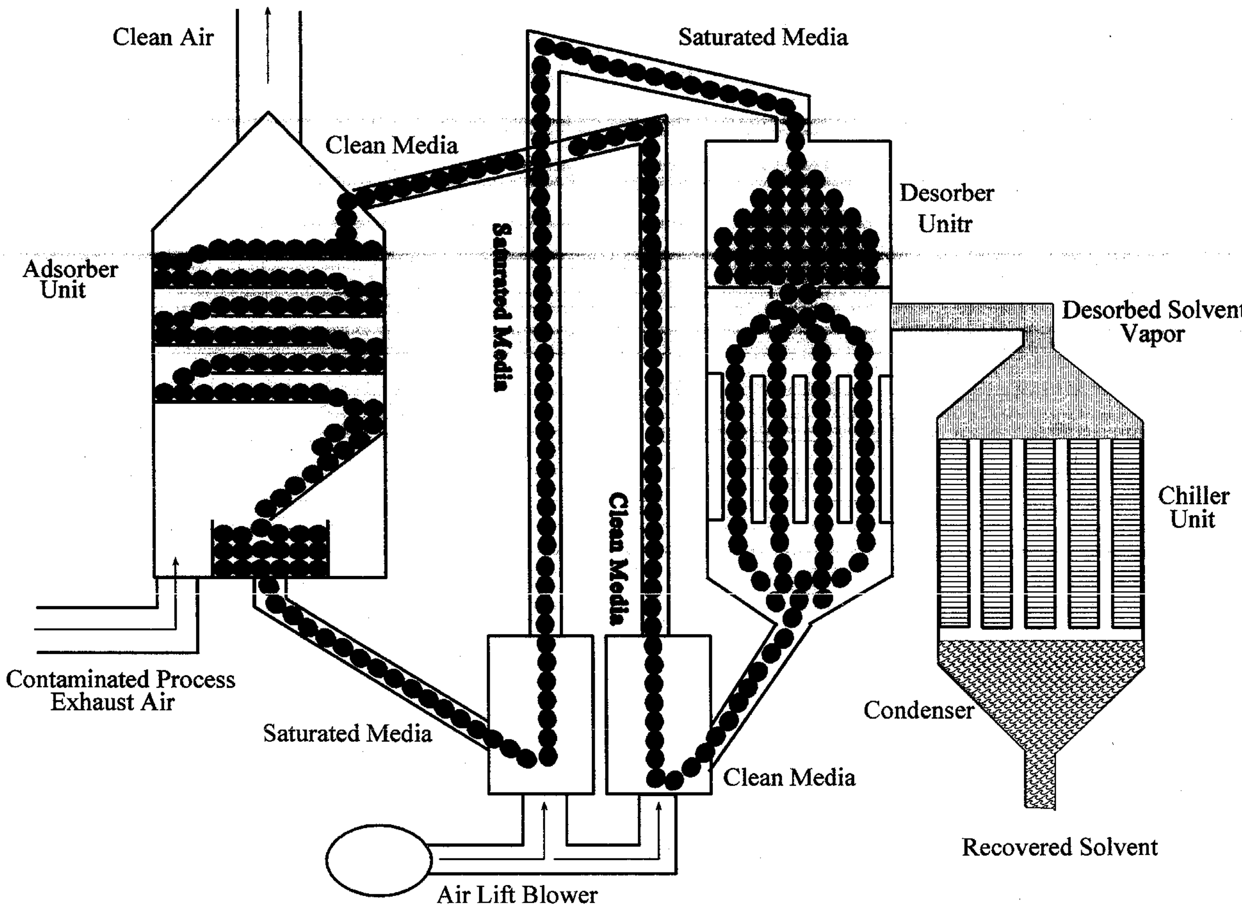
1.3.2 Fluidized Bed Concentrator/Solvent Recovery (or Destruction)

Technological innovations in VOC emission control system design and the development of more cost effective control strategies are necessary to bring non-attainment areas into compliance with state and federal regulations. One approach for reducing emission control system installation and operating costs is the use of a VOC concentrator device that reduces process exhaust flow rates and correspondingly reduces the size and cost of the emission control system. Concentrator systems are designed to collect exhaust stream organic compounds via surface adsorption; active sites on the adsorbing media remove solvent molecules from the process stream, which is subsequently vented to atmosphere. When all active sites are filled (saturated) the media is regenerated using a low-flow hot gas stream which thermally releases the solvent molecules from the active sites. The low volume flow regeneration stream (which contains high solvent vapor concentrations) is then directed to an emission control device, where the solvent vapors are either recovered or destroyed via oxidation.

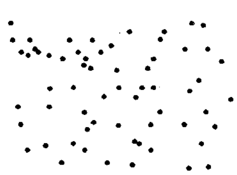
As indicated in the fluidized bed schematic diagram (Figure 2) the system is comprised of two separate components; one is designated as the adsorber module (which receives the process exhaust air stream) and the second component is designated as the desorber module (where the media is regenerated via hot gas desorption). The adsorber media is continuously transferred between the two modules to achieve the high flow reduction levels achieved by this technology. Process exhaust air enters the bottom of the adsorber module and flows upward through sieve trays containing the adsorber media (flowing in a downward, counter-current direction).

The process exhaust air passes vertically through the adsorber module, where it contacts progressively cleaner media. Purified air exits the top of the adsorber vessel, and spent (saturated) media exits the bottom of the adsorber module. The spent media is then transferred to the top of the desorber module, where it flows downward and is stripped of solvent vapors by a low-flow, hot gas stream flowing vertically in an upward (counter current) direction. As the media progresses down the desorber module, it contacts progressively cleaner desorption gas, and is fully regenerated before it is transferred back into the adsorber module. The low flow rate of the desorbed stream, coupled with high solvent vapor concentrations, maximizes the emission control device operating efficiency. The Steelcase system operates in conjunction with a solvent condenser, which enables Steelcase to recover purified solvent for re-use in the coating process.

Figure 2. Schematic Diagram of a Fluidized Bed Concentrator System



The adsorber media employed in the Steelcase fluidized bed system is a hard, spherical form of activated carbon known as bead activated carbon, or BAC (see reproduction of BAC media provided at left). Key variables that govern the adsorption process are the polarity of the adsorbing media, and the polarity of the solvent being adsorbed. Because activated carbon achieves high adsorption capacities for a wide range of solvent types and polarities (e.g., ketones, alcohols, aromatics), BAC media is well suited to process applications involving multiple solvent types (such as Steelcase). Moreover, the BAC manufacturing process renders the media much more hydrophobic than unprocessed activated



BAC Media

carbon, thus the BAC media does not preferentially adsorb water vapor and therefore has a higher solvent retention capacity. In addition, the BAC media has a very high thermal resistance, and can withstand excessive temperatures (which is very important in desorbing solvents with high boiling points) without impacting media surface characteristics or adsorption capacities.

The continuous media processing aspect of the fluidized bed concentrator technology provides numerous advantages over other concentrator technologies, including:

- The possibility of solvent breakthrough is reduced because the media continuously passes through the adsorption zone.
- Inert gas desorption recovers purified solvent (e.g., it is not diluted with water).
- Continuously regenerating small quantities of media reduces inert gas usage rates.
- The media is evenly exposed to the process exhaust stream, and is regenerated only after saturation is achieved; this increases system efficiency and decreases media wear.

SECTION 2

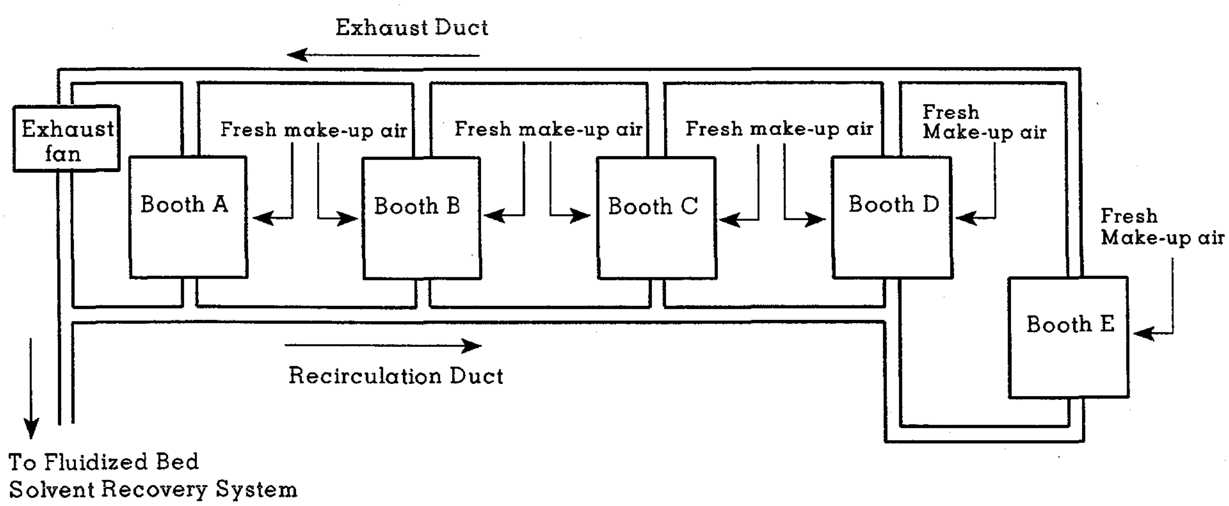
TECHNOLOGY DEVELOPMENT WORK PURSUANT TO THE PROJECT

This section presents, in detail, the technology implementation and evaluation activities that were completed to successfully implement the four-phase approach identified in Section 1; a chronology of events is presented by phase to better describe the efforts undertaken.

2.1 PHASE 1 - DYNAMIC RECIRCULATION IMPLEMENTATION

Under Phase 1, Steelcase worked with AQS to design and install the dynamic recirculation system on one of the paint spray lines operated at the Tustin facility. File Spray Line 3 consisted of 5 spray booths, and was retrofit with dynamic recirculation in accordance with the general arrangement drawing provided in Figure 3. As indicated in the figure provided, retrofitting required that the exhaust from the individual booths be combined, and that all booths achieve the same level of recirculation. Numerous engineering design and regulatory compliance issues were addressed in this phase, including:

Figure 3. General Arrangement Drawing of the Steelcase File Paint Line.



Booth Ventilation System Integration and Control - To ensure product finish quality and adequate emission capture, the booths must operate under a slight negative pressure. This posed significant engineering difficulties, because the booths are only partially enclosed, thus the potential exists for recirculation air to escape into the surrounding work area. To prevent this occurrence, a comprehensive and fully integrated flow control strategy based on flow sensor output data was designed into the dynamic recirculation system. This approach continuously maintains proper ventilation rates and air flow balance within the booths across the entire range of recirculation and exhaust flow rates generated by the dynamic recirculation system.

Engineering Calculations to Project Recirculation and Exhaust Flow Rates - An engineering analysis to determine appropriate recirculation and exhaust flow rates was performed prior to developing the final system design and fan/ductwork/control system specifications. This analysis was based on continuous organic concentration data collected at one of the spray booths by Steelcase over a 3 week period. These data were reconciled with speciated organic sampling data, Material Safety Data Sheet (MSDS) information, and flow rate design specifications to establish the appropriate recirculation rate. The model that was developed successfully accounted for the rather complicated booth design in which clean air knives and recirculated air slots are employed, as indicated in Figure 4. The model was also employed to predict the frequency with which the ventilation system will operate in maximum recirculation mode vs. minimum recirculation mode; these results are summarized in Table 1.

Figure 4. Schematic Diagram of an Individual File Paint Line Spray Booth.

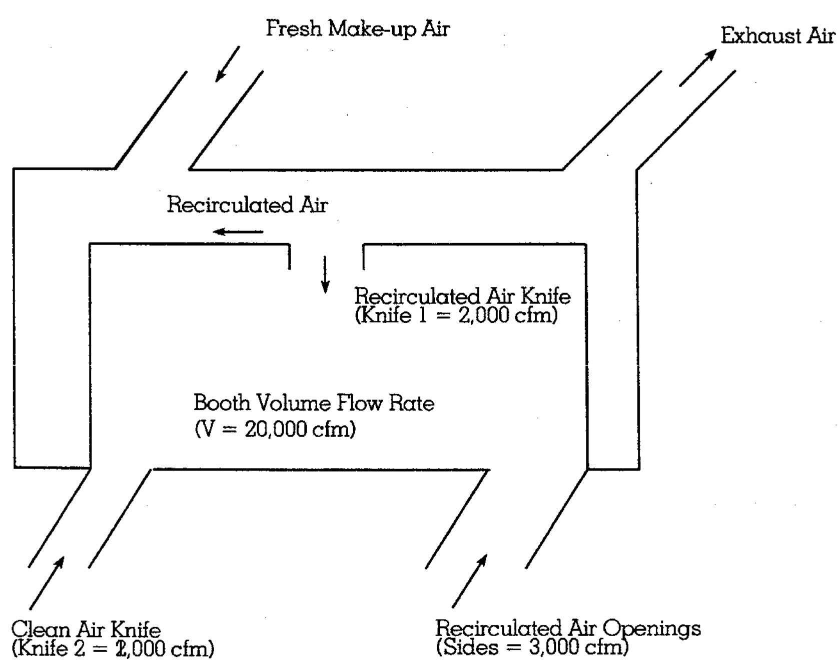


Table 1. Predicted Recirculation Operating Modes for the Steelcase Operations.

Recirculation mode	Frequency Predicted in Engineering Calculations
Minimum (<38%)	5%
Mid-Level	16%
Maximum (>44%)	79%

<u>Compliance with Health, Safety, and Fire Prevention Provisions</u> - Steelcase's design and engineering team had frequent and detailed discussions with staff from both the Orange County Fire Department and California Occupational Safety and Health Administration (Cal OSHA) to ensure all applicable health, safety and fire prevention provisions were addressed. Due to the generally innovative and developmental aspects of this program, Cal OSHA issued a Research and Development Variance to address specific ventilation system provisions contained within Section 5153 of the California Code of Regulations. The Orange County Fire Department issued an approval for the final design following their review of the system requirements specified in Cal OSHA's R&D Variance; these provisions include:

- Monitoring air quality via the FTIR output data and reconciling this information with Cal OSHA Permissible Exposure Limits (PELs). The variance specifically requires that a 20 minute rolling average of the cumulative OSHA Factor be maintained; if the rolling average exceeds one-half (50%) of the Cal OSHA safety limit over any 20 minute period, the spray guns are turned off and an audible alarm is sounded. The paint guns remain inoperable until the rolling average drops to less than 40% of the Cal OSHA established safety limit.
- Reconciling the FTIR output data with the Cal OSHA Short Term Exposure Limits (STELs) and Ceiling Limits is also required; If the FTIR results exceed one half (50%) of the short term or ceiling limits established by Cal OSHA at any time, the spray guns are turned off. The spray guns remain inoperable until the FTIR results drop to less than 40% of the Cal OSHA Short term and/or ceiling limit.
- Upon start-up of the ventilation equipment, both the FTIR monitor and the central control system undergo an automatic diagnostic evaluation; if any components are not working properly, the paint guns do not operate.

- The exhaust, recirculation, and make-up air fans are interlocked with the FTIR monitor and the paint supply system; in the event that any of these components fail during operation, the paint guns will be turned off.
- The paints used in the file line shall contain no compounds that have Cal OSHA PEL values that are below the FTIR detection limits.
- Periodic exposure sampling is required to confirm that employee exposure is within acceptable limits.

Development of FTIR Analytical Software Tailored to the Steelcase Application - The key to achieving accurate and reliable FTIR data is the development of a comprehensive software analysis package which 1) properly identifies and resolves the infra-red spectral regions of concern; 2) resolves fine structures within these spectral regions to ensure data specificity; 3) reasonably estimates measurement error and identifies the presence of unknown compounds; and 4) is sufficiently modular to expedite modifications in response to process changes. The FTIR system supplier developed the requisite software package which meets these requirements and is tailored to the Steelcase coating application. For the most part, the modular software package was developed from existing subroutines and published spectral data which were modified as appropriate. For several of the compounds present in the Steelcase coatings, it was necessary to develop reference spectra that was then input to the system spectral library. These software developments were necessary to achieve the instrument sensitivity required for this application (see Table 2); the FTIR installed at the Steelcase facility meets and exceeds these requirements.

Fluidized Bed System Integration - The fluidized bed concentrator can only operate within a specified flow rate range; initial manufacturer data established the viable exhaust flow rate range between 42,500 cfm and 57,500 cfm. After equipment start-up, the manufacturer reduced the working range considerably; the current exhaust flow rate range is 48,000 cfm to 54,000 cfm. The fluidized bed manufacturer has indicated that the media will be over-fluidized if the influent flow rate is too high, and under-fluidized if the influent flow rate is too low. Of course, this places an artificially rigid constraint on the dynamic recirculation ventilation system (which was designed to vary the exhaust flow rate from 30,600 cfm to 61,200 cfm for Steelcase's particular application). This constraint presents a considerable challenge for the dynamic recirculation system, however if the technology can be conclusively demonstrated to work well in the

Table 2. FTIR Monitor Sensitivity Requirements.

Compound	FTIR Sensitivity Requirements (ppm)
Butyl acetate	5 ppm +/- 2
Ethyl acetate	5 ppm +/- 2
Toulene	2 ppm +/- 1
m-Xylene	2 ppm +/- 1
o-Xylene	2 ppm +/- 1
p-Xylene	2 ppm +/- 1
Methyl n amyl ketone	1 ppm +/- 0.5
1-Butoxy 2-propanol	2 ppm +/- 1
Methanol	5 ppm +/- 2
1,2,4-Trimethylbenzene	1 ppm +/- 0.5
1,3,5 - Trimethylbenzene	1 ppm +/- 0.5
1,2,3-Trimethylbenzene	1 ppm +/- 0.5
4-Ethyltoluene	2 ppm +/- 1
Ethyl benzene	2 ppm +/- 1

Steelcase application, then it will perform even better in other, less constrained applications. In fact, most control devices (such as thermal oxidizers) available on the market today are able to process air flow rate turn down ratios of 10:1, and should therefore work quite well with the dynamic recirculation ventilation strategy.

2.2 PHASE 2 - LONG TERM PERFORMANCE EVALUATION

Under Phase 2, AQS conducted long term performance evaluations of the fluidized bed concentrator and dynamic recirculation systems; details concerning each of these performance evaluations are presented separately below.

Dynamic Recirculation Performance Evaluation - The dynamic recirculation system was evaluated over a 24 week period to assess the quality of the work environment that the ventilation system provides, and to establish the level of flow optimization achieved. The work environment was evaluated through extensive sampling in each of the spray booths in accordance with the test matrix provided in Table 3. The matrix (which was reviewed and approved by ARB staff prior to initiating any sampling) included both organic specie concentration measurements as well as particulate concentration measurements. The flow optimization characteristics were established by recording ventilation system exhaust and recirculation flow rates on a minute-by-minute basis between September, 1999 and February, 2000. In addition, Edison measured electrical usage rates of spray booth fans and recirculation system fans in several operating modes including no recirculation, simple recirculation, and dynamic recirculation.

Fluidized Bed Concentrator Performance Evaluation - The fluidized bed concentrator was evaluated over a 24 week period to ascertain the long term effectiveness of the adsorbing media. Data were collected related to energy use, adsorption media effectiveness, solvent collection/emission reductions, and cross media pollutant transfer impacts. The fluidized bed system data collection parameters are summarized in Table 4. Steelcase performed sampling studies to establish the concentrator emission profile, and periodically recorded the volume of solvent that was recovered by the fluidized bed concentrator/condenser system. The results of these efforts are presented and discussed in detail in Section 3.

2.3 PHASE 3 - DATA REDUCTION, ECONOMIC ASSESSMENTS, REPORTING, AND TECHNOLOGY TRANSFER

Under Phase 3, the data collected in Phase 2 were assembled and analyzed to confirm and/or modify technology performance predictions. The dynamic recirculation system profile data was particularly useful; the data collected in September were used subsequently in November to enhance ventilation system controls. These system modifications were implemented by Steelcase's control system contractor, who also installed improved flow monitoring and recording equipment.

In addition to implementing system enhancement, Phase 3 efforts include assessing the economic benefits of the two technologies that were evaluated. The dynamic recirculation and fluidized bed concentrator technologies operate independently, therefore each technology was evaluated individually to ensure accurate projections of their effectiveness in other industries or applications.

Table 3. Booth Evaluation Test Matrix.

	Parameter	Sampling Method	# Samples/booth	# QC Samples
Single pass (non-recirculating) conditions for each of 5 booths	Coating application	Observation	N/A	N/A
	Total particulate	NIOSH 500	5	1 blind duplicate
	Organic analytes	NIOSH 1400	10	2 blind duplicates
Dynamic recirculating conditions for each of 5 booths	Coating usage rate	Observation	N/A	N/A
	Total particulate	NIOSH 500	5	1 blind duplicate
	Organic analytes	NIOSH 1400	10	2 blind duplicates
Dynamic recirculating conditions for each of 5 booths	Coating usage rate	Observation	N/A	N/A
	Total particulate	NIOSH 500	5	1 blind duplicate
	Organic analytes	NIOSH 1400	10	2 blind duplicates

TABLE NOTES:

***TARGET ORGANIC ANALYTES*:**

Xylene (3 isomers) Ethyl Benzene Ethyl toluene (3 isomers) n-Butanol Ethyl Acetate
Toluene Trimethylbenzene (3 isomers) Butyl Acetate Methyl n-Amyl Ketone

(Note: the baseline evaluation target analytes differ from the follow up recirculation evaluation analytes because Steelcase made some minor modifications to their paint formulations).

NIOSH 1400 (with minor modifications) - Two 200/400 coconut shell charcoal tubes are placed in series using a sealed Teflon connector, and sample air at a known volume flow rate passes through this sample unit, where the organics are collected via adsorption on the charcoal. A 60 minute sampling interval was employed at an approximate sample flow rate of 1 liter/minute (lpm). Constant flow sample pumps were employed for this effort, and were calibrated before and after each sampling event. Additionally, the sample number, location, pump flow rate, booth temperature and barometric pressure data were recorded for each sampling event. The front and back halves of each sample are recovered and extracted separately. The laboratory first analyzed the front and back halves of the front tube of each sample unit; if the concentration measured in the back half of the front tube exceeded 10% of the concentration measured in the front half of the front tube, then the laboratory analyzed the front and back sections of the back tube. The laboratory also performed replicates of a 3 level spike/recovery analysis to assess method accuracy.

NIOSH 500 (with minor modifications) - Particulate concentrations at each location were measured by passing sample air at a known volume flow rate through a cassette containing a $2\mu m$ pore size Teflon filter. The particulate collect on the filter, which are subsequently analyzed gravimetrically. A 60 minute sampling interval was employed at an approximate sample flow rate of 2 liter/minute (lpm). Constant flow sample pumps were employed for this effort, and were calibrated before and after each sampling event. Additionally, the sample number, location, pump flow rate, booth temperature and barometric pressure data were recorded for each sampling event.

QA/QC - Method accuracy, precision and representativeness were assessed through the collection and analysis of various QA samples, including field blanks, trip blanks, duplicate field samples, as well as the performance of duplicate sample analyses and spike/recovery assessments.

Table 4. System Performance Evaluation Matrix

	SAMPLING/MEASUREMENT FREQUENCY					
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Energy Efficiency						
Booth fan electrical usage[1]	2 Weeks	2 Weeks			1 Week	
Recirc. fan electrical usage[1]	1 Week	1 Week			1 Week	
Fluid bed electrical usage[1]	1 Week				1 Week	
BAC Media Analysis						
Apparent density	4	4	2	2	2	2
Adsorption number	1	1	2	2	2	2
Surface Area analysis	1	1	1	1	1	1
Cross Media Transfer Evaluation						
BAC Toxicity Characteristic Leachate Procedure	1					1
Solvent purity evaluation	1					1
Fluidized Bed Control Efficiency						
Inlet FTIR measurement	4	4	4	4	4	4
Outlet FTIR measurement	4	4	4	4	4	4
Third party source test						1

[1] Ventilation system electrical energy usage was measured by Southern California Edison technical staff for the following operating modes: no recirculation, simple recirculation, and dynamic recirculation.

Dynamic Recirculation Economic Assessment - The objective of an economic evaluation of dynamic recirculation is to quantify the cost benefits (and corresponding pollution reduction benefits) achievable through widespread implementation. Cost benefits considered pertain to reduced VOC emission control installation and operating costs and reduced HVAC equipment operating costs. This economic evaluation was completed based on system operating profile data collected in Phase 2. Two cases were considered in this effort; dynamic recirculation vs. no recirculation and dynamic recirculation vs. simple (39%) recirculation. The results of this analysis are provided in Section 3.

Fluidized Bed Concentrator Economic Assessment - The objective of this assessment was to determine the long-term applicability of the fluidized bed concentrator device in terms of cost and emission reduction potential. The performance evaluation data collected in Phase 2 was reconciled with cost and implementation data obtained from Steelcase and the fluidized bed system manufacturer to develop the economic assessment. Additional information pertaining to installation and operating costs of competing technologies were also collected; these data provided the basis for developing a detailed cost comparison analysis. The results of this analysis are provided in Section 3.

Phase 3 efforts also included coordinating critical technology transfer activities, which is of key importance in the overall ICAT Program. As discussed in detail in the commercialization plan submitted with this report, the two primary barriers to commercialization of the dynamic recirculation and fluidized bed concentrator technologies are 1) Full scale demonstration of these technologies; and 2) Dissemination of technological data to appropriate industrial sectors that may use these strategies for achieving air quality compliance, and to regulators that are in a position to promote widespread implementation of these strategies. With the successful completion of this ICAT program, the viability and applicability of the dynamic recirculation and fluidized bed concentrator technologies have been successfully demonstrated, thus data transfer to industry and regulators is the remaining barrier to commercialization. The data dissemination efforts undertaken as part of Phase 3 technology transfer activities include:

- Technical presentations on this ICAT Program were made at the following symposia:

  The A&WMA Association Annual Meeting, San Diego, CA - June, 1998
  The CAPCOA Engineering Seminar in Monterey, CA - April, 1999
  Exploring New Technologies for Clean Air, Irvine, CA - October 1999
  The A&WMA Association Annual Meeting, Salt Lake City, CA - June, 2000

- A technology transfer seminar hosted by Southern California Edison was held in November, 1999 at their Customer Technology Application Center (CTAC) in Irwindale, CA. The symposium was well attended by individuals from industrial manufacturing and military maintenance facilities as well as air quality regulators.
- Southern California Edison worked closely with AQS to develop a multi-page, color technical brochure on the Steelcase ICAT technology demonstration program. This brochure has been distributed to interested parties from industrial manufacturing and military maintenance facilities as well as air quality regulators.

- A website focusing on recirculation ventilation in general and dynamic recirculation in particular was established and will be maintained by AQS after completion of the ICAT program.

2.4 PHASE 4 - PROJECT MANAGEMENT/TECHNICAL COORDINATION

Phase 4 activities pertain exclusively to maintaining the overall technical program and achieving program goals. These activities included coordinating subcontractor and partner efforts and identifying technical, budget, and schedule concerns. A critical project management tool that was used by AQS was the submittal of periodic progress reports to ARB and SCAQMD; these reports summarized ongoing and recently completed activities, identified activities planned for the next reporting period, and summarized plan vs actual ICAT expenditure data.

SECTION 3

RESULTS

This section presents, in detail, the results obtained from the performance evaluations and the economic assessments conducted on the dynamic recirculation and fluidized bed concentrator technologies. The results obtained for each technology are presented separately.

3.1 DYNAMIC RECIRCULATION EVALUATION RESULTS AND CONCLUSIONS

As indicated in Section 2, a long term performance evaluation of the dynamic recirculation system was completed under Phase 2, and an economic assessment was completed under Phase 3; these results are presented sequentially below.

3.1.1 Dynamic Recirculation Performance Evaluation Results

The performance of the dynamic recirculation system was evaluated in terms of the work environment that it provided, as well as the ventilation system optimization level achieved:

In-Booth Work Environment Evaluation Results: As indicated in the test matrix (Table 3), AQS conducted baseline (no recirculation) sampling in each of the spray booths, followed by two sampling events during which the dynamic recirculation system was fully operational. The sampling results were reconciled with Cal OSHA PEL values to calculate the cumulative exposure factor (or exposure level) that occurs in each spray booth; Health and Safety regulations mandate that the cumulative OSHA Factor remain below 1.0 throughout an entire work shift. The OSHA Factor results of the baseline, initial recirculation and final recirculation sampling efforts are provided in Tables 5, 6 and 7, respectively. These figures were developed based on detailed spreadsheet calculation results which are provided in Appendix A. As indicated by the information provided, exposure levels generated due to the use of dynamic recirculation are well within regulatory limits.

Ventilation System Optimization Evaluation Results: The advantage of dynamic recirculation over other ventilation system strategies is that it optimizes ventilation system operation and reduces process exhaust flows on a continuous basis. Obviously, the more often the system operates in maximum recirculation mode, the more successful the technology application. To successfully evaluate dynamic recirculation at the Steelcase facility, AQS continually monitored the ventilation system exhaust and recirculation flow rates, and generated more than 100,000 data points by recording this operating profile data on a minute-by-minute basis. These data provide

Table 5 - Baseline OSHA Factor Sampling Results

Location		Painter Vicinity				Intake Face		
		Test 1	Test 2	Test 3	Avg	Test 1	Test 2	Avg
Booth 1	Organics	0.008	0.019	0.012	0.013	0.006	0.007	0.0065
	Particulate	0.030	<0.024	0.064	0.039	<0.027	<0.025	<0.026
Booth 2	Organics	0.030	0.019	0.030	0.027	0.013	0.000	0.006
	Particulate	0.058	0.068	0.043	0.056	<0.025	<0.025	<0.025
Booth 3	Organics	0.012	0.030	0.011	0.018	0.003	0.011	0.007
	Particulate	0.482	0.195	0.192	0.289	<0.024	0.027	0.026
Booth 4	Organics	0.60	0.038	0.089	0.062	0.057	0.071	0.064
	Particulate	0.201	0.140	0.419	0.253	<0.028	0.033	0.031
Booth 5	Organics	0.087	0.089	0.041	0.072	0.073	0.065	0.069
	Particulate	0.028	0.047	0.025	0.033	<0.032	0.030	0.031

Table 6. Recirculation Test 1 OSHA Factor Sampling Results.

Location		Painter Vicinity				Intake Face		
		Test 1	Test 2	Test 3	Avg	Test 1	Test 2	Avg
Booth 1	Organics	0.269	0.285	0.255	0.269	0.227	0.254	0.240
	Particulate	0.203	<0.025	0.096	0.108	0.046	<0.025	0.035
Booth 2	Organics	0.300	0.502	0.315	0.372	0.407	0.354	0.381
	Particulate	<0.027	0.028	0.231	0.095	0.056	0.044	0.050
Booth 3	Organics	0.481	0.255	0.346	0.341	0.270	0.369	0.319
	Particulate	<0.025	0.757	0.083	0.288	0.058	<0.024	0.041
Booth 4	Organics	0.196	0.246	0.261	0.234	0.107	0.133	0.120
	Particulate	0.385	0.108	<0.031	0.175	<0.027	<0.024	<0.026
Booth 5	Organics	0.186	0.287	0.319	0.264	0.159	0.295	0.227
	Particulate	0.079	0.030	0.065	0.058	0.045	0.045	0.045

Table 7. Recirculation Test 2 OSHA Factor Sampling Results.

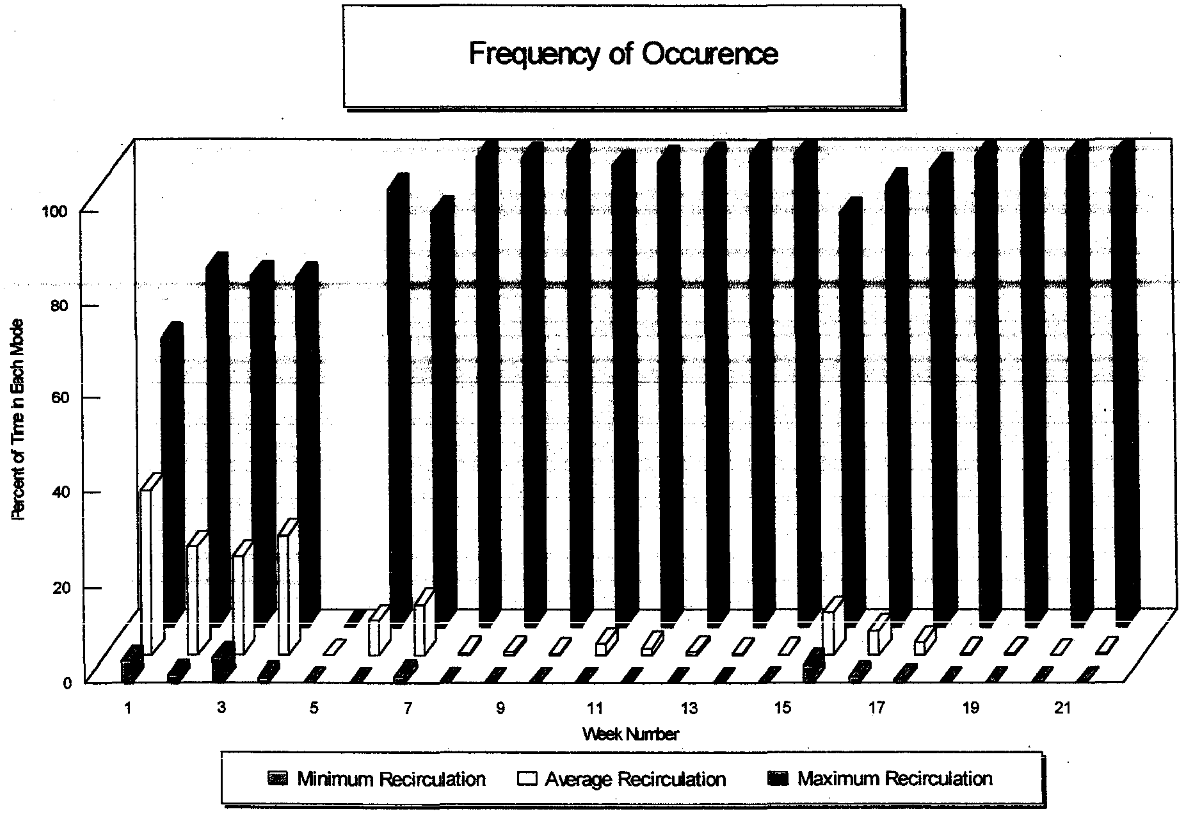
Location		Painter Vicinity				Intake Face		
		Test 1	Test 2	Test 3	Avg	Test 1	Test 2	Avg
Booth 1	Organics	0.098	0.159	0.134	0.130	0.121	0.151	0.136
	Particulate	0.301	0.053	0.058	0.137	<0.024	<0.025	<0.025
Booth 2	Organics	0.330	0.319	0.301	0.317	0.304	0.250	0.277
	Particulate	<0.024	0.086	0.127	0.079	<0.024	<0.024	<0.024
Booth 3	Organics	0.200	0.154	0.215	0.190	0.152	0.162	0.157
	Particulate	0.036	0.272	0.534	0.281	<0.023	<0.024	<0.024
Booth 4	Organics	0.151	0.093	0.144	0.129	0.065	0.106	0.085
	Particulate	0.079	0.051	0.063	0.064	<0.027	<0.024	<0.027
Booth 5	Organics	0.256	0.312	0.348	0.305	0.293	0.320	0.307
	Particulate	<0.024	<0.024	<0.024	<0.024	<0.024	<0.024	<0.024

the basis for determining the frequency in which the ventilation system operated in maximum recirculation mode vs. minimum recirculation mode. The results of this evaluation, presented in bar-chart format in Figure 5, indicate that the system achieved a 91% maximum recirculation operating mode, and a 1% minimum recirculation operating mode. For the 8% operating time that remained, the system operated in mid-recirculation mode. As indicated in Table 8, these results conform with engineering predictions completed at the beginning of this project (as discussed in Section 2).

Table 8. Actual vs. Predicted Recirculation Operating Modes for the Steelcase Operations.

Recirculation mode	Frequency predicted in Engineering Calculations	Frequency Determined from Operating Profile Data
Minimum (<38%)	5%	1%
Mid-Level	16%	8%
Maximum (>44%)	79%	91%

Figure 5. Dynamic Recirculation System Operating Profile.



The cumulative OSHA Factor results, combined with the long-term ventilation system profile data, indicate that dynamic recirculation can successfully provide an appropriate work environment and still achieve optimized system operation.

3.1.2 Dynamic Recirculation Economic Analysis

The advantage of dynamic recirculation over other ventilation system strategies is that it optimizes HVAC and ventilation system operation and reduces process exhaust flows on a continual basis. For this study, the economic benefits of dynamic recirculation were assessed through a cost comparison analysis in which various ventilation system and emission control scenarios were projected for a hypothetical facility located in Southern California. Cost profiles for three different operating scenarios were developed: 1) The facility has no recirculation, and installs a regenerative thermal oxidizer (RTO) pollution control device; 2) The facility installs a simple recirculation system and an RTO; and 3) The facility installs a dynamic recirculation system and an RTO. These cost profiles were developed based on the following general assumptions:

- The process volume flow rate is 100,000 cfm; simple recirculation reduces this flow rate by 40%; dynamic recirculation achieves the following flow reduction profile:

Recirculation Rate	Mode Operating Frequency
80%	5%
70%	20%
60%	25%
50%	25%
40%	20%
< 40%	5%

(Based on these numbers, the average recirculation rate is calculated at 55.5%).

- RTO capital and installation cost data were obtained from a reputable manufacturer located in Southern California. Costs for installing the recirculation ventilation system were based on the costs incurred by Steelcase.
- Utility rates are $2.70/ MBtu and $0.057/kW-hr (these rates apply to facilities that have a very high electrical demand; actual rates paid could be much higher if facility electrical demand is not particularly high).
- The facility paint operation requires that the process air temperature be maintained at 80°F for 18 hours per day, 5.5 days per week. While this does not require substantial heating on summer days, significant heating is required during winter months as well as mornings and evenings in the summer. To simplify the calculation, the following ambient temperature profiles are assumed during operating hours (based on 30 avg temperature data for Los Angeles obtained from the 2000 Almanac): 60.5°F in winter (6 months/year) and 71.5°F in summer (6 months/year).
- A regenerative thermal oxidation system operated at 1600°F is assumed for the pollution control equipment cost comparison; a local manufacturer provided the capital and installation costs.
- The average solvent concentration is 25 ppm_V without recirculation, and 45 ppm_V with recirculation; these concentrations are too low to provide any heat value advantages.

- An operating schedule of 18 hours/day, 5 ½ days/week; 52 weeks/year is assumed.
- An interest rate of 8% and an equipment life of 15 years is assumed; this corresponds to a capital recovery factor of 0.11683.

The results of this economic analysis are presented in Table 9, along with additional, case-specific assumptions. These results clearly demonstrate the cost reduction potential of recirculation in general, and dynamic recirculation in particular. It should be noted that the extremely high cost of implementing recirculation at the Steelcase facility is atypical; for most facilities, the cost to implement recirculation is approximately double the cost of installing a single pass (no recirculation) ventilation system. However, for the Steelcase application, recirculation installation costs were 4 times higher than single pass ventilation. This abnormally high cost is primarily due to the configuration of the Steelcase booths, the roof structural requirements, and the duct location requirements. Correspondingly, Table 9 also includes a cost comparison that reflects more "typical" recirculation implementation costs.

3.2 FLUIDIZED BED CONCENTRATOR EVALUATION RESULTS AND CONCLUSIONS

Fluidized bed analytical and operational data were collected and analyzed over a 24 week period in accordance with the matrix specified in Table 4. These data were employed in both the technology performance and economic evaluations.

3.2.1 Fluidized Bed Concentrator Performance Evaluation Results

The performance evaluation of the fluidized bed concentrator focussed on two primary areas: 1) The long term durability and effectiveness of the BAC adsorption media; and 2) The emission control capability of the equipment.

3.2.1.1 BAC Media Effectiveness Evaluation Results

Like all other adsorption media, BAC is not completely regenerated when it exits the desorber module, and a small amount of solvent heel remains on the media following each adsorption/desorption cycle. Over time, this solvent heel increases to a point where media effectiveness is impacted, at which stage the media must be removed from the equipment and re-activated. A primary objective of this ICAT Program was to evaluate the long term viability of the fluidized media, thus monitoring media performance and tracking the heel build-up rate on the media was a major concern. Moreover, determining the re-activation frequency (which varies

Table 9. Dynamic Recirculation Economic Evaluation Results.

Case-Specific Assumptions	Simple Recirculation	Dynamic Recirculation	No Recirculation
% Flow reduction	40%	55.5% (avg)	0%
Exhaust flow rate	60,000 cfm	44,500 cfm	100,000 cfm
Ventilation system electricity demand	169.7 kW	158.8 kW	135.5 kW
Ventilation system installed cost (determined from Steelcase experience)	$800,000	$800,000	$250,000
Device installed cost (data supplied by manufacturer)	$447,125	$447,125	$750,000
Device electricity demand (data supplied by manufacturer)	132 kW	94.6 kW	220 kW
Device natural gas demand (calculated based on enthalpy analysis)	4.8 MBtu/hr	3.6 MBtu/hr	8.0 MBtu/hr
HVAC heating demand [summer] (calculated based on enthalpy analysis)	0.606 MBtu/hr	0.449 MBtu/hr	1.01 MBtu/hr
HVAC heating demand [winter] (calculated based on enthalpy analysis)	1.25 MBtu/hr	0.926 MBtu/hr	2.08 MBtu/hr
Operating Cost Evaluation Results			
Device natural gas cost ($2.70/ MBtu)	$ 67,052	$ 49, 730	$111,753
Device electrical cost ($0.057/kW-hr)	$ 38,743	$ 27,759	$ 64,556
Ventilation electrical cost ($0.057/kW-hr)	$ 49,796	$ 46,451	$ 39,761
HVAC heating cost ($2.70/ MBtu)	$ 12,899	$ 9,556	$ 21,475
Annualized Cost Results			
Annualized capital cost	$145,7021	$145,7021	$116,830
Annual operating cost	$168,480	$133,496	$237,544
Total Annualized cost:	**$314,182**	**$279,198**	**$354,374**
Annualized cost of "typical" recirculation:	**$279,133**	**$244,149**	**$354,374**

from application to application) is important not only in establishing performance characteristics, but also in evaluating the overall system economics. The long-term system evaluation was completed through extensive media sampling and analysis; analytical methods included specific gravity, adsorption number, surface area, and media leaching characteristics. The fluidized bed concentrator manufacturer relied upon the adsorption number analysis results to determine the media re-activation schedule because it is a direct measurement of the media adsorption performance.

Adsorption Number Measurements- determine the adsorption capacity of activated carbon relative to a known amount of solvent such as carbon tetrachloride, chlorobromomethane, or equivalent. Media samples were analyzed in accordance with ASTM Method 3467-94, which determines the mass of solvent adsorbed by the media at saturation; this quantity is divided by the mass of media used for the measurement, and the result is expressed as $\%_{wt}$ of solvent adsorption. The adsorption number of virgin BAC is typically 75% ± 5%. For this project, media samples were initially collected and analyzed on a monthly basis, however the sampling frequency was increased in the second month. The results of the adsorption number analyses are presented in Table 10, which indicate the expected decrease in adsorption capacity due to heel build up which is typical for all adsorption technologies. After 155 days in service, the adsorption number value decreased to below 15%, at which point the fluidized bed concentrator manufacturer recommended BAC media re-activation; this occurred on September 23, 1999 after which the media was restored to full adsorption capacity.

Apparent Density Measurements - which provide a simple method for quantifying heel buildup. This test method (ASTM D 2854-89, "Standard Test Method for Apparent Density of Activated Carbon") determines the apparent density of porous media (such as BAC) by weighing the volume of media collected in a graduated cylinder after it is poured from a vibrating feeder at a fixed delivery rate (ranging from 0.75 to 1.0 ml/minute) from a vibrating feeder. The results are reported in units of grams/cubic centimeter. By using this media compaction technique, the potential for erroneous volume data due to void fractions is eliminated. Media samples were initially collected and analyzed on a weekly basis. Unfortunately, the laboratory improperly analyzed the first 5 samples, thus AQS selected an alternate laboratory that was used for the remainder of the study. The second laboratory suggested it should be adequate to perform the

Table 10. Adsorption Number Sample Analyses Results

Sample Date	Days in Service	Adsorption Number
Beginning of Evaluation	0	75%
4/21/99	1	32%
5/20/99	30	32%
6/16/99	57	29%
7/1/99	72	25%
7/15/99	86	25%
7/29/99	100	24%
8/11/99	113	24%
8/27/99	129	18%
9/9/99	141	24%
9/21/99	154	16%
9/23/99 before reactivation	155	15%
9/25/99 after reactivation	0	79%

Table 11. Apparent Density Sample Analyses Results

Sample Date	Days in Service	Apparent Density (g/cc)
Beginning of Evaluation	0	0.61
4/21/99	1	0.76
5/20/99	30	0.75
6/16/99	57	0.77
7/1/99	72	0.78
7/15/99	86	0.78
7/29/99	100	0.78
8/11/99	113	0.797
8/27/99	129	0.826
9/9/99	141	0.803
9/21/99	154	0.836
9/23/99 before reactivation	155	0.84
9/25/99 after reactivation	0	0.592

gravity and adsorption number analyses simultaneously on a bi-weekly basis, and the test matrix was adjusted to reflect this recommendation. The specific gravity analysis results, presented in Table 11, indicate the gradual increase in media density, and provides a solid means of predicting the BAC reactivation interval. The BAC media was reactivated on September 23, 1999 and subsequently restored to a reduced density state.

Specific Surface Area Analysis (or BET Analysis) - As the heel deposition increases on the media, the active surface area available for solvent adsorption is decreased, thus another means of evaluating media effectiveness is to periodically measure the active surface area. This is accomplished through the use of a multi-point nitrogen adsorption measurement (ASTM Method D 4820-99) which is based on the assumption that nitrogen adsorption will occur on all active sites not already occupied by the solvent heel deposition (technical details of this analytical procedure are provided in Appendix B). For this project, BET samples were collected and analyzed on a monthly basis; the results are provided in Table 12. The first six data points represent media surface characteristics over the 155-day time interval prior to media re-activation; the seventh data point indicates media surface characteristics following re-activation. These data indicate that the active surface area is fully restored following re-activation, which is quite consistent with the apparent density and adsorption number results

Table 12. BET Sample Analyses Results

Sample Date	Days in Service	BET Surface Area (m^2/g)
Beginning of Evaluation	0	1026.87
5/20/99	30	551.82
6/16/99	57	35.38
7/15/99	86	38.53
8/11/99	113	11.03
9/9/99	141	13.28
9/23/99 after re-activation	0	1192.69

Media Leaching Characteristics - At inception of the media performance evaluation, there was some concern that the BAC may contain leachable toxic contaminants which potentially creates cross-media pollutant transfer problems. There was additional concern that the re-activation process could alter BAC media characteristics and create the potential for toxic compound leaching. To address these concerns, both virgin BAC and re-activated BAC samples were collected and analyzed for organic and inorganic toxic leaching characteristics in accordance with EPA Methods 1311/8260 and 6010B/7470, respectively. The results, presented in detail in Appendix B, indicate that neither the virgin BAC nor the re-activated BAC exhibit toxic characteristics, and were below method reporting limits identified in Table 13.

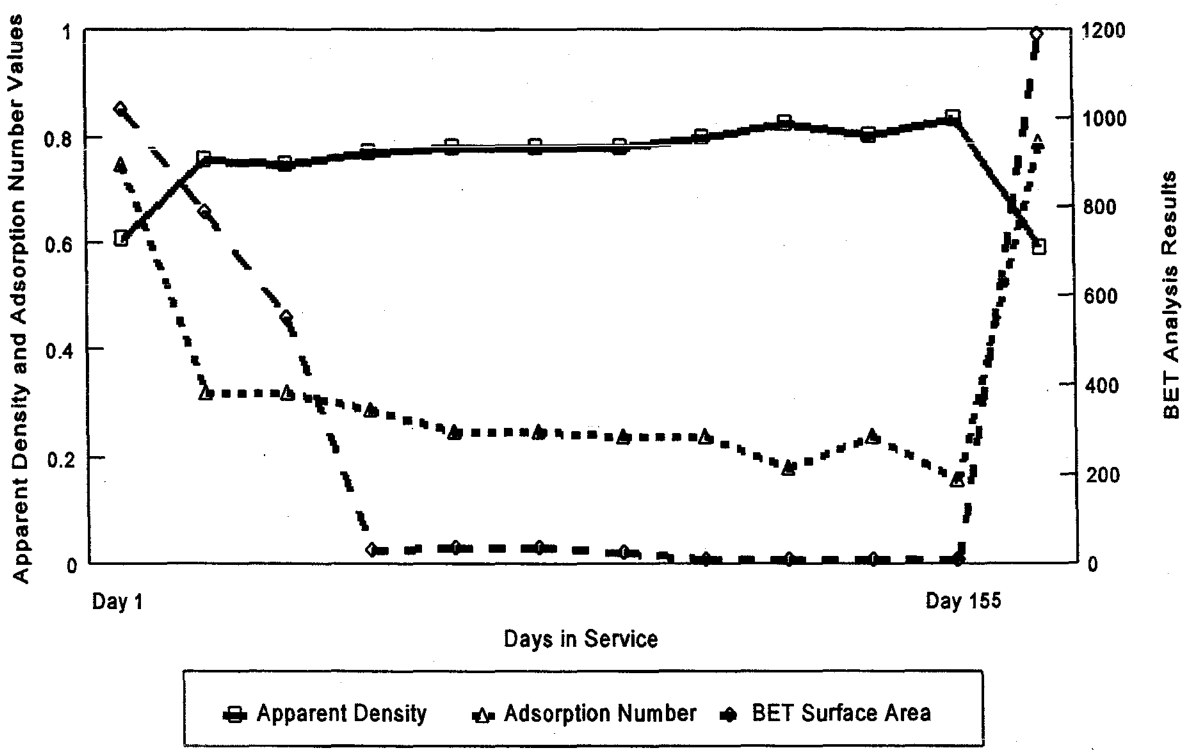
Table 13. Organic and Inorganic TCLP Limits (BAC Media Report Non-Exceedances).

Method	Compound	Report Limits (ppm)
TCLP VOCs [EPA Method 1311/8260)	Benzene	0.050
	Carbon Tetrachloride	0.050
	Chlorobenzene	10.000
	Chloroform	0.600
	1,4-Dichlorobenzene	0.050
	1,2-Dichloroethane	0.050
	1,1-Dichloroethane	0.070
	Hexachlorobutadiene	0.010
	Methyl Ethyl Ketone	0.050
	Tetrachloroethene	0.070
	Trichloroethene	0.050
	Vinyl Chloride	0.020
TCLP Metals [EPA Method 6010B/7470]	Arsenic	0.500
	Barium	10.000
	Cadmium	0.100
	Chromium	0.500
	Lead	0.500
	Mercury	0.020
	Selenium	0.100
	Silver	0.500

The results of the long-term BAC media characteristic analyses, illustrated graphically in Figure 6, clearly establish a 5-month re-activation cycle for the fluidized bed concentrator in the Steelcase application. As demonstrated below, an accurate economic evaluation of the fluidized bed concentrator system relies on establishing the correct re-activation cycle. It must be reiterated that the re-activation cycle is an application dependent parameter, thus one should not infer that a 5 month cycle uniformly applies for this technology. The Steelcase facility operates six to seven days per week at two to three shifts per day, which presents a very rigorous duty cycle for the media. Other, less demanding applications can have a much longer re-activation cycle.

Figure 6. BAC Media Characterization Analysis Results

(Note uniformity of BAC media re-activation interval indicators)



3.2.1.2 Fluidized Bed Emission Control Performance Evaluation Results

The fluidized bed concentrator emission control performance was evaluated via three separate data collection efforts: 1) Monitoring the volume of solvent collected in the condenser; 2) Performing inlet and outlet concentration measurements via FTIR; and 3) Independent source testing performed by a third-party contractor after the fluidized bed system was operational for nearly 1 year. In addition, secondary emissions generated by the fluidized bed technology were also evaluated. The results of these efforts are described below.

Solvent Volume Recovery Results - Most of the solvent collected in the condenser is re-used in the Steelcase paint facility; that which cannot be re-used is disposed of through a licensed waste solvent recycling company. During the 24 week evaluation period, Steelcase reported an average solvent liquid recovery rate of 50 gal/day, 95% of which was pure solvent, and 5% of which was water (solvent sample analyses performed at the beginning and end of the 24 week evaluation period confirm this solvent purity level - see Appendix B). Steelcase reported an average solvent density of 7.2 lb/gal, thus the fluidized bed concentrator system achieved an average VOC emission reduction rate of 342 lb/day, or 51 tons/year during the 24 week evaluation period. As subsequently discussed in more detail, re-use of the solvent by Steelcase presents a modest payback incentive, and does in fact contribute to the overall cost-effectiveness of the fluidized bed concentrator/solvent recovery system.

FTIR Inlet/Outlet Concentration Measurement Results - At the inception of this program, it was anticipated that the FTIR could be used as a tool for monitoring the fluidized bed concentrator system emission control efficiency. As indicated in Table 4, the FTIR was employed to measure the fluidized bed system inlet and outlet organic concentrations on a weekly basis; it was anticipated that the control efficiency could be ascertained by reconciling these results. Typical concentrations measured by the FTIR at the inlet are provided in Table 14, along with theoretical exhaust concentration projections calculated based on a 95% control efficiency. By inspection, it must be concluded that the projected outlet concentrations are well below the FTIR instrument sensitivity levels (see Table 2). The FTIR capabilities are adequate for the dynamic recirculation application, however the instrument is not sufficiently sensitive to use in monitoring outlet concentrations, thus the fluidized bed inlet/outlet monitoring effort did not provide useful data.

Independent Source Testing Performed by Third Party Contractor - Steelcase performed several third party emission control efficiency tests of the fluidized bed concentrator between April, 1999 and January, 2000. Integrated VOC samples were collected in accordance with SCAQMD Methods 25.1 and 25.3, and continuous VOC measurements were collected in accordance with EPA Method 25A. For all the test sequences, the exhaust concentration results are slightly above

Table 14. FTIR Inlet Organic Concentrations and Projected Outlet Concentrations.

Compound	Location	Compound Concentration (ppm)				
		Dataset 1	Dataset 2	Dataset 3	Dataset 4	Dataset 5
Butyl acetate	Inlet data	4.9	0.0	0.0	0.0	0.0
	Projected outlet	0.25	0.0	0.0	0.0	0.0
Ethyl acetate	Inlet data	1.1	1.0	0.9	1.5	1.5
	Projected outlet	0.055	0.05	0.045	0.075	0.075
Toluene	Inlet data	0.3	0.3	0.3	0.4	0.7
	Projected outlet	0.015	0.015	0.015	0.02	0.035
m-, o-, & p-Xylene	Inlet data	4.3	1.5	0.6	3.8	2.9
	Projected outlet	0.215	0.075	0.03	0.19	0.145
Methyl n-amyl ketone	Inlet data	0.0	0.7	0.3	2.2	2.0
	Projected outlet	0.0	0.035	0.015	0.11	0.10
1-Butoxy-2-propanol	Inlet data	2.3	1.7	1.2	3.9	4.0
	Projected outlet	0.115	0.085	0.06	0.195	0.20
Methanol	Inlet data	1.7	1.5	1.1	5.0	4.8
	Projected outlet	0.085	0.075	0.055	0.25	0.24
1,2,4-, 1,3,5-, & 1,2,3-TMB (Trimethylbenzene)	Inlet data	4.8	8.4	5.6	9.1	9.7
	Projected outlet	0.24	0.42	0.28	0.455	0.485
4-Ethyltoluene	Inlet data	7.1	6.0	2.8	13.0	12.9
	Projected outlet	0.355	0.30	0.14	0.65	0.645
4-Chlorobenzotrifluoride (non- VOC)	Inlet data	3.2	5.9	4.8	12.2	12.3
	Projected outlet	0.64	0.295	0.24	0.61	0.612
Total Organic Concentration	Inlet data	29.7	27.0	17.6	51.1	50.8
	Projected outlet	1.485	1.35	0.88	2.555	2.54
Total VOC Concentration	Inlet data	26.5	21.1	12.8	38.9	38.5
	Projected outlet	1.325	1.055	0.64	1.945	1.95

method detection limits, and indicate solvent concentrations of less than 2.5 parts per million [ppm] as solvent (13 ppm as carbon [ppm_C]). The inlet measurement results reveal a relatively low influent solvent concentration; the data range from 120 ppm_C to 350 ppm_C. Based on these results, the calculated control efficiency ranges from 89% to 96%, depending on which inlet concentration data set is selected, simply because the exhaust concentration measurement data are consistently low (<2.5 ppm).

VOC control device inlet concentrations are typically very low in most industrial painting operations; these low concentrations often make it difficult to precisely measure the control efficiency. For example, if a control device must demonstrate a 95% efficiency, and the inlet concentration is 125 ppm_c, the corresponding outlet concentration must be 6.25 ppm_C. The difficulty arises in accurately measuring this low outlet concentration because it is only slightly above method detection limits for accepted VOC sampling procedures. A control device which consistently reduces exhaust concentrations to below 10 ppm_C, yet has a highly variable inlet concentration (e.g. 125 to 250 ppm_C) will have a reported control efficiency that ranges from 92% to 96%. This can pose a problem for facilities and regulators alike, because even though a device consistently achieves an acceptably low exhaust concentration, the control efficiency cannot be precisely established if the inlet concentration varies. This seems to be the situation at Steelcase; results of source tests performed over a ten-month period indicate that the fluidized bed concentrator consistently reduces VOC exhaust concentrations to less than 2.5 ppm, even thought the inlet VOC concentration varies by a factor of 3. Nonetheless, the low exhaust concentrations achieved by the fluidized bed concentrator demonstrates that the system consistently achieves an acceptably high VOC emission control efficiency.

Secondary Emissions Streams - Aside from uncontrolled solvent emissions and the solvent condensate that is not re-used in Steelcase painting operations, a third emission stream is potentially generated by the BAC re-activation process. The media is re-activated off site at a fully permitted cement kiln which bakes off the solvent heel. Solvent vapors generated in this process are oxidized in the high temperature kiln, thus solvent emissions are negligible, although emissions of nitrogen oxides (NO_X) are generated.

3.2.2 Fluidized Bed Concentrator Economic Evaluation Results

A detailed economic evaluation of the fluidized bed concentrator system was performed to establish the cost competitiveness of this technology. This cost evaluation consisted of 2 independent assessments: 1) Developing an installation and operating cost profile for the fluidized bed concentrator in the Steelcase application, based on the data collected in the Phase 2 effort; and 2) Developing similar cost profiles for competing technologies. The results of these two assessments were compared to derive definitive conclusions regarding the economic viability of the fluidized bed technology.

3.2.2.1 Fluidized Bed Concentrator System Cost Profile

Both system installation and annual operating costs were considered in this analysis; installation costs were obtained directly from Steelcase, and operating costs (e.g. utilities, liquid nitrogen consumption rates, BAC media re-activation, and solvent re-use cost benefits) were determined from data collected from Steelcase under the Phase 2 effort.

The Steelcase fluidized bed concentrator cost evaluation was developed based on the following cost assumptions and system configurations:

- The 50,000 cfm fluidized bed concentrator combined capital and installation cost is $814,000, which includes an initial charge of 3,000 lb of BAC media, and assumes that utilities and the process air are brought to within 10 feet of the device. *(Note: since Steelcase started up the fluidized bed concentrator system in Spring, 1999 the manufacturer improved the system design; these improvements have significantly reduced the price. If the newly designed equipment were purchased and installed at the Steelcase facility today, capital and installation costs would not exceed $625,000. However, to ensure conservative results for this particular analysis, the higher cost is assumed).*
- The device electrical demand is 52 kW total (Phase 2 data) and the ventilation electricity demand (to bring the process exhaust air to the fluidized bed system) is 41 kW (Phase 2 data); the electricity rate is $0.057 per kW-hr.
- The operating schedule is 18 hours/day, 5 ½ days/week; 52 weeks/year.
- The BAC media re-activation interval is 5 months, the media attrition rate is 720 lb/year, and the media replacement interval is 5 years. The BAC reactivation costs are $1.30/lb for the first run, $2.6/lb for subsequent runs, and the transportation cost is $450. The cost of replacement BAC media is $15/lb. The cumulative annualized media expenses incurred by Steelcase based on these data is $25,892.
- A net annual solvent recovery cost savings (due to avoided solvent purchases) is calculated at $8,064 based on an average solvent recovery rate of 50 gal/day.
- An equipment life of 15 years (due to low temperature operation), an interest rate of 8% and a corresponding capital recovery factor of 0.11683
- Additional annual costs related to labor, materials, etc of $13,200.

Based on these parameters, the annualized equipment capital cost is calculated as \$95,100, and the annual operating cost is \$58,318. The corresponding total annualized cost is \$153,417; reconciling this with an annual emission control rate of 51 TPY (see Section 3.2.1.2) yields an annualized emission control cost (or control cost-effectiveness) of \$3,008/ton. This is fairly low, particularly when compared to the control cost threshold of \$10,000/ton typically employed across the U.S.

3.2.2.1 Cost Comparison: Fluidized Bed Concentrator vs. Competing Technologies

Three manufacturers provided economic data for three different emission control technologies which represent competing strategies for the fluidized bed concentrator device. Cost profiles for each technology were developed based on both general assumptions (which were drawn from the Phase 2 data collection efforts and apply to all three cost profile analyses) and equipment-specific parameters. Details on specific assumptions are provided below, along with a brief description of each technology. The general cost profile assumptions include:

- The process flow rate is 50,000 cfm, and has a solvent concentration of <25 ppm (avg), which is insufficient to provide heat value or utility cost savings.
- Process air and utilities are located within 10 feet of the device, and a pad is provided.
- Electricity and natural gas utility rates are \$0.057/kW-hr and \$2.70/MBtu, respectively.
- An operating schedule of 18 hours/day, 5 ½ days/week; 52 weeks/year is assumed.
- An interest rate of 8% and an equipment life of 15 years is employed (although it is unlikely that natural gas combustion devices will last this long).

Zeolite Concentrators - Zeolite is a naturally occurring adsorbing material that has come into recent use in the pollution control market. Synthetic zeolite has excellent adsorption properties for the types of solvents that are employed at the Steelcase facility, and works well in both fixed bed and rotor concentrator configurations. Capital and installation cost data for both configurations were obtained from manufacturers. The fixed bed system achieves a flow reduction ratio that often exceeds 20:1, and rotor system flow reductions typically range from 10:1 to 15:1. Because these flow reduction ratios are lower than the >100:1 flow reduction ratio achieved by the fluidized bed concentrator, the control devices associated with these systems (e.g. condenser or oxidizer) are typically much larger. Cost profiles for the rotor and fixed bed zeolite concentrator systems were developed based on the following specific assumptions:

- Both the fixed bed and rotor systems control emissions via a catalytic oxidizer.
- Natural gas usage rates are 1.82 and 0.8 MBtu/hr for the rotor and fixed systems, respectively. These results were derived using an enthalpy analysis approach.
- Manufacturers report electricity demands of 66 kW and 160 kW for rotor and fixed systems, respectively.
- Materials/maintenance requirements (such as zeolite replacement rates) are estimated at 10% percent of the other operating costs.

Regenerative Thermal Oxidizer - The dual chamber regenerative thermal oxidizer device employs ceramic heat transfer media to maintain a high (90-95%) thermal efficiency. Oxidation of the 50,000-CFM exhaust stream occurs at a temperature of 1,600°F to ensure complete combustion. The regenerative thermal oxidizer cost profile was developed based on the following specific assumptions:

- The system maintains bed temperatures throughout the work week, and thermal start-up of the bed is required only once per week - thermal start-up costs are not included.
- In operation, the natural gas demand is 4.4 MBtu/hr; (derived using an enthalpy analysis approach). According to the manufacturer, the electricity demand is 103 kW.

The results of this competing technology cost profile analysis is presented in Table 15, along with a revised cost analysis for the fluidized bed concentrator system based on current manufacturer prices (see Section 3.2.2.1). The comparative analysis results demonstrate the cost-competitiveness of the fluidized bed concentrator technology. It should be noted that the results presented in Table 15 are based on fixed cost data provided by various manufacturers as well as variable cost parameters such as electricity and natural gas rates, percent interest rates, actual equipment life, etc. Variations in these parameters can result in different cost profile results. Therefore, facilities that intend to install add-on VOC pollution controls and are contemplating one or more of the technologies identified in Table 15 (or any VOC control technology for that matter) are strongly encouraged to develop site-specific cost profiles for the control options being considered. These cost profiles should accurately reflect actual facility operating variables; for example:

- If natural gas is not available at the facility, the cost of bringing natural gas to the VOC emission control device must be factored into the system installation cost.

- If the facility electrical supply is insufficient to accomodate the VOC control device, the cost of increasing the electricity supply infrastructure must be factored in, and could significantly increase the installation cost.
- Depending on the control device that is considered, the VOC concentration can have an impact on the equipment operating cost.
- Depending on the control device that is considered, the facility operating schedule (hours/day, days/week, weeks/year) can have a large impact on the operating cost.

Table 15. Cost Comparison of Competing Control Technologies

Cost Item	Fluidized Bed	Zeolite Rotor	Zeolite Fixed Bed	RTO
Capital Cost Parameter				
Capital & Installation Cost	$625,000	$626,000	$635,100	$447,125
Capital Recovery Factor	0.1168	0.1168	0.1168	.1168
Annualized Capital Cost	$73,025	$73,142	$74,205	$52,242
Operating Cost Parameters				
Device Electrical Cost	$11,737	$19,367	$46,950	$30,224
Natural Gas Energy Requirements	$0	$25,297	$11,120	$61,158
Total BAC Reactivation & Replacement Cost	$25,892	$0	$0	$0
Other Operating Cost	$13,200	$4,466	$5,807	$2,000
Solvent Savings	$8,064	$0	$0	$0
Total Annual Operating Cost	$50,829	$49,130	$63,876	$93,382
Total Annualized Cost	$123,854	$122,272	$138,081	$145,624

REFERENCES

1. 1995 Estimated Statewide Emissions by Category; data obtained from the California Air Resources Board Website in August, 1999.

2. Air Toxics Monitoring Using FTIR Spectrometry; R. Hovan, et al; Paper No. 95-TA 32.04; presented at the Air and Waste Management Association 88th Annual Meeting and Exhibition in San Antonio, TX; June, 1995.

3. Comprehensive VOC Source Emissions Assessment: a Combined Approach of EPA Method TO-14, EPA Method TO-11, and Extractive FTIR; W. Reagan, et al; Paper No. 95-TA 32.02; presented at the Air and Waste Management Association 88th Annual Meeting and Exhibition in San Antonio, TX; June, 1995.

APPENDIX A

DETAILED SPREADSHEET RESULTS OBTAINED FROM IN-BOOTH PARTICULATE AND ORGANIC SAMPLING

STEELCASE/ICAT BASELINE SAMPLING RESULTS

Filename: Baseline
Worksheet: NIOSH 1300
Directory: c:\123r5w\work\icat
Print Date: 05-Jun-2000

Method NIOSH 1300
Engineer Initials: JA
[STP defined at 68F and 29.9 in Hg]

					Xylene		Trimethyl benzene		MIBK		Ethyl benzene		Ethyl toluene		Cummulative
Location	Type	Date	Shift	Volume (l @ stp)	mg/tube	mg/m3	mg/tube	mg/m3	mg/tube	mg/m3	mg/tube	mg/m3	mg/tube	mg/m3	OSHA Factor
Booth 1	Tripod/field	May 12	1	68.5	0.061	0.89	0.037	0.54	0.000	0.00	0.015	0.22	0.018	0.26	0.005641
Booth 5	Painter/field	May 12	1	48.4	0.222	4.59	0.442	9.13	0.006	0.13	0.005	0.10	0.239	4.94	0.086789
Booth 2	Tripod/field	May 12	1	46.0	0.019	0.42	0.063	1.36	0.000	0.00	0.004	0.10	0.029	0.63	0.012726
Booth 3	Painter/field	May 12	1	57.0	0.236	4.14	0.051	0.90	0.000	0.00	0.058	1.02	0.032	0.57	0.011503
Booth 2	Tripod/blank	May 12	1	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0
Booth 3	Tripod/field	May 12	1	64.4	0.006	0.09	0.021	0.33	0.000	0.00	0.000	0.00	0.011	0.17	0.003069
Booth 5	Painter/field	May 12	2	56.4	0.149	2.64	0.528	9.35	0.003	0.06	0.034	0.60	0.270	4.78	0.088791
Booth 4	Painter/field	May 12	2	57.9	0.222	3.83	0.356	6.14	0.003	0.05	0.049	0.85	0.182	3.14	0.059711
Booth 4	Tripod/field	May 12	2	51.7	0.063	1.22	0.310	6.00	0.002	0.04	0.014	0.27	0.157	3.04	0.056518
Booth 2	Painter/field	May 12	2	51.0	0.230	4.51	0.141	2.76	0.005	0.09	0.051	1.00	0.089	1.74	0.029734
Booth 1	Painter/field	May 18	1	65.2	0.258	3.96	0.036	0.56	0.000	0.00	0.047	0.72	0.022	0.34	0.00756
Booth 4	Painter/field	May 18	1	56.1	0.190	3.38	0.215	3.83	0.003	0.06	0.038	0.68	0.116	2.07	0.038073
Booth 5	Painter/field	May 18	1	57.6	0.540	9.38	0.216	3.75	0.004	0.07	0.110	1.91	0.116	2.02	0.04101
Booth 3	Painter/field	May 18	1	43.4	0.094	2.16	0.125	2.88	0.007	0.17	0.023	0.53	0.084	1.93	0.030123
Booth 1	Painter/field	May 18	1	68.9	0.420	6.10	0.063	0.91	0.000	0.00	0.077	1.12	0.032	0.47	0.01203
Booth 2	Painter/field	May 18	1	62.1	0.236	3.80	0.112	1.80	0.003	0.05	0.047	0.76	0.060	0.97	0.019377
Booth 2	Painter/blank	May 18	1	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0
Booth 5	Tripod/dup	May 18	1	66.2	0.134	2.02	0.497	7.51	0.007	0.10	0.029	0.44	0.285	4.31	0.072645
Booth 5	Tripod/field	May 18	1	69.4	0.166	2.39	0.630	9.08	0.007	0.10	0.035	0.50	0.350	5.05	0.08731
Work area	Field	May 18	1	58.7	0.177	3.01	0.590	10.05	0.011	0.19	0.037	0.63	0.349	5.94	0.098008
Booth 2	Painter/field	May 18	2	56.7	0.160	2.82	0.173	3.05	0.003	0.06	0.030	0.53	0.095	1.67	0.030434
Booth 1	Painter/field	May 18	2	61.1	0.780	12.77	0.076	1.24	0.000	0.00	0.150	2.46	0.040	0.66	0.019031
Booth 3	Tripod/field	May 18	2	73.6	0.028	0.38	0.082	1.11	0.000	0.00	0.006	0.08	0.047	0.64	0.010763
Booth 4	Tripod/field	May 18	2	67.3	0.130	1.93	0.500	7.42	0.007	0.10	0.027	0.40	0.278	4.13	0.071445
Booth 4	Painter/blank	May 18	2	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0
Booth 3	Painter/field	May 18	2	65.0	0.042	0.64	0.071	1.09	0.003	0.04	0.009	0.14	0.042	0.65	0.010989
Booth 4	Painter/field	May 18	2	54.7	0.245	4.48	0.499	9.12	0.010	0.17	0.052	0.95	0.267	4.88	0.088783
Booth 5	Tripod/field	May 18	2	56.8	0.112	1.97	0.384	6.76	0.007	0.11	0.025	0.44	0.210	3.69	0.065107
Booth 1	Tripod/field	May 18	2	65.1	0.022	0.34	0.050	0.77	0.000	0.00	0.005	0.07	0.025	0.39	0.007329
Booth 2	Tripod/field	May 19	1	76.1	0.026	0.35	0.041	0.54	0.000	0.00	0.006	0.07	0.019	0.25	
				CAL OSHA PEL:		435 mg/m3 (s)		125 mg/m3 (s)		205 mg/m3 (s)		435 mg/m3 (s)		400 mg/m3 (s)	
						100 ppm		25 ppm		50 ppm		100 ppm		NE ppm	

Note:
- The estimated level of detection for this measurement is 2 ug per sample.
- Barometric pressure data obtained from Long Beach Airport station pressure records provided by NOAA.
- The relative percent difference of results (based on duplicate samples): 18.3%

Filename: Baseline
Worksheet: NIOSH 500
Directory:
Print Date: 05-Jun-2000

Method: NIOSH 500
Engineer Initials: JA
[STP defined at 68F and 29.9 in Hg]

Location	Type	Date/Time	Shift	Temp (F)	Pressure* (in Hg)	Sample I.D.	Pump No.	Pre-Cal (lpm)	Post-Cal (lpm)	Time (min)	Volume (l @ STP)	Total particulate (mg/filter)	Total particulate (mg/m3)	OSHA Factor
Booth 1	Tripod/field	May 19/0905	1	86	29.98	487	4	2.083	2.043	56	112	< 0.0150	< 0.134	< 0.027
Booth 1	Painter/field	May 19/0925	1	86	29.98	494	2	2.018	1.981	62	120	0.0180	0.150	0.030
Booth 1	Painter/blank	May 19/0925	1	N/A	N/A	500	N/A	N/A	N/A	N/A	N/A	< 0.0150	N/A	N/A
Booth 2	Painter/field	May 19/0942	1	86	29.98	858	1	2.006	1.959	52	100	0.0290	0.290	0.058
Booth 5	Tripod/field	May 19/1006	1	86	29.98	490	3	2.022	2.024	48	94	< 0.0150	< 0.159	< 0.032
Booth 4	Tripod/field	May 19/1015	1	86	29.98	860	4	2.043	2.036	54	107	< 0.0150	< 0.141	< 0.028
Booth 4	Painter/field	May 20/0803	1	86	29.97	489	2	2.114	2.094	63	128	0.1290	1.004	0.201
Booth 3	Painter/field	May 20/0800	1	86	29.97	495	1	2.096	2.078	62	125	0.3020	2.408	0.482
Booth 3	Painter/blank	May 20/0800	1	N/A	N/A	485	N/A	N/A	N/A	N/A	N/A	< 0.0150	N/A	N/A
Booth 2	Tripod/field	May 20/0742	1	86	29.97	492	4	2.055	2.050	60	119	< 0.0150	< 0.126	< 0.025
Booth 3	Tripod/field	May 20/0746	1	86	29.97	497	3	2.032	2.023	64	126	< 0.0150	< 0.119	< 0.024
N/A	Lab blank	May 20/0800	1	N/A	N/A	484	N/A	N/A	N/A	N/A	N/A	0.0320	N/A	N/A
Booth 3	Painter/blank	May 20/0800	1	N/A	N/A	859	N/A	N/A	N/A	N/A	N/A	< 0.0150	N/A	N/A
N/A	Lab blank	May 20/0800	1	N/A	N/A	496	N/A	N/A	N/A	N/A	N/A	< 0.0150	N/A	N/A
Booth 1	Tripod/field	May 20/0853	1	86	29.99	857	4	2.050	2.043	61	121	< 0.0150	< 0.124	< 0.025
Booth 2	Tripod/field	May 20/0900	1	86	29.99	493	3	2.023	2.022	60	118	< 0.0150	< 0.127	< 0.025
Booth 5	Painter/field	May 20/0909	1	87	29.99	486	1	2.078	2.061	61	122	0.0170	0.139	0.028
Booth 1	Painter/field	May 20/0930	1	87	29.99	488	2	2.094	2.088	61	123	< 0.0150	< 0.121	< 0.024
Booth 2	Painter/field	May 20/1021	1	87	30.00	498	1	2.061	2.061	62	124	0.0420	0.339	0.068
Booth 3	Painter/field	May 22/1330	2	85	29.91	499	1	2.107	2.065	63	127	0.1240	0.974	0.195
Booth 4	Painter/field	May 22/1335	2	85	29.91	474	2	2.118	2.095	60	122	0.0860	0.702	0.140
Booth 4	Tripod/field	May 22/1340	2	85	29.91	478	3	2.016	2.013	68	133	0.0220	0.166	0.033
Booth 5	Tripod/field	May 22/1344	2	85	29.91	476	4	2.035	2.038	67	132	0.0200	0.151	0.030
Booth 4	Painter/blank	May 22/1335	2	N/A	N/A	477	N/A	N/A	N/A	N/A	N/A	0.0200	N/A	N/A
Booth 5	Tripod/blank	May 22/1344	2	N/A	N/A	472	N/A	N/A	N/A	N/A	N/A	0.0160	N/A	N/A
Booth 1	Painter/field	May 22/1545	2	87	29.89	481	1	2.065	2.067	60	120	0.0380	0.318	0.064
Booth 5	Painter/field	May 22/1550	2	87	29.89	475	2	2.095	2.085	61	123	0.0290	0.236	0.047
Booth 3	Tripod/field	May 22/1557	2	87	29.89	482	3	2.013	2.019	60	117	0.0160	0.137	0.027
Booth 3	Tripod/dup	May 22/1557	2	87	29.89	471	4	2.038	2.047	60	118	0.0190	0.161	0.032
Booth 2	Painter/field	May 29/1407	2	86	30.04	470	1	2.092	2.062	60	121	0.0260	0.215	0.043
Booth 3	Painter/field	May 29/1423	2	86	30.04	480	2	2.122	2.097	61	125	0.1200	0.960	0.192
Booth 4	Painter/field	May 29/1440	2	86	30.02	473	3	2.031	2.018	60	118	0.2470	2.094	0.419
Booth 5	Painter/field	May 29/1455	2	86	30.02	483	4	2.024	2.018	61	120	0.0150	0.125	0.025
N/A	Field blank	May 29	2	N/A	N/A	479	N/A	N/A	N/A	N/A	N/A	0.0190	N/A	N/A

Note:
- Barometric pressure data obtained from Long Beach Airport station pressure records provided by NOAA.
- The relative percent difference of results (based on duplicate samples): 15.8%
- CAL OSHA PEL (respirable fraction of particulate not otherwise regulated): 5.0

Filename: Baseline
Worksheet: SUMMARY
Directory: c:\123r5w\work\icat

OSHA FACTOR SUMMARY RESULTS

BOOTH 1

	Organics		Particulate
Painter	0.008		0.030
	0.019	<	0.024
	0.012		0.064
(avg)	0.013		0.039
Intake	0.006	<	0.027
	0.007	<	0.025
(avg)	0.006	<	0.026

BOOTH 2

	Organics		Particulate
Painter	0.030		0.058
	0.019		0.068
	0.030		0.043
(avg)	0.027		0.056
Intake	0.013	<	0.025
	0.000	<	0.025
(avg)	0.006	<	0.025

BOOTH 3

	Organics		Particulate
Painter	0.012		0.482
	0.030		0.195
	0.011		0.192
(avg)	0.018		0.289
Intake (1)	0.003	<	0.024
	0.011		0.027
(avg)	0.007		0.026

BOOTH 4

	Organics		Particulate
Painter	0.060		0.201
	0.038		0.140
	0.089		0.419
(avg)	0.062		0.253
Intake	0.057	<	0.028
	0.071		0.033
(avg)	0.064		0.031

BOOTH 5

	Organics		Particulate
Painter	0.087		0.028
	0.089		0.047
	0.041		0.025
(avg)	0.072		0.033
Intake (2)	0.073	<	0.032
	0.065		0.030
(avg)	0.069		0.031

STEELCASE/ICAT INITIAL RECIRCULATION SAMPLING RESULTS

Filename: Rcrc1cor
Workshee NIOSH 1300
Directory: C:\123r5w\work\icat\sampling
Print Date: 05-Jun-2000

Method NIOSH 1300
Engineer Initials: JA
[STP defined at 68F and 29.9 in Hg]

			Xylene		n-Butyl Alcohol		Toluene		Butyl Acetate		TMB		MnAK		Ethyl benzene		Ethyl toluene		Cum. OSHA	Adjusted OSHA
Location	Type	Volume (l @ stp)	mg/tube	mg/m3	mg/tube	mg/m3	mg/tube	mg/m3	mg/tube	mg/m3	mg/tube	mg/m3	mg/tube	mg/m3	mg/tube	mg/m3	mg/tube	mg/m3	Factor	Factor
Booth 2	Painter/field	42.1	0.950	22.55	0.022	0.52	0.011	0.26	0.020	0.47	0.550	13.05	0.480	11.39	0.250	5.93	0.332	7.88	0.244	0.300
Booth 5	Painter/field	41.4	0.620	14.97	0.016	0.39	0.005	0.12	0.021	0.51	0.335	8.09	0.260	6.28	0.150	3.62	0.213	5.14	0.151	0.186
Booth 1	Painter/field	43.7	1.500	34.30	0.022	0.50	0.011	0.25	0.023	0.53	0.374	8.55	0.390	8.92	0.330	7.55	0.221	5.05	0.221	0.269
Booth 5	Tripod/field	41.8	0.393	9.41	0.009	0.22	0.0067	0.16	0.012	0.29	0.322	7.71	0.250	5.99	0.110	2.63	0.191	4.57	0.130	0.159
Booth 4	Tripod/field	42.4	0.272	6.41	0.009	0.21	0.003	0.06	0.015	0.35	0.213	5.02	0.180	4.24	0.072	1.70	0.121	2.85	0.087	0.107
Booth 4	Painter/field	39.6	0.490	12.39	0.013	0.33	0.004	0.10	0.021	0.53	0.393	9.94	0.240	6.07	0.120	3.03	0.239	6.04	0.160	0.196
Booth 3	Tripod/field	39.7	0.520	13.11	0.024	0.61	0.007	0.17	0.024	0.61	0.557	14.04	0.380	9.58	0.130	3.28	0.337	8.50	0.219	0.270
Area	Tripod/blank	0.0	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	N/A	N/A
Booth 1	Painter/field	40.7	0.630	15.50	0.023	0.57	0.014	0.34	0.034	0.84	0.602	14.81	0.380	9.35	0.150	3.69	0.348	8.56	0.231	0.285
Booth 2	Painter/field	39.9	1.260	31.60	0.037	0.93	0.017	0.43	0.067	1.68	1.030	25.83	0.550	13.79	0.310	7.78	0.670	16.80	0.410	0.502
Booth 3	Painter/field	39.3	1.020	25.98	0.031	0.79	0.016	0.41	0.061	1.55	0.840	21.40	0.490	12.48	0.250	6.37	0.530	13.50	0.343	0.421
Booth 2	Tripod/field	41.2	0.810	19.66	0.042	1.02	0.015	0.36	0.056	1.36	0.870	21.12	0.580	14.08	0.200	4.85	0.530	12.86	0.329	0.407
Booth 1	Painter/field	44.4	0.770	17.35	0.013	0.29	0.010	0.22	0.064	1.44	0.602	13.57	0.250	5.63	0.180	4.06	0.402	9.06	0.210	0.255
Booth 2	Painter/field	41.3	0.710	17.20	0.018	0.44	0.012	0.29	0.059	1.43	0.669	16.21	0.440	10.66	0.180	4.36	0.420	10.18	0.257	0.315
Booth 3	Painter/field	45.2	0.680	15.03	0.014	0.31	0.010	0.22	0.034	0.75	0.589	13.02	0.390	8.62	0.160	3.54	0.359	7.94	0.208	0.255
Booth 1	Tripod/field	45.5	0.580	12.74	0.020	0.44	0.006	0.13	0.026	0.57	0.474	10.41	0.360	7.91	0.150	3.29	0.474	10.41	0.185	0.227
Booth 4	Painter/field	41.6	0.291	6.99	0.008	0.19	0.002	0.06	0.026	0.62	0.699	16.80	0.160	3.84	0.065	1.56	0.490	11.77	0.203	0.246
Booth 5	Painter/field	38.4	0.341	8.87	0.010	0.25	0.003	0.07	0.026	0.68	0.732	19.04	0.200	5.20	0.078	2.03	0.510	13.26	0.236	0.287
Booth 4	Tripod/field	43.2	0.156	3.61	0.005	0.11	0.004	0.09	0.019	0.44	0.376	8.71	0.140	3.24	0.036	0.83	0.232	5.37	0.109	0.133
Booth 4	Tripod/dup	45.0	0.155	3.45	0.005	0.11	0.004	0.08	0.018	0.40	0.377	8.38	0.140	3.11	0.035	0.78	0.231	5.13	0.105	0.128
Booth 5	Tripod/blank	0.0	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	N/A	N/A
Booth 3	Painter/field	43.2	1.040	24.09	0.028	0.65	0.015	0.35	0.037	0.86	0.700	16.21	0.490	11.35	0.260	6.02	0.470	10.89	0.283	0.346
Booth 4	Painter/field	42.7	0.730	17.11	0.019	0.45	0.010	0.22	0.039	0.91	0.575	13.47	0.300	7.03	0.170	3.98	0.369	8.65	0.214	0.261
Booth 5	Painter/field	45.5	0.720	15.84	0.025	0.55	0.010	0.22	0.035	0.77	0.770	16.94	0.480	10.56	0.180	3.96	0.490	10.78	0.260	0.319
Booth 5	Tripod/field	46.2	0.600	12.98	0.026	0.56	0.010	0.21	0.038	0.82	0.770	16.65	0.380	8.22	0.140	3.03	0.520	11.25	0.240	0.295
Booth 1	Tripod/field	43.7	0.600	13.72	0.032	0.73	0.005	0.11	0.024	0.55	0.532	12.16	0.430	9.83	0.150	3.43	0.332	7.59	0.205	0.254
Booth 2	Tripod/field	45.4	0.870	19.18	0.027	0.60	0.007	0.15	0.039	0.86	0.790	17.41	0.630	13.89	0.220	4.85	0.490	10.80	0.288	0.354
Booth 3	Tripod/field	45.8	0.374	8.17	0.021	0.46	0.004	0.09	0.024	0.52	1.050	22.93	0.290	6.33	0.086	1.88	0.750	16.38	0.279	0.341
Booth 3	Tripod/dup	43.0	0.375	8.72	0.021	0.49	0.004	0.09	0.023	0.53	1.070	24.88	0.300	6.98	0.084	1.95	0.750	17.44	0.302	0.369
Booth 3	Tripod/blank	0.0	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	0.000	N/A	N/A	N/A
	ACGIH PEL:		435 mg/m3(s) 100 ppm		150 mg/m3 (s) 50 ppm		185 mg/m3 50 ppm		710 mg/m3 150 ppm		125 mg/m3 25 ppm		230 mg/m3 50 ppm		441 mg/m3 100 ppm		400 mg/m3 NE ppm			
	Spike/Recovery Adjustment Factor:		90.0%		43.0%		82.0%		70.0%		81.9%		78.0%		75.0%		87.7%			

Note: - Adjusted OSHA Factor determined from calculated OSHA Factor reconciled with spike/recovery results for each constituent.
- The level of detection for this measurement is 1-2 ug per sample, depending on the compound and sample.
- The relative percent difference of OSHA Factor results (based on duplicate samples): 4.0% (Booth 4 tripod sample)
7.9% (Booth 3 tripod sample)

STEELCASE/ICAT INITIAL RECIRCULATION SAMPLING RESULTS

Filename: Rcrc1cor
Worksheet: NIOSH 500
Directory: C:\123r5w\work\icat
Print Date: June 1, 2000

Method: NIOSH 500
Engineer Initials: JA
[STP defined at 68F and 29.9 in Hg]

Location	Type	Date/Time	Shift	Temp (F)	Pressure (in Hg)	Sample I.D.	Pump No.	Pre-Cal (lpm)	Post-Cal (lpm)	Time (min)	Volume (l @ STP)	Total particulate (mg/filter)	Total particulate (mg/m3)	OSHA Factor
Booth 2	Painter/field	Aug 9/1030	1	82	29.88	982	1	1.960	1.894	60	113	< 0.0150	< 0.133	< 0.027
Booth 4	Painter/field	Aug 9/1116	1	82	29.86	983	2	1.910	1.854	61	112	0.2150	1.925	0.385
Booth 1	Tripod/field	Aug 9/1045	1	82	29.88	979	3	1.907	1.684	60	105	0.0240	0.229	0.046
Booth 2	Tripod/field	Aug 9/1009	1	82	29.89	980	4	1.926	1.872	60	111	0.0310	0.279	0.056
Booth 2	Painter/blank	Aug 9/1030	1	82	29.89	984	N/A	N/A	N/A	N/A	N/A	0.0220	N/A	N/A
Booth 3	Tripod/field	Aug 9/1133	1	82	29.86	985	3	1.901	1.872	60	110	0.0320	0.291	0.058
Booth 4	Tripod/field	Aug 9/1130	1	82	29.86	986	4	1.872	1.870	60	109	< 0.0150	< 0.137	< 0.027
Booth 5	Painter/field	Aug 9/1145	1	82	29.86	987	1	1.894	1.997	48	91	0.0360	0.396	0.079
Booth 1	Painter/field	Aug 10/0725	1	82	29.9	988	1	2.08	2.064	60	121	0.1230	1.016	0.203
Booth 3	Painter/field	Aug 10/0746	1	82	29.9	989	2	2.067	2.030	60	120	< 0.0150	< 0.125	< 0.025
Booth 1	Tripod/field	Aug 10/0716	1	82	29.9	990	3	2.041	2.108	60	121	< 0.0150	< 0.124	< 0.025
Booth 5	Tripod/field	Aug 10/0720	1	82	29.9	991	4	2.042	2.032	60	119	0.0270	0.227	0.045
Booth 5	Tripod/field	Aug 10/0840	1	82	29.91	992	3	2.108	2.112	61	125	< 0.0150	< 0.120	< 0.024
Booth 5	Tripod/dup	Aug 10/0840	1	82	29.91	993	4	2.032	2.037	61	121	0.0270	0.223	0.045
Booth 1	Painter/field	Aug 10/0941	1	82	29.92	994	1	2.064	2.060	60	121	< 0.0150	< 0.124	< 0.025
Booth 2	Painter/field	Aug 10/1008	1	82	29.92	995	2	2.030	2.017	61	120	0.0170	0.141	0.028
Booth 4	Tripod/field	Aug 10/1016	1	82	29.91	996	3	2.112	2.109	61	125	< 0.0150	< 0.120	< 0.024
Booth 4	Tripod/dup	Aug 10/1016	1	82	29.91	997	4	2.037	2.053	61	122	< 0.0150	< 0.123	< 0.025
Booth 5	Painter/field	Aug 11/1448	2	84	29.94	998	1	2.073	2.009	60	119	0.0180	0.151	0.030
Booth 1	Painter/field	Aug 11/1505	2	84	29.94	999	2	2.060	2.055	24	48	0.0230	0.479	0.096
Booth 2	Painter/field	Aug 11/1515	2	84	29.94	1000	3	2.111	2.080	60	122	0.1410	1.154	0.231
Booth 2	Tripod/field	Aug 11/1453	2	84	29.94	1001	4	2.060	2.067	61	122	0.0270	0.221	0.044
Booth 4	Painter/field	Aug 11/1600	2	84	29.94	1002	1	2.009	1.994	60	117	0.0630	0.540	0.108
Booth 3	Tripod/field	Aug 11/1610	2	84	29.94	1003	4	2.067	2.064	61	122	< 0.0150	< 0.122	< 0.024
Booth 3	Painter/field	Aug 11/1625	2	84	29.94	1004	3	2.080	2.068	60	121	0.4580	3.787	0.757
Booth 5	Painter/blank	Aug 11/1630	2	84	29.94	1005	N/A	N/A	N/A	N/A	N/A	< 0.0150	N/A	N/A
Booth 5	Painter/field	Aug 11/1655	2	84	29.94	1009	2	2.055	2.043	60	119	0.0390	0.326	0.065
Booth 1	Painter/field	Aug 11/1700	2	84	29.94	1006	1	2.003	1.998	60	117	0.0480	0.412	0.082
Booth 3	Painter/field	Aug 11/1743	2	82	29.94	1007	3	2.068	2.073	60	121	0.0500	0.413	0.083
Booth 4	Painter/field	Aug 11/1815	2	82	29.94	1008	1	2.043	2.027	48	95	< 0.0150	< 0.157	< 0.031

Note:
- The estimated level of detection for this measurement is 15 ug.
- Barometric pressure data obtained from Long Beach Airport station pressure records provided by NOAA.
- The relative percent difference of concentration results (based on duplicate samples): 60.1% (Booth 5 tripod sample)

Filename: Rcrc1cor
Worksheet: Summary
Directory: C:\123r5w\work\icat
Print Date: 05-Jun-2000

OSHA FACTOR SUMMARY RESULTS

BOOTH 1

	Organics	Particulate
Painter	0.269	0.203
	0.285	< 0.025
	0.255	0.096
(avg)	0.269	0.108
Intake	0.227	0.046
	0.254	< 0.025
(avg)	0.240	0.035

BOOTH 2

	Organics	Particulate
Painter	0.300	< 0.027
	0.502	0.028
	0.315	0.231
(avg)	0.372	0.095
Intake	0.407	0.056
	0.354	0.044
(avg)	0.381	0.050

BOOTH 3

	Organics	Particulate
Painter	0.421	< 0.025
	0.255	0.757
	0.346	0.083
(avg)	0.341	0.288
Intake	0.270	0.058
	0.369	< 0.024
(avg)	0.319	0.041

BOOTH 4

	Organics	Particulate
Painter	0.196	0.385
	0.246	0.108
	0.261	< 0.031
(avg)	0.234	0.175
Intake	0.107	< 0.027
	0.133	< 0.024
(avg)	0.120	< 0.026

BOOTH 5

	Organics	Particulate
Painter	0.186	0.079
	0.287	0.030
	0.319	0.065
(avg)	0.264	0.058
Intake	0.159	0.045
	0.295	0.045
(avg)	0.227	0.045

Filename Recirc2
Workshe NIOSH 1300
Directory C:\123r5w\work\icat\sampling
Print Dat 05-Jun-2000

Method NIOSH 1300
Engineer Initials: JA
[STP defined at 68F and 29.9 in Hg]

			Xylene		n-Butyl Alcohol		Toluene		Butyl Acetate		TMB		MnAK		Ethyl benzene		Ethyl toluene		OSHA	Corrected OSHA
Location	Type	Date	mg/tube	mg/m3	mg/tube	mg/m3	mg/tube	mg/m3	mg/tube	mg/m3	mg/tube	mg/m3	mg/tube	mg/m3	mg/tube	mg/m3	mg/tub	mg/m3	Factor	Factor
Booth 4	Painter/field	Nov 16/1550	0.471	7.65	0.016	0.26	0.012	0.19	0.030	0.49	0.461	7.49	0.380	6.17	0.120	1.95	0.253	4.11	0.122	0.151
Booth 3	Painter/field	Nov 16/1545	0.630	11.21	0.020	0.36	0.017	0.30	0.039	0.69	0.523	9.30	0.480	8.54	0.170	3.02	0.289	5.14	0.162	0.200
Booth 1	Painter/field	Nov 16/1700	0.332	6.32	0.013	0.25	0.011	0.21	0.021	0.40	0.217	4.13	0.230	4.38	0.090	1.71	0.116	2.21	0.079	0.098
Booth 4	Painter/field	Nov 16/1710	0.258	5.28	0.013	0.27	0.010	0.20	0.013	0.27	0.201	4.11	0.200	4.09	0.072	1.47	0.109	2.23	0.075	0.093
Booth 3	Painter/field	Nov 16/1820	0.650	11.10	0.023	0.39	0.014	0.24	0.057	0.97	0.358	6.11	0.410	7.00	0.170	2.90	0.185	3.16	0.125	0.154
Booth 1	Painter/field	Nov 17/0920	0.540	9.52	0.020	0.35	0.0083	0.15	0.066	1.16	0.405	7.14	0.390	6.87	0.140	2.47	0.200	3.52	0.128	0.159
Booth 5	Painter/field	Nov 17/0945	0.560	10.52	0.029	0.54	0.007	0.13	0.094	1.77	0.653	12.26	0.700	13.14	0.140	2.63	0.281	5.28	0.205	0.256
Booth 2	Painter/field	Nov 17/1050	0.800	15.20	0.036	0.68	0.017	0.32	0.110	2.09	0.810	15.39	0.860	16.34	0.210	3.99	0.376	7.15	0.265	0.330
Booth 5	Painter/field	Nov 17/1121	0.900	17.81	0.042	0.83	0.024	0.48	0.110	2.18	0.650	12.87	0.790 *	15.64	0.240	4.75	0.330	6.53	0.250	0.312
Booth 2	Painter/field	Nov 17/1210	0.920	17.61	0.041	0.78	0.026	0.50	0.061	1.17	0.720	13.78	0.820	15.69	0.250	4.78	0.359	6.87	0.257	0.319
Booth 3	Painter/field	Nov 17/1520	0.780	15.28	0.034	0.67	0.027	0.53	0.040	0.78	0.397	7.78	0.530	10.38	0.230	4.51	0.227	4.45	0.172	0.215
Booth 1	Painter/field	Nov 17/1642	0.392	7.80	0.021	0.42	0.004	0.07	0.041	0.82	0.271	5.40	0.360	7.17	0.100	1.99	0.125	2.49	0.107	0.134
Booth 2	Painter/field	Nov 17/1820	1.330	26.52	0.051	1.02	0.035	0.70	0.100	1.99	0.425	8.48	0.810	16.15	0.390	7.78	0.228	4.55	0.241	0.301
Booth 4	Painter/field	Nov 18/1008	0.384	6.82	0.019	0.34	0.009	0.15	0.017	0.30	0.377	6.69	0.400	7.10	0.100	1.78	0.182	3.23	0.116	0.144
Booth 5	Painter/field	Nov 18/1011	1.000	19.18	0.046	0.88	0.022	0.42	0.055	1.05	0.780	14.96	0.910	17.45	0.270	5.18	0.392	7.52	0.280	0.348
Booth 2	Tripod/field	Nov 18/1202	0.760	14.26	0.028	0.53	0.016	0.30	0.043	0.81	0.770	14.45	0.780	14.64	0.210	3.94	0.391	7.34	0.246	0.304
Booth 2	Tripod/dup	Nov 18/1202	0.710	14.08	0.026	0.52	0.015	0.30	0.040	0.79	0.730	14.47	0.710	14.08	0.190	3.77	0.370	7.34	0.242	0.300
Booth 1	Tripod/field	Nov 18/1622	0.462	8.42	0.020	0.36	0.020	0.36	0.017	0.31	0.236	4.30	0.350	6.38	0.130	2.37	0.119	2.17	0.097	0.121
Booth 2	Tripod/field	Nov 18/1625	0.850	17.26	0.036	0.73	0.035	0.71	0.030	0.61	0.437	8.88	0.660	13.40	0.240	4.87	0.215	4.37	0.201	0.250
Booth 3	Tripod/field	Nov 18/1800	0.538	9.91	0.025	0.46	0.014	0.26	0.030	0.55	0.312	5.75	0.430	7.92	0.150	2.76	0.158	2.91	0.122	0.152
Booth 4	Tripod/field	Nov 18/1805	0.196	3.73	0.010	0.19	0.005	0.10	0.012	0.23	0.143	2.72	0.170	3.24	0.052	0.99	0.068	1.30	0.052	0.065
Booth 5	Tripod/field	Nov 19/0900	1.330	24.04	0.049	0.89	0.032	0.58	0.070	1.27	0.512	9.25	0.860	15.54	0.380	6.87	0.271	4.90	0.235	0.293
Booth 3	Tripod/field	Nov 19/0942	0.670	12.05	0.026	0.47	0.022	0.40	0.032	0.58	0.309	5.56	0.470	8.45	0.190	3.42	0.165	2.97	0.130	0.162
Booth 4	Tripod/field	Nov 19/1030	0.343	6.34	0.012	0.22	0.009	0.16	0.017	0.31	0.247	4.56	0.270	4.99	0.095	1.76	0.128	2.37	0.085	0.106
Booth 5	Tripod/field	Nov 19/1055	1.440	26.50	0.064	1.18	0.047	0.87	0.055	1.01	0.493	9.07	1.000	18.41	0.410	7.55	0.233	4.29	0.255	0.320
Booth 1	Tripod/field	Nov 19/1147	0.373	6.71	0.018	0.32	0.009	0.15	0.029	0.52	0.425	7.65	0.350	6.30	0.096	1.73	0.232	4.17	0.122	0.151
Booth 1	Painter/blank	Nov 16/1500	0.002	N/A	0.002	N/A	0.002	N/A	0.002	N/A	0.002	N/A	0.002	N/A	0.002	N/A	0.002	N/A	0.000	0.000
Booth 2	Painter/blank	Nov 17/1815	0.002	N/A	0.002	N/A	0.002	N/A	0.002	N/A	0.002	N/A	0.002	N/A	0.002	N/A	0.002	N/A	0.000	0.000
Booth 2	Tripod/blank	Nov 18/1200	0.002	N/A	0.002	N/A	0.002	N/A	0.002	N/A	0.002	N/A	0.002	N/A	0.002	N/A	0.002	N/A	0.000	0.000
			435 mg/m3(s)		150 mg/m3 (s)		185 mg/m3		710 mg/m3		125 mg/m3		230 mg/m3		441 mg/m3		400			
			100 ppm		50 ppm		50 ppm		150 ppm		25 ppm		50 ppm		100 ppm		NE			
Spike/Recovery Correction Factors:			90.0%		43.0%		82.0%		70.0%		81.9%		78.0%		75.0%		87.7%			

Note: - The level of detection for this measurement is 1-2 ug per sample, depending on the compound and sample.
- The relative percent difference of OSHA Factor results (based on 1.6% (Booth 2 tripod sample)

* Results exceeded instrument calibration range.

STEELCASE/ICAT RECIRCULATION SERIES II SAMPLING RESULTS

Filename: Rcrc2cor
Worksheet: NIOSH 500
Directory: C:\123r5w\work\icat
Print Date: 05-Jun-2000

Method: NIOSH 500
Engineer Initials: JA
[STP defined at 68F and 29.9 in Hg]

Location	Type	Date/Time	Shift	Temp (F)	Pressure (in Hg)	Sample I.D.	Pump No.	Pre-Cal (lpm)	Post-Cal (lpm)	Time (min)	Volume (l @ STP)	Total particulate (mg/filter)	Total particulate (mg/m3)	OSHA Factor
Booth 5	Painter/field	Nov 16/1635	2	80	29.94	3054	4	2.099	2.077	62	127	< 0.0150	< 0.118	< 0.024
Booth 1	Painter/field	Nov 16/1807	2	80	29.96	3052	4	2.077	2.062	57	116	0.1740	1.506	0.301
Booth 2	Painter/field	Nov 17/0950	1	80	29.99	3067	4	2.109	2.088	60	123	< 0.0150	< 0.121	< 0.024
Booth 3	Painter/field	Nov 17/1020	1	81	29.97	3041	3	2.044	2.013	61	121	0.0220	0.182	0.036
Booth 4	Painter/field	Nov 17/1100	1	81	29.97	3069	4	2.088	2.063	61	124	0.0490	0.396	0.079
Booth 1	Painter/field	Nov 17/1155	1	81	29.95	3072	3	2.013	2.009	60	118	0.0310	0.263	0.053
Booth 3	Painter/field	Nov 17/1222	1	81	29.93	3060	4	2.063	2.080	60	121	0.1650	1.359	0.272
Booth 1	Painter/field	Nov 17/1450	2	81	29.91	3075	3	2.041	2.020	61	121	0.0350	0.289	0.058
Booth 2	Painter/field	Nov 17/1502	2	81	29.91	3059	4	2.132	2.100	60	124	0.0530	0.428	0.086
Booth 4	Painter/field	Nov 17/1555	2	81	29.92	3047	3	2.020	2.011	60	118	0.0300	0.254	0.051
Booth 5	Painter/field	Nov 17/1608	2	80	29.92	3053	4	2.100	2.083	60	123	< 0.0150	< 0.122	< 0.024
Booth 2	Painter/field	Nov 17/1717	2	80	29.92	3073	3	2.011	2.010	60	118	0.0750	0.635	0.127
Booth 3	Painter/field	Nov 17/1743	2	80	29.92	3064	4	2.083	2.086	60	122	0.3270	2.672	0.534
Booth 4	Painter/field	Nov 17/1830	2	80	29.94	3074	3	2.010	2.018	61	120	0.0380	0.316	0.063
Booth 5	Painter/field	Nov 17/1855	2	80	29.94	3061	4	2.086	2.096	60	123	< 0.0150	< 0.122	< 0.024
Booth 1	Tripod/field	Nov 18/1155	1	80	30.05	3043	3	2.034	2.018	63	125	< 0.0150	< 0.120	< 0.024
Booth 1	Tripod/dup	Nov 18/1156	1	80	30.05	3044	4	2.123	2.100	64	133	< 0.0150	< 0.113	< 0.023
Booth 1	Tripod/field	Nov 18/1622	2	80	30.03	3045	2	2.029	2.028	60	120	< 0.0150	< 0.126	< 0.025
Booth 2	Tripod/field	Nov 18/1625	2	80	30.03	3046	4	2.137	2.100	60	125	< 0.0150	< 0.120	< 0.024
Booth 3	Tripod/field	Nov 18/1800	2	80	30.07	3048	2	2.148	2.135	62	131	< 0.0150	< 0.115	< 0.023
Booth 4	Tripod/field	Nov 18/1805	2	80	30.07	3050	4	2.100	2.106	60	124	0.0170	0.137	0.027
Booth 5	Tripod/field	Nov 19/0900	1	80	30.23	3055	2	2.129	2.114	60	126	< 0.0150	< 0.119	< 0.024
Booth 3	Tripod/field	Nov 19/0942	1	80	30.23	3056	4	2.134	2.117	60	126	< 0.0150	< 0.119	< 0.024
Booth 4	Tripod/field	Nov 19/1030	1	80	30.22	3058	2	2.114	2.099	60	125	< 0.0150	< 0.120	< 0.024
Booth 4	Tripod/blank	Nov 19/1030	1	80	30.22	3065	N/A	N/A	N/A	N/A	N/A	< 0.0150	N/A	N/A
Booth 5	Tripod/field	Nov 19/1055	1	80	30.22	3062	4	2.117	2.098	60	125	< 0.0150	< 0.120	< 0.024
Booth 5	Tripod/blank	Nov 19/1055	1	80	30.22	3066	N/A	N/A	N/A	N/A	N/A	< 0.0150	N/A	N/A
Booth 2	Tripod/field	Nov 19/1200	1	80	30.19	3063	4	2.098	2.094	60	124	< 0.0150	< 0.121	< 0.024
Booth 5	Painter/blank	Nov 17/1745	2	81	29.92	3042	N/A	N/A	N/A	N/A	N/A	< 0.0150	N/A	N/A
Booth 4	Tripod/blank	Nov 18/1810	2	80	30.07	3051	N/A	N/A	N/A	N/A	N/A	< 0.0150	N/A	N/A
Booth 5	Tripod/blank	Nov 19/0900	1	80	30.23	3057	N/A	N/A	N/A	N/A	N/A	< 0.0150	N/A	N/A
N/A	Method blank	N/A	N/A	N/A	N/A	3068	N/A	N/A	N/A	N/A	N/A	< 0.0150	N/A	N/A
N/A	Method blank	N/A	N/A	N/A	N/A	3070	N/A	N/A	N/A	N/A	N/A	< 0.0150	N/A	N/A
N/A	Method blank	N/A	N/A	N/A	N/A	3071	N/A	N/A	N/A	N/A	N/A	< 0.0150	N/A	N/A
													5.0	

Note:
- The estimated level of detection for this measurement is 15 ug.
- Barometric pressure data obtained from Long Beach Airport station pressure records provided by NOAA.
- The relative percent difference of results (based on duplicate samples) could not be assessed; both samples were below quantitation limits.
- CAL OSHA PEL (respirable fraction of particulate not otherwise regulated): 5.0

Filename: Rcrc2cor
Worksheet: Summary
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Print Date: 05-Jun-2000

OSHA FACTOR SUMMARY RESULTS

BOOTH 1

	Organics	Particulate
Painter	0.098	0.301
	0.159	0.053
	0.134	0.058
(avg)	0.130	0.137
Intake	0.121	< 0.024
	0.151	< 0.025
(avg)	0.136	< 0.025

BOOTH 2

	Organics	Particulate
Painter	0.330	< 0.024
	0.319	0.086
	0.301	0.127
(avg)	0.317	0.079
Intake	0.304	< 0.024
	0.250	< 0.024
(avg)	0.277	< 0.024

BOOTH 3

	Organics	Particulate
Painter	0.200	0.036
	0.154	0.272
	0.215	0.534
(avg)	0.190	0.281
Intake	0.152	< 0.023
	0.162	< 0.024
(avg)	0.157	< 0.023

BOOTH 4

	Organics	Particulate
Painter	0.151	0.079
	0.093	0.051
	0.144	0.063
(avg)	0.129	0.064
Intake	0.065	< 0.027
	0.106	< 0.024
(avg)	0.085	< 0.026

BOOTH 5

	Organics	Particulate
Painter	0.256	< 0.024
	0.312	< 0.024
	0.348	< 0.024
(avg)	0.305	< 0.024
Intake	0.293	< 0.024
	0.320	< 0.024
(avg)	0.307	< 0.024

APPENDIX B

RECOVERED SOLVENT ANALYSIS DATA & SUPPLEMENTAL BAC MEDIA ANALYSIS DATA

DETAILS ON BET SURFACE AREA SAMPLING METHOD

Recovered Solvent and BAC Media Analysis Results for Samples Collected at Inception of the Fluidized Bed System Evaluation Period.

Test Method	Compounds	Result (ppm)	Dilution Factor	Reportable Limit [RL] (ppm)
VOC TCLP (EPA 1311/8260)	Benzene	< R.L.	None	0.050
	Carbon Tetrachloride	< R.L.		0.050
	Chlorobenzene	< R.L.		10
	Chloroform	< R.L.		0.60
	1,4-Dichlorobenzene	< R.L.		0.050
	1,2-Dichloroethane	< R.L.		0.050
	1,1-Dichloroethane	< R.L.		0.070
	Hexachlorobutadiene	< R.L.		0.010
	Methyl ethyl ketone	< R.L.		0.050
	Tetrachloroethene	< R.L.		0.070
	Trichloroethene	< R.L.		0.050
	Vinyl Chloride	< R.L.		0.020
Metals TCLP (EPA 6010B/7470)	Arsenic	< R.L.	None	0.50
	Barium	< R.L.		10
	Cadmium	< R.L.		0.10
	Chromium	< R.L.		0.50
	Lead	< R.L.		0.50
	Mercury	< R.L.		0.020
	Selenium	< R.L.		0.10
	Silver	< R.L.		0.50
Extractable Fuel Hydrocarbons (EPA 8015 [mod])	Extractable Hydrocarbons	980,000	1,000	5,000
Volatile Fuel Hydrocarbons/ BTEX Distinction (EPA 8015B/8021B [mod])	Volatile Hydrocarbons	200,000	100,000	100,000
	Benzene	< R.L.		500
	Toluene	< R.L.		500
	Ethyl Benzene	12,000		500
	Total Xylenes	47,000		1,500
MTBE (EPA 8021B Mod.)	Methyl tert-Butyl Ether	< R.L.	100,000	3,500

Recovered Solvent and BAC Media Analysis Results for Samples
Collected at the End of the BAC Media Re-activation Period

Test Method	Compounds	Result (ppm)	Dilution Factor	Reportable Limit [RL] (ppm)
VOC TCLP (EPA 1311/8260)	Benzene	< R.L.	None	0.050
	Carbon Tetrachloride	< R.L.		0.050
	Chlorobenzene	< R.L.		10
	Chloroform	< R.L.		0.60
	1,4-Dichlorobenzene	< R.L.		0.050
	1,2-Dichloroethane	< R.L.		0.050
	1,1-Dichloroethane	< R.L.		0.070
	Hexachlorobutadiene	< R.L.		0.010
	Methyl ethyl ketone	< R.L.		0.050
	Tetrachloroethene	< R.L.		0.070
	Trichloroethene	< R.L.		0.050
	Vinyl Chloride	< R.L.		0.020
Metals TCLP (EPA 6010B/7470)	Arsenic	< R.L.	None	0.50
	Barium	< R.L.		10
	Cadmium	< R.L.		0.10
	Chromium	< R.L.		0.50
	Lead	< R.L.		0.50
	Mercury	< R.L.		0.020
	Selenium	< R.L.		0.10
	Silver	< R.L.		0.50
Extractable Fuel Hydrocarbons (EPA 8015 [mod])	Extractable Hydrocarbons	1,200,000 (a)	1,000	5,000
Volatile Fuel Hydrocarbons/ BTEX Distinction (EPA 8015B/8021B [mod])	Volatile Hydrocarbons	1,400,000 (a)	200,000	100,000
	Benzene	< R.L.		500
	Toluene	< R.L.		500
	Ethyl Benzene	18,000		500
	Total Xylenes	130,000		3,000
MTBE (EPA 8021B Mod.)	Methyl tert-Butyl Ether	< R.L.	200,000	7,000

(a) The laboratory confirmed that the results are reported at levels above 100% and speculated that a number of factors could have attributed to this circumstance (response factor variations, error introduced by the high dilution of the samples, etc.)

DETAILS ON BET SURFACE AREA SAMPLING METHOD

The ability to experimentally measure surface area was developed during the early to mid-nineteenth century. In 1940, Brunauer, Deming, Deming and Teller found that all adsorption isotherms fit into one of five types (Types I, II, III, IV and V)[1]. In 1941, Langmuir was able to describe the Type I isotherm based upon the assumption that adsorption was limited to a monolayer, which is more indicative of chemisorption and the occupation of all of the surface sites with the adsorbate. Langmuir's theory, however, fell short, when it attempted to describe physical adsorption and isotherms of Types II through Type V.

In 1938, Brunauer, Emmett, and Teller (BET) extended Lagmuir's kinetic theory to multilayer adsorption. During the process of physical adsorption, at very low pressures, more energetic sites are covered quicker than less energetic sites. The complex phenomena of physical adsorption creates multilayers, whereby, prior to complete surface coverage, second and higher adsorbed layers will be formed. In essence, there is no pressure that exists at which the surface is covered with exactly a completely physically adsorbed monolayer. The BET theory allows for an experimental determination of the number of molecules required to form a monolayer even though exactly one monomolecular layer is never formed. The BET theory assumes dynamic equilibrium between the uppermost molecules in adsorbed stacks and the vapor. Based on this assumption and a series of derivations beginning with the Langmuir theory, the BET Theory surface area is determined from the following equation[1]

$$\frac{1}{W\left[\frac{P_o}{P}-1\right]}=\frac{1}{W_mC}+\left[\frac{C-1}{W_mC}\right]\left[\frac{P}{P_o}\right]$$

Where: W = Weight adsorbed

W_m = Weight adsorbed in a monolayer

P/Po = Relative pressure

C = Constant (a function of the monomolecular layer heat of adsorption)

Additional substitutions yield the following BET theory equation that is employed in ASTM Method D-4820 to determine the surface area of carbon by multipoint nitrogen adsorption:

$$\frac{1}{V_{ADS}\left[\frac{P}{P_o}-1\right]}=\frac{1}{V_mc}+\left[\frac{C-1}{V_mc}\right]\left[\frac{P}{P_o}\right]$$

Where: P = Manometer pressure in kPa

V_{ADS} = Total volume of nitrogen adsorbed per gram of carbon (cm^3/g)

Po = Saturation vapor pressure of nitrogen

V_mc = Volume of nitrogen/gram of carbon covering one monomolecular layer (cm^3/g)

C = Constant (a function of the monomolecular layer heat of absorption)

B = Y-axis intercept, ±0.00001

M = Slope of straight line determined to ±0.00001

V_m = $1/(B + M)$

P/Po is plotted versus $P/ [V_{ADS} (P_o - P)]$ for data sets having P/P_o in the range of 0.06 to 0.35 (which defines the linear region of the BET equation). The nitrogen surface area is calculated to the nearest 0.1 m^2/g as follows:

$$\text{Surface Area} = V_m \times 4.35 \ m^2/g$$

Where 4.35 is the area (in m^2) occupied by 1 cm^3 of nitrogen.

Assuming the solvent heel occupies a portion of the active surface sites on the carbon, the surface area of the unoccupied active sites can be calculated using this procedure. As expected, the BET surface area decreases as the solvent heel fraction increases.

[1] S. Lowell and J. Shields, Powder and Surface Area and Porosity, (3rd Edition) Chapman & Hall, New York, 1991.