DEVELOPMENT OF REFINED EMISSION INVENTORY AND RISK REDUCTION GUIDELINES FOR MOTION PICTURE FILM PROCESSING

Contract No. 00040

Submitted to

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Submitted On

June 23, 2000

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DISCLAIMER

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ACKNOWLEDGMENTS

The author would like to thank Tracy Goss and Gary Quinn of the South Coast Air Quality Management District for their assistance and guidance in this project. Pacific Environmental Services, Inc. (PES) staff conducting field interviews included Dennis Becvar, Hugh Brown, Robert Bryan, Glenn Reed and Michael Rogozen. The author would also like to express his appreciation for the work of research assistants Gary Feder and June Minamizono.

Finally, PES is grateful for the technical insights provided by numerous individuals in the film laboratory industry.

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EXECUTIVE SUMMARY

The motion picture and television industries are major contributors to the economy of Southern California. These industries rely heavily upon motion picture film processing laboratories to develop, clean, and print copies of the films that are shown in movie theaters and broadcast on television. Other post production facilities add titles to films or transfer motion picture film to videotape. Many of the printing and cleaning processes use tetrachloroethylene (perchloroethylene, or "perc"), which is released to the atmosphere. As a carcinogen, perc is the subject of several air pollution laws and regulations, including the Air Toxics "Hot Spots" Information and Assessment Act of 1987 (AB 2588), Title III of the 1990 Clean Air Act Amendments, California's Proposition 65, and Rule 1401 of the South Coast Air Quality Management District (AQMD).

In 1998, AQMD staff conducted an assessment of the effects that the then new amendments to Rule 1401 would have on expansion of the motion picture film laboratory industry (Goss, 1998). The assessment included visits to several laboratories and a written survey. The assessment concluded that some facilities may not be able to add new wet gate printing or film cleaning equipment in the future if they do not avail themselves of various "flexibility provisions" of Rule 1401 or use alternative materials and/or technologies that are currently available.

The purpose of the present project was to assist the AQMD in developing a comprehensive emissions inventory for the motion picture film laboratory industry and to develop air toxics risk reduction methods.

OBJECTIVES

The objectives of this research program, which was conducted by Pacific Environmental Services, Inc. were to (1) identify all facilities in the South Coast Air Basin that do motion picture film printing and cleaning; (2) develop a comprehensive industry-wide emission inventory database covering the motion picture film processing industry in the Basin; and (3) identify, evaluate and recommend control equipment, material substitution, process change, and other means for reducing risk due to air toxics emissions from this industry.

BASIC EQUIPMENT

Motion picture film is cleaned in enclosed cabinets under negative pressure. The film is conveyed between a feed reel and a take-up reel, passing through a heated solvent bath. Until several years ago, the solvent of choice was 1,1,1-trichloroethane (methyl chloroform). Because of restrictions on the manufacture of ozone depleting compounds, perchloroethylene ("perc") has been substituted for 1,1,1-trichloroethane in many film cleaning machines. Isopropyl alcohol and other volatile organic compounds (VOCs) are also used. In the solvent bath, ultrasonic shock waves are sometimes generated to remove impurities from the film. Additional scrubbing action is often available by engaging a built-in rotary buffing system that is submerged in the bath. Next, as the film is coming out above the solvent bath, a high-pressure solvent jet is applied over the wet film surface to ensure no loose particles are carried away. Finally, a high-pressure air jet dries the clean film.

In optical printing from a color negative, scratches and other surface blemishes on the negative show up on the print. The main reason for this is that a significant difference in the refractive indexes of air and film causes scattering of the light from the blemishes. One way to avoid this problem is to have the light pass first through a medium whose refractive index is similar to that of the film. The most widely used medium for this purpose is perchloroethylene, whose refractive index (1.505) is midway between those of triacetate film and the gelatin coating on the emulsion side. Wet gate (or "liquid gate") printing has been used commercially in the motion picture industry for over 40 years. In *optical printing*, light passes through the negative and is projected onto the unexposed film. The negative runs through a printing gate between two glass plates. The liquid is introduced under pressure to the space between the plates and is removed by vacuum. In *contact printing*, the negative and print film are in direct contact, and the entire printer movement is immersed in a liquid bath. Wet gates are sometimes used in telecine machines, which convert motion picture film to videotape.

RESULTS

Motion Picture Film Processing Facilities

There are 50 facilities in the District that print motion picture film using wet gate printers, use wet gate telecine machines, and/or clean motion picture film with organic solvents. About three quarters of the facilities in the inventory are in Hollywood, Burbank or Santa Monica.

Equipment Inventory

The survey identified and characterized 107 motion picture film cleaning machines, most of which use perchloroethylene (perc). Seven machines are used to clean 70 mm film. The rest clean 35 and 16 mm film.[1,2] About 27 percent of the film cleaning machines that use perc, and 53 percent of the machines that use VOC (including isopropyl alcohol) do not have permits from the AQMD. Most of the facilities have one or two film cleaning machines; the maximum per facility is ten.

The survey identified 102 wet gate printers, all of which use perchloroethylene as the wet gate fluid. Roughly equal numbers of contact and optical printers use wet gates. About 80 percent of the wet gate printers have AQMD permits. The majority of facilities in the inventory do not have any wet gate printers; those that do have printers have 1 to 27.

The survey found only one facility that uses a wet gate telecine machine.

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[1] Film size was unknown for ten machines.
[2] In this report use of the term "35 mm" film implies use of 16 mm film as well, unless otherwise noted.

Film Footage

The facilities in the inventory clean 543 million feet of film per year, and a maximum of 2.1 million feet per day. The overwhelming majority of this footage is 35 or 16 mm. Perc is used to clean all the 70 mm film and about 61 percent of the rest. The feet of film processed per machine per day or per year varies widely from machine to machine. The median values for 35 mm film are 20,000 ft/day and 3,207,600 ft/yr. The median values for 70 mm film are 20,000 ft/day and 4,000,000 ft/yr.

The facilities in the inventory print 199.6 million feet of film per year and a maximum of 3.1 million feet per day.[3] The great majority of this footage is 35 or 16 mm. Contact and optical printing account for 153 million and 35 million ft/yr, respectively. The type of printer is unknown for the rest of the footage.

The amount of film printed per year per wet gate printer varies widely from device to device. The median values for 35 mm contact and optical printers are 2.5 million and 750,000 ft/yr, respectively.

Material Consumption

Film cleaning solvents currently used include perchloroethylene (6,070 gal/yr), 1,1,1-trichloroethane (2,900 gal/yr), other VOC[4] (2,890 gal/yr), isopropyl alcohol (600 gal/yr), and HFE 7200 (a hydrofluoroether blend) (370 gal/yr). The median values of consumption per 35 mm film cleaning machine are 83 gal/yr of perchloroethylene, 126 gal/yr of 1,1,1-trichloroethane, and 37 gal/yr of isopropyl alcohol. The median perchloroethylene consumption per 70 mm film cleaning machine is 52 gal/yr.

Wet gate printing consumes about 16,400 gal/yr of perc.[5] The median values of consumption per contact printer and per optical printer are 125 gal/yr and 97 gal/yr, respectively.

Emission Control Devices

Add-on control devices, which consist solely of carbon adsorbers, are used at 7 facilities. In some systems, the captured pollutant is desorbed and recycled on-site. In others, saturated carbon is removed from the premises and replaced with new adsorbent. Perchloroethylene and 1,1,1-trichloroethane are the only pollutants whose film cleaning emission are controlled. Eleven devices are controlled by regenerative systems and eight are controlled by disposable canisters; these represent 18 percent of the film cleaners in the inventory.

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[3] Footage data were provided for only 62 of the 102 printers in the inventory; therefore actual footage printed is likely higher than that reported here. Note that emissions data are more complete.

[4] Hexane, cyclohexane and hydrotreated naphtha.

[5] Wet gate telecine perc use and emissions are included under optical printing, to preserve confidentiality of data.

Regenerative carbon adsorbers are used to treat 37 wet gate printers, while disposable canisters are used for 11 printers; these represent 47 percent of the wet gate printers in the inventory.

Emissions

In the following discussion, "maximum potential emissions" are total losses to the atmosphere assuming no carbon adsorption. "Emissions from uncontrolled equipment" are losses from equipment not served by carbon adsorbers. "Emissions from controlled equipment" are those downstream from external emission control equipment. "Net emissions" are emissions to the atmosphere, taking controls into account, where applicable.

Basinwide net emissions of perc from film cleaning are 61,700 lb/yr and 169 lb/day (30.9 tons/yr and 0.085 ton/day). About one quarter of the maximum potential perc emissions and about 36 percent of the maximum potential 1,1,1-trichloroethane emissions are removed by carbon adsorbers. Volatile organic compound (VOC) emissions from film cleaning total 20,620 lb/yr and 56.5 lb/day (10.1 tons/yr and 0.028 ton/day). None of these emissions are controlled. The median value of net emissions of perchloroethylene per facility from film cleaning is 730 lb/yr.

Relatively few facilities account for the great majority of the emissions of 1,1,1-trichloroethane. Emissions of perc are more evenly distributed than those of 1,1,1-trichloroethane, but about 55 percent of the net emissions are from 14 percent of the facilities.

Net perchloroethylene emissions from contact printers, optical printers, and printers whose type is not known are 20,420 lb/yr, 49,990 lb/yr and 4,400 lb/yr, respectively. About 72 percent of the emissions from contact printing and about 15 percent of the emissions from optical printing are controlled. The median value of net emissions of perchloroethylene per facility from wet gate printing is 840 lb/yr. The top 25 percent of the facilities account for 88 percent of the emissions from wet gate printing.

About 130,000 lb/yr of emissions are not treated by carbon adsorption and are therefore available for reduction. Film cleaning and optical printing are responsible for 84 percent of these uncontrolled emissions.

Emission Factors

Detailed monthly data useful for calculating credible emission factors were available for nine devices at three facilities. Mean perchloroethylene emission factors for film cleaning ranged from 0.11 to 0.40 lb/1000 feet of film cleaned. The mean perchloroethylene emission factor for contact printing was 2.6 lb/1000 ft printed for one facility and ranged from 0.032 to 0.18 lb/1000 ft at another. There appears to be a statistically significant inverse relationship between film printing rate and the emission factor for contact printing.

Emission factors were also derived from a subset of the annual film footage and solvent consumption values reported by facilities. The 95-percent confidence intervals for the mean emission factor for contact printers and optical printers were about 0.8 – 1.8 and 0.7 – 1.7 lb/1000 ft, respectively; the difference in means was not statistically significant.

The 95-percent confidence interval for the mean emission factor for 35-mm film cleaning with perchloroethylene was about 0.3 to 0.5 lb/1000 ft. The interval for 70-mm film cleaning with perchloroethylene was about 0.1 to 0.35 lb/1000 ft.

Variability in emission factors is due to differences among machines in maintenance practices, film processing speeds, performance of vapor condensation equipment, solvent temperature, and other factors. Some variability is also due to uncertainty in the underlying estimates of film footage and solvent consumption.

Risk Reduction Measures

Currently used risk reduction or minimization measures include in-machine recovery and recycling, emission capture and removal, solvent substitution, and careful housekeeping practices. In-machine recovery and recycling already goes a long way towards reducing emissions, and the technology continues to improve. Carbon adsorption is the only practical "add-on" measure for this industry. There is currently no practical substitute for perchloroethylene in wet gate printing. The alternatives to perc and 1,1,1-trichloroethane presently comprise about 30 percent of the total volume of film cleaning solvents.

Any substitute for perchloroethylene in wet gate printing must have an acceptable index of refraction, not damage film, and pose less of a community and occupational health risk than perc. Isobutylbenzene (IBB) has been used in Sweden as a wet gate fluid with satisfactory results. Because it has a low flash point, it may pose a fire hazard in some cases. It is relatively non-toxic. Film cleaning solvent alternatives reviewed included HFE 7200, AK-225, HFC-43-10 mee, IBB, hydrotreated naphtha, and n-propyl bromide.

The only near-term alternatives for risk reduction are increasing the extent to which perchloroethylene emissions are controlled by carbon adsorption and use of HFE 7200, AK-225, or HFC-43-10 mee in new or modified film cleaning machines. The costs of these alternatives were estimated for two facility sizes, using U.S. Environmental Protection Agency methods. (HFE 7200 was used as the alternative solvent because some operating data for it were available.) The "base cases" were installation of one or eight new perchloroethylene film cleaning machines without add-on controls.

For a small laboratory, the lowest incremental cost (over the base case) would be use of HFE 7200 and no carbon adsorption.

For the case of eight machines, the lowest incremental cost (over the base case) would be use of perchloroethylene and emission control with a regenerative carbon adsorption system.

RECOMMENDATIONS

Better Characterization of Emissions

The emission factors developed in this project apply only to a limited number of circumstances. For determining risk under Rule 1401/1402, better annual average and maximum hourly emission estimates are needed. The material balance approach used for most of the survey data cannot "see" the influence of process variables, such as film speed. If the District wishes to obtain better emission estimates, then they could be obtained through a systematic program of emissions testing. The purpose of the tests would be to relate mass emissions to readily observable and quantifiable operating parameters.

The contractor recommends (1) testing a variety of film cleaning machines; (2) continuous monitoring for perchloroethylene in the vent duct from the cleaning machine's cabinet, and from the cleaning room exhaust, using flame ionization analyzers calibrated directly with perc; and (3) careful recording of process parameters, including film size, film speed, and solvent bath temperature.

The contractor also recommends testing emissions from wet gates that are enclosed during operation and whose vapors are exhausted in ducts, and, for non-enclosed wet gates, sampling the exhaust ventilation from a relatively small room in which one or two printers is operating. As in the case of film cleaning machines, process parameters should be monitored continuously during each test.

Performance Testing of Alternative Materials

It would be to the advantage of the industry as a whole if the resources of the motion picture film laboratory industry, wet gate and cleaning machine manufacturers, the AQMD, the California Air Resources Board, and solvent manufacturers could be pooled to sponsor commercial-scale testing. This testing would resolve questions such as whether isobutylbenzene leaves a residue on film, or what additives would enable various solvents to clean more effectively. At a minimum, isobutylbenzene should be tested extensively for use as wet gate fluid.

1.0
INTRODUCTION

1.1 PURPOSE AND OBJECTIVES

The motion picture and television industries are major contributors to the economy of Southern California. These industries rely heavily upon motion picture film processing laboratories to develop, clean, and print copies of the films that are shown in movie theaters and broadcast on television. Other post production facilities add titles to films or transfer motion picture film to videotape. Many of the printing and cleaning processes use tetrachloroethylene (perchloroethylene, or "perc"), which is released to the atmosphere. As a carcinogen, perc is the subject of several air pollution laws and regulations, including the Air Toxics "Hot Spots" Information and Assessment Act of 1987 (AB 2588), Title III of the 1990 Clean Air Act Amendments, California's Proposition 65, and Rule 1401 of the South Coast Air Quality Management District (AQMD).

In 1998, AQMD staff conducted an assessment of the effects that the then new amendments to Rule 1401 would have on expansion of the motion picture film laboratory industry (Goss, 1998). The assessment included visits to several laboratories and a written survey. The assessment concluded that some facilities may not be able to add new wet gate printing or film cleaning equipment in the future if they do not avail themselves of various "flexibility provisions" of Rule 1401 or use alternative materials and/or technologies that are currently available.

The purpose of the present project was to assist the AQMD in developing a comprehensive emissions inventory for the motion picture film laboratory industry and to develop air toxics risk reduction methods.

The contractor's specific objectives were to:

(1) Identify all facilities in the South Coast Air Basin that do motion picture film printing and cleaning;

(2) Develop a comprehensive industrywide emission inventory database covering the motion picture film processing industry in the Basin; and

(3) Identify, evaluate and recommend control equipment, material substitution, process change, and other means for reducing risk due to air toxics emissions from this industry.

1.2 PROCESS DESCRIPTIONS

1.2.1 Film Cleaning

Almost all motion picture film is cleaned in enclosed cabinets under negative pressure. The following description is from the AQMD's permit files. "Film to be cleaned is mounted on a feed reel. The film lead is threaded to a take-up reel, passing through a warm solvent bath. The solvent is usually heated to about 120°F, well below its boiling point. At this temperature, the solvent has an optimum cleaning effect. In this solvent bath, ultrasonic shock waves are sometimes generated to remove impurities from the film. Additional scrubbing action is often available by engaging a built-in rotary buffing system that is submerged in the bath. Next, as the film is coming out above the solvent bath, a high-pressure solvent jet is applied over the wet film surface to ensure no loose particles are carried away. Finally, a high-pressure air jet dries the clean film."

Almost all film cleaning machines that use chlorinated solvents (e.g. perchloroethylene and 1,1,1-trichloroethane) have a primary emission control system consisting of refrigerated coils mounted in the freeboard area. Vapors condense on the coils and are collected, desiccated, and stored for future use. The film cleaning machine can be operated as a still to recover spent solvent.

Most facilities house their film cleaning machines in a dedicated room. Besides the cleaning machines, the rooms typically contain drums of unused solvent, an apparatus for attaching and removing film leaders, and various recordkeeping materials, such as maintenance logs. Most models of film cleaning machines are vented through flexible hoses to a wall or the ceiling. In some cases, the vent lines join a manifold, which carries exhaust vapors to an emission control system on the outside. Many cleaning rooms also have room exhaust systems. Because perc and other cleaning solvents are heavier than air, the pickups for these systems are near the floor.

Some film cleaning machines are vented to a secondary control system, consisting of a carbon adsorption bed. Carbon adsorption systems used by the industry include disposable canisters and fixed-bed regenerative systems. In the latter, the solvent is recovered from the carbon bed and re-used.

1.2.2 Wet Gate Printing

In optical printing from a color negative, scratches and other surface blemishes on the negative show up on the print. The main reason for this is that a significant difference in the refractive indexes of air and film causes scattering of the light from the blemishes. One way to avoid this problem is to have the light pass first through a medium whose refractive index is similar to that of the film. The most widely used medium for this purpose is perchloroethylene, whose refractive index (1.505) is midway between those of triacetate film and the gelatin coating on the emulsion side (Schmidt, 1971). Wet gate (or "liquid gate") printing has been used commercially in the motion picture industry for over 40 years. This process has several variations. In *optical printing*, light passes through the negative and is projected onto the unexposed film. The negative runs through a printing gate between two glass plates. The liquid is introduced under pressure to the space between the plates and is removed by vacuum. In *contact printing*, the negative and print film are in direct contact, and the entire printer movement is immersed in a liquid bath. Wet gates are sometimes used in telecine machines, which convert motion picture film to videotape.

Emissions from wet gate printers are generally uncontrolled, although some installations use carbon adsorption systems.

1.3 OUTLINE OF THE REPORT

Methods used to conduct the survey and estimate emissions are described in Section 2. Section 3 presents and summarizes the equipment, materials, and emissions inventory; emission factors are also developed and presented. Current and potential risk reduction measures are identified and evaluated in Section 4; the evaluation includes a preliminary cost analysis of major alternatives. Conclusions and recommendations are presented in Section 5. References are found in Section 6. Copies of the survey instruments are presented in Appendix A. Appendix B contains a detailed description of the methods used for the cost analyses. Finally, Appendix C contains a spreadsheet used for part of the cost analysis.

2.0

SURVEY METHODS

2.1 DEVELOPMENT OF THE FACILITIES LIST

2.1.1 Sources of Names

On October 6, 1999, the AQMD provided the contractor with facility and equipment information on 36 facilities in its jurisdiction (Goss, 1999). The facilities were chosen for having basic equipment category (BCAT) codes 279 (miscellaneous air-dry printing equipment), 362 (wet gate printing with perchloroethylene), and/or 408 (film cleaning machine).

Another major source of names of potentially relevant facilities was an online database maintained by InfoUSA.com,[1] a commercial mailing list provider. A search of this database by standard industrial classification (SIC) code 781907, "Motion Picture Laboratories," found the names of 14 facilities that were not already in the AQMD file. Other sources of potentially relevant facilities were:

- Listings in the *Creative Industry Handbook* and *Film & Tape Storage* directories;
- Listings of motion picture laboratories and film schools on various Internet web sites;
- An Eastman Kodak Company directory of motion picture film-to-videotape transfer facilities in Southern California;[2] and
- A customer list on a RTI/Lipsner-Smith brochure.

Information on all putative motion picture film processing laboratories was entered into a table called "Facilities" in a Microsoft Access™ database, which will be described in Section 2.6. The table included names, addresses and telephone numbers and, for the facilities identified by the AQMD, facility ID numbers, SIC codes and contact names.

2.1.2 Refinement of the Facility List

The sources named in the previous section yielded the names and at least partial address information on 89 facilities. The Facilities database table was sorted alphabetically by facility name, street address, contact name, and telephone number. Where a facility identified by non-AQMD sources appeared to be a duplicate of one identified by

[1] Located at www.lookupusa.com.
[2] Located at www.kodak.com/US/en/motion/postProduction/transfer/la.shtml.

the AQMD, only the AQMD record was kept. However, it was updated with information from the other source(s).

Once the duplicates were eliminated, the contractor telephoned companies that were not on the AQMD list. Each company was asked whether it cleaned motion picture film or had wet gate printers or telecine machines on the premises. If a facility was eligible for the survey, the name of the appropriate contact person was requested. Information for several facilities was obtained from the company's web site on the Internet. It was learned from online industry newsletters that some of the firms had gone out of business several years ago. After facilities that were out of business or were otherwise ineligible for the survey were eliminated, 73 facilities remained in the database.

As a check on the facility list, a copy was sent to Local 683 of The International Alliance of Theatrical Stage Employees, Moving Picture Technicians, Artists and Allied Crafts of the United States and Canada (IATSE). The union was asked whether it was aware of any other motion picture film laboratories in the AQMD. On November 15, 1999 the business representative of Local 683 confirmed that the tentative list of 73 facilities was complete. As no additional facilities were identified, the list of 73 became the potential sample for the survey.

2.2 NOTIFICATION LETTERS

On November 18, 1999 each facility on the final survey list was mailed a "notification package" consisting of the following:

- A notification letter on the contractor's letterhead;
- An explanatory letter from the AQMD;
- A form for declaring that the facility is exempt; and
- A list of data to be obtained at the site interview

Appendix A contains a copy of the notification package. The notification letter was sent to the latest known contact at each facility. It explained the objectives of the survey and stated that any "confidential" or "trade secret" information obtained would be held as such by the contractor and the AQMD. Attached to the notification letter was a copy of an October 8, 1999 letter from Jill Whynot, which stated the AQMD's policies regarding treatment of confidential and trade secret information, and encouraged the facility to provide the requested information.

Because it was still uncertain whether many of the facilities were indeed eligible for the inventory, the notification package included a "Confirmation of Exemption From Motion Picture Laboratory Survey" form. All three conditions on the form (no motion picture film cleaning, no wet-gate printing, and no wet-gate telecine) had to be met before a firm was exempted. Each facility was asked to sign and date the form and fax or mail it back to the contractor. Twenty facilities claimed that they were exempt from the survey. The potential sample thus became 53 facilities.

2.3 FIELD VISITS

About a week after the notification letters were mailed, the contractor began calling facilities to schedule appointments for on-site inspections and data gathering. Per AQMD guidance, the highest priority for the field visits was given to firms that did <u>not</u> have permits. Representatives of the contractor visited 34 of the 53 remaining facilities. Of these 19 had permits and 15 did not. The purposes of the site visits were:

- To identify; enumerate and describe all film cleaning equipment, wet gates, and emission controls;
- To obtain data on film footage, solvent purchase, hazardous waste disposal; and operating costs;
- To observe film handling and equipment maintenance practices; and
- To discuss risk reduction options with laboratory operators.

2.3.1 Field Data Forms

On each visit, the contractor's representative brought a set of forms for recording observations and facility-specific data. Appendix A contains the forms, along with instructions to the field survey staff. The same forms, minus the instructions, were faxed to the laboratories that were not visited. (See Section 2.4.) The forms are described briefly as follows.

<u>Equipment Summary Form</u>. The purpose of this form was to record data for the facility's equipment inventory. One section was for film cleaning machines and the other was for wet gate printers. Data requested included make and model of the device, whether it was used for 35 and 16 mm film or for 70 mm film, the type of cleaning solvent or wet gate fluid, the AQMD permit number (if any), the year the device was placed in service, and its maximum film-handling capacity. A "device number" (which was sometimes a letter or a word) was assigned to each device by the facility.

<u>Operating Data Form</u>. This form was used to collect data on the amount of film processed by, and the operating schedule for, each device. Each device was identified by the "device number" assigned on the previous form. The "General Operating Schedule" was for the entire film cleaning or printing operation, rather than for particular devices. For example, if the cleaning room was available 8 hours per day but only 1 hour was spent actually cleaning film, 8 hours were reported. The "Monthly Activity Pattern" section of the form recorded the percentage of annual activity (usually measured by feet of film processed) in each month.

<u>Solvent Inventory Form</u>. This form was intended to record information necessary to calculate emissions by material balance. It asked for the amounts of solvent on hand at the end of 1997 and the beginning of 1998, and a list of all purchases in 1999.[3] It also asked for information on waste disposal.

Control and Stack Information Form. One purpose of this form was to obtain basic operating information on emission control devices currently used by each facility; this data would be useful in the risk reduction measure analyses. The form also requested information on various release parameters, such as stack height and volumetric flow rate, that could be used in risk assessment modeling in the future.

Operating and Maintenance Costs Form. Information to be used in estimating the costs of various alternative risk reduction measures was recorded on this form. Questions covered film cleaning machines and carbon adsorption systems.

2.3.2 Site Visit Protocol

A visit typically began with a discussion with the facility representative about the objectives of the survey and the types of information desired. Where facilities had prepared some materials (such as invoices of solvent purchases) in advance, data gaps were identified. The initial discussion also touched on some of the proposed alternatives to the use of perchloroethylene in film cleaning. The facility's special film cleaning requirements were also discussed.

Next, the contractor's representative toured the facility. The tours included, at a minimum, and wherever applicable:

- Film cleaning equipment;
- Motion picture film printers and/or telecine machines using wet gates;
- Unused solvent storage;
- Emission capture and control equipment; and
- Film cleaning logs and other records

On the tour, the contractor sketched equipment layouts and ductwork and recorded various observations. In many cases, typical operation of the film cleaning and printing equipment was observed. The visit usually ended with a request for the information that was not available that day.

2.4 FAXED INFORMATION REQUESTS

Because of schedule conflicts and time limitations, it was not possible to visit all the facilities eligible for the inventory. Eighteen facilities were given the option of filling out the field survey forms themselves and sending them back to the contractor. These forms, along with an explanatory note, were faxed between December 6, 1999 and January 31, 2000.

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[3] The AQMD requested that the inventory reflect the most recent data and operating conditions.

2.5 PERMIT FILES

Eight facilities were either unwilling or unable to provide data for this inventory. Emission inventory information for those facilities was obtained through a review of their permit files at the AQMD. These files included permit applications, AQMD engineering reviews, vendor brochures, and other useful information.

2.6 SURVEY MANAGEMENT DATABASE

A Microsoft Access™ database, designed for this project, kept track of the status of each facility's participation in the survey and recorded the information obtained. It was also used to extract data for further analysis by Microsoft Excel™. For the field survey portion of the project, the database, which was called "movielabs.mdb," kept track of the response status (eliminated, need to visit, visited, etc.) of each facility. Information on contact names, telephones and other facility data was updated continually. The database made daily printouts of appointments and of facilities that had not yet been visited. Later in the project, the equipment, material use, and operations information, as well as the results of emission calculations, were entered into the database.

2.7 FOLLOW-UP

Very few facilities had all the requested information on hand for the site visit, and most of the laboratories that filled out the faxed survey forms omitted at least some essential information. Almost all facilities were re-contacted by telephone, mail, fax, and/or e-mail. These follow-up communications usually included a list of missing types of information (e.g. purchases of perchloroethylene during the year). Telephone conversations were documented on forms designed for the project and kept in a loose-leaf notebook. Copies of all faxes, letters and e-mails were archived.

2.8 FINAL SURVEY STATUS

Figure 2-1 summarizes the status of the survey. At least some useful emission inventory information was obtained from 50 facilities. Twenty facilities were ineligible for the inventory, usually because they claimed not to do any film cleaning or use wet gate printers or telecine machines. Three facilities were confirmed to be out of business. As will be discussed in Section 3.1, inventory data were obtained directly from 42 facilities (84 percent of the final inventory), and from AQMD permit files for the rest.

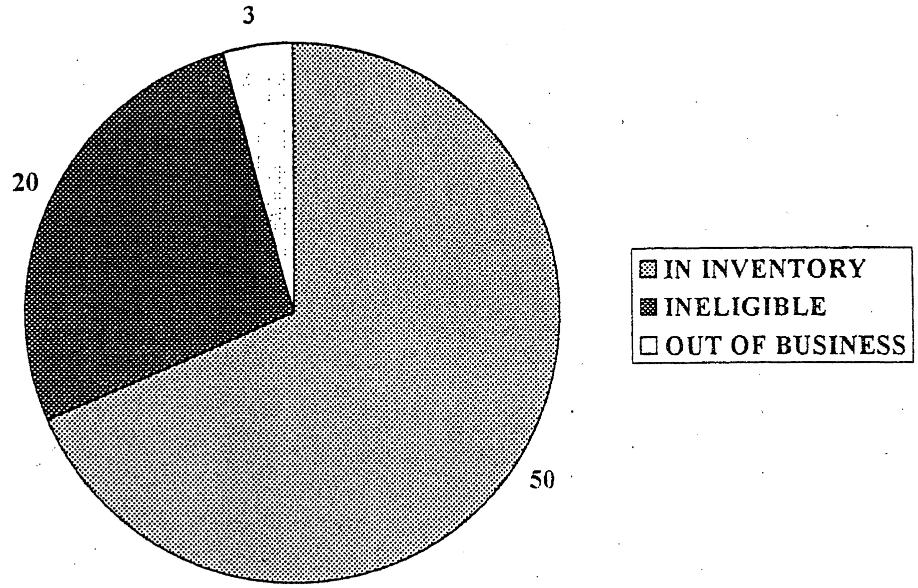

Figure 2-1. Final Status of the Emission Inventory Survey.

2.9 EMISSION CALCULATIONS

2.9.1 Basic Method

Because reliable emission factor data (e.g. pounds emitted per 1,000 feet of film cleaned) were unavailable, a material balance method was used to estimate losses to the atmosphere. Emissions were computed by the following formula:

$$E = (I - F + P - W)(R) \qquad [2\text{-}1]$$

where

I = Amount on hand at end of previous year
F = Amount on hand at end of inventory year
P = Makeup solvent[4] applied during inventory year
W = Waste disposed for the inventory year
R = Release fraction

Makeup solvent is comprised of solvent purchases plus solvent reclaimed on-site. Reclaimed solvent includes condensate from vapor condensers in film cleaning machines and the solvent desorbed from carbon adsorption beds. The amount of solvent reclaimed

[4] Makeup solvent is defined as the solvent that must be added to a device's reservoir to replace that which has been lost to evaporation or a waste stream.

on-site at a given facility is generally unknown. However, the more that is reclaimed, the less that has to be purchased. It was assumed that on-site recycling (if any) was implicit in the amount of solvent reported as purchased or used.

Waste disposal values were obtained, wherever possible, from hazardous waste manifests. Only those waste shipment corresponding to solvent use in the inventory year were considered. For example, suppose that one drum of waste was shipped at the beginning of November of the year before the inventory year, and the next was shipped at the end of February of the inventory year. The amount of waste assigned to the inventory year would be (2 months/4 months) x 1 drum, or 0.5 drum. In the absence of any waste analysis data, it was assumed that the waste contained 50 percent solvent by weight.

In Equation 2-1, the quantity (I - F + P - W) equals the maximum potential (uncontrolled) emissions for the facility. The release fraction is defined as the fraction of the maximum potential emissions that enter the atmosphere. Except for cases in which add-on controls (e.g. carbon adsorbers) are applied, R = 1. Thus the emission reduction which results from the use of internal controls, such as vapor condensers, is implicit in the reduced value of the makeup solvent consumed; in the absence of those internal control, it is assumed, a greater quantity of makeup solvent would be needed for the same amount of film processed.

For carbon adsorbers, the release fraction was assumed to be equal to $1 - \varepsilon$, where ε is the control equipment's capture and removal efficiency. Values of ε reported by the surveyed facilities or their consultants, or those assumed by the AQMD in permit application reviews, were used without adjustment.

2.9.2 Other Special Cases

Several variations on the basic emission calculation method were used. A few facilities provided results of in-house tests of the efficiency of their cleaning and/or printing equipment. Solvent mileage data from those tests were used in conjunction with consumption figures to estimate emissions.

In many cases, facilities did not provide any information on I and F in Equation 2-1. They did, however, have a list of dates and amounts of recent solvent purchases. It was assumed that the first purchase on the list was to replace solvent that had been consumed up to the purchase date. The gallons or pounds of solvent from that first purchase were ignored. Let $P_1, P_2, \ldots, P_k$ be the purchases on dates 1 through k, and let d be the number of calendar days between the first and last days. Then average daily consumption was calculated as:

$$C = \left(\sum_{j=2}^{k} P_j \right)/d \qquad [2\text{-}2]$$

The average daily consumption was then multiplied by 365 to obtain the annual consumption.

Finally, if no other data were available, emission estimates contained in the facility's AQMD permit file were used. In some cases, these estimates were provided as part of the permit application, and in others, they were part of the AQMD's engineering analysis.

3.0

EMISSION INVENTORY RESULTS

3.1 FACILITIES

At least some emission inventory data were received from 50 facilities in the South Coast Air Basin. As seen in Figure 3-1, data from most of the laboratories were obtained mainly by site visits. Ten facilities responded to faxed questionnaires, and were not visited. Finally, information on eight facilities was obtained through a review of AQMD permit files. Most of the facilities that were visited or surveyed by fax were contacted again for additional or clarified information.

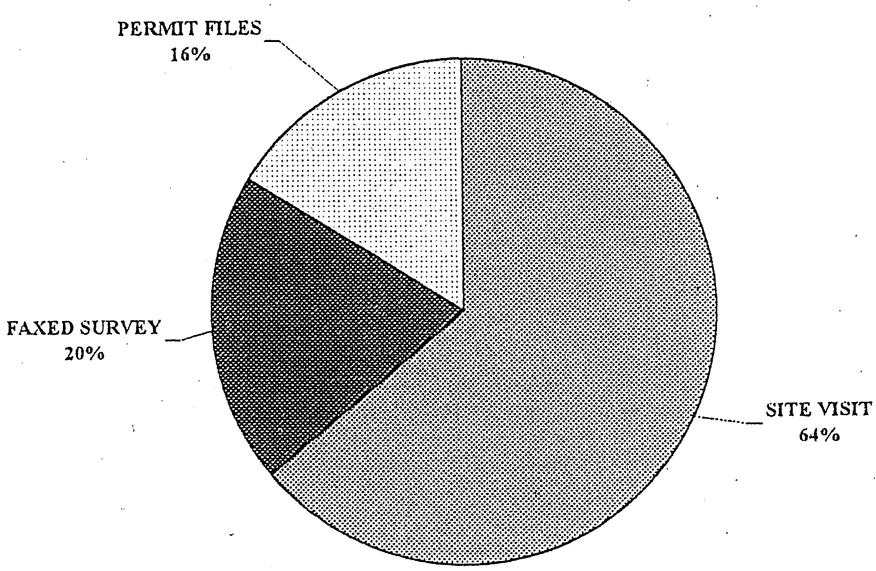

Figure 3-1. Sources of Emission Inventory Information (50 Facilities).

3.1.1 Facility Types

Figure 3-2 shows the distribution of the facilities in the inventory by their principal business activity. The largest group consists of production and post-production facilities. These include motion picture and television studios, producers of television commercials, and title houses. "Laboratories" are defined here as companies whose main business is to print and/or clean film. They comprise 26 percent of the inventoried. Telecine houses make up another 22 percent. Finally, six companies specialize in preservation and restoration of old films.

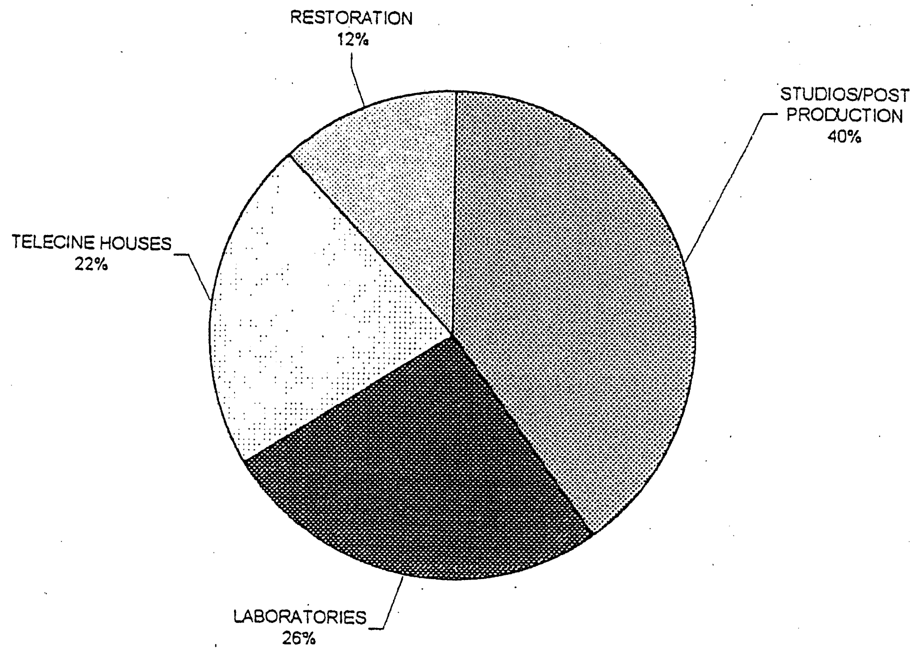

Figure 3-2. Distribution of Inventoried Facilities, by Type of Activity.

3.1.2 Geographic Distribution of Facilities in the Inventory

To preserve the confidentiality of the survey responses, specific locations of the facilities in the inventory cannot be provided. However, it may be noted that 37 of the 50 facilities (74 percent) are in Hollywood, Burbank or Santa Monica.

3.2 EQUIPMENT INVENTORY

3.2.1 Film Cleaning Machines

The survey identified 107 motion picture film cleaning machines in the inventoried facilities. Tables 3-1 and 3-2 show how they are distributed by film size[1] and by solvent, respectively. Each table shows how many machines in each category have AQMD permits or have permit applications pending. The great majority of the film cleaning machines in the Basin are used for 16- and 35-mm film.

About 58 percent of the film cleaning machines in the Basin use perc. Although it is rapidly being phased out, 1,1,1-trichloroethane is still used in 12 film cleaners. Isopropyl alcohol is also used in 12 machines. Other solvents include cyclohexane, HFE 7200,[2] and hydrotreated naphtha.

[1] Many 35-mm film cleaning machines are also used to clean 16-mm film.
[2] HFE 7200 is a tradename for a mixture of ethyl perfluoroisobutyl ether and ethyl perfluorobutyl ether.

Of the 62 film cleaning machines that use perc, 17 (27 percent) do not have permits from the AQMD. Most of the isopropyl alcohol machines do not have permits.

Table 3-1

DISTRIBUTION OF FILM CLEANING MACHINES BY FILM SIZE

	35[a]	70	Unknown	Totals
Permitted	53	6	10	69
Non-Permitted	37	1	0	38
Totals	90	7	10	**107**

[a]Includes both 35 mm and 16 mm film cleaning.

Table 3-2

DISTRIBUTION OF FILM CLEANING MACHINES BY TYPE OF SOLVENT

Solvent	Permitted	Non-Permitted	Totals
Perchloroethylene	45	17	62
Isopropanol	5	7	12
1,1,1-Trichloroethane	9	3	12
Other VOC[a]	10	10	20
HFE 7200	0	1	1
Total	69	38	107

[a]VOC = Volatile organic compounds.

Most of the facilities in the inventory have one or two film cleaning machines, and the maximum number of film cleaners per laboratory is ten. Figure 3-3 shows the distribution of numbers of film cleaners per facility.

3.2.2 Wet Gate Printers

The survey identified 102 wet gate printers. Table 3-3 shows the breakdown by type of printing (contact vs. optical) and permit status. There are roughly the same number of contact printers as there are optical models, and the great majority of wet gate printers are now permitted. All the printers use perchloroethylene as the wet gate fluid, although one facility uses a blend of perc and another compound.[3]

[3] Identity of the compound is unnamed to preserve confidentiality.

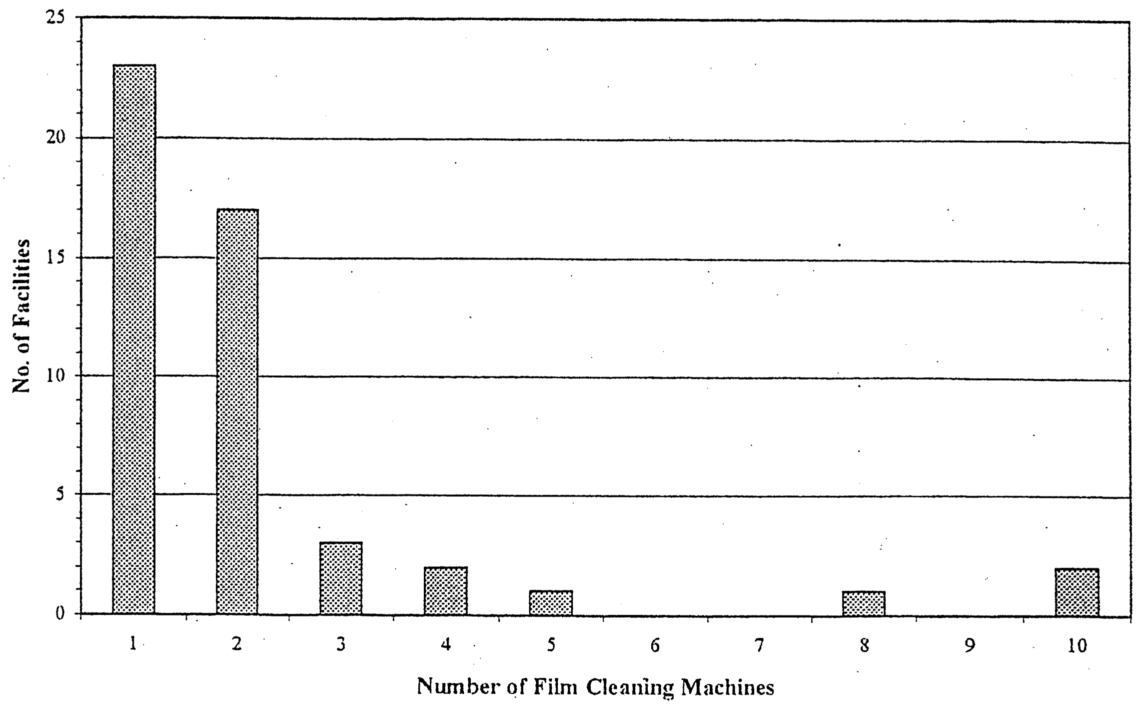

Figure 3-3. Number of Film Cleaning Machines per Facility in the Inventory.

Table 3-3

DISTRIBUTION OF WET GATE PRINTERS BY TYPE AND PERMIT STATUS

	Contact	Optical	Unknown	Totals
Permitted	35	41	6	82
Non-Permitted	9	7	4	20
Totals	44	48	10	**102**

Figure 3-4 shows the number of wet gate printers per facility in the inventory. The majority of the facilities in the inventory do not have any wet gate printers, and the most that any laboratory has is 27.

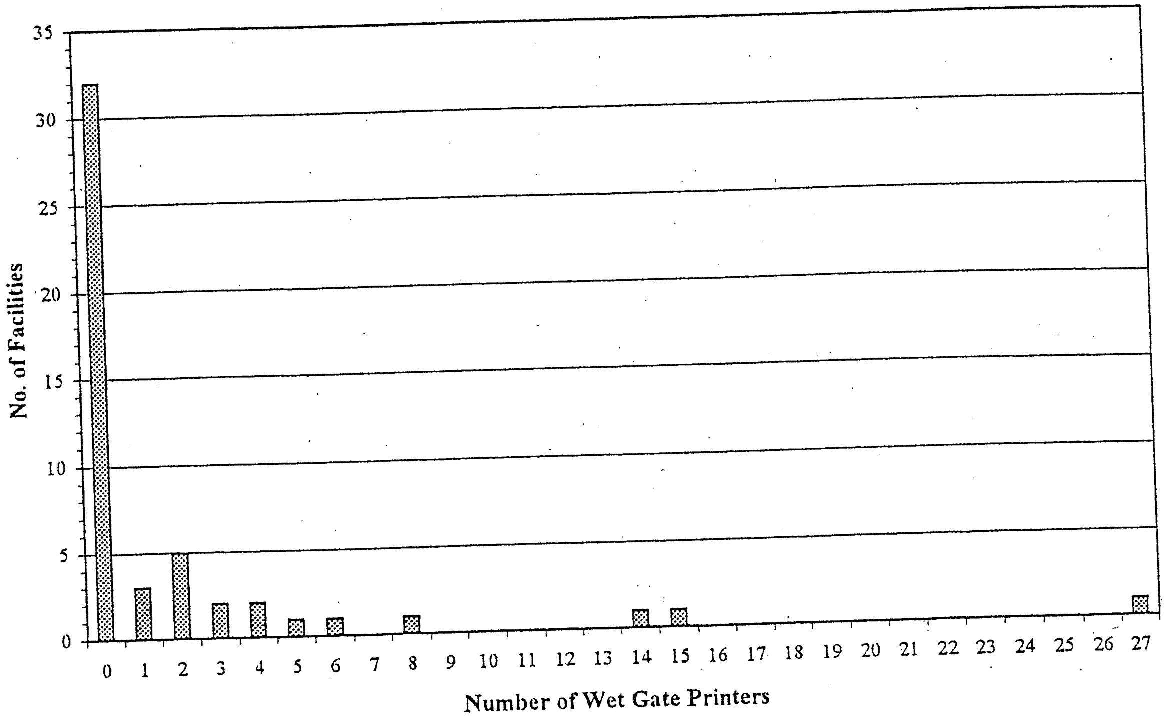

Figure 3-4. Number of Wet Gate Printers per Facility in the Inventory.

3.2.3 Wet Gate Telecine

Only one facility was found to use a wet gate telecine machine. According to several facility contacts, the current trend is to use "digital wet gates," in which the potential effects of scratches and other imperfections are removed electronically.

3.3 FILM FOOTAGE

3.3.1 Film Cleaning Machines

Table 3-4 shows the feet of film cleaned annually and per day, by film size and solvent used. The facilities in the inventory clean about 543 million feet of film per year, about 96 percent of which is for 16 or 35 mm film. Figure 3-5 shows the distribution of the annual footage by solvent. Perchloroethylene is the only solvent used to clean 70 mm film, and accounts for about 62 percent of all the cleaned footage (16, 35 and 70 mm).

The feet of film processed per machine per day or per year varies widely from machine to machine. The frequency distributions of feet per cleaner are not normal, and are skewed toward lower values; i.e. most of the machines have fairly low annual processing rates and a few have very high rates. Table 3-5 shows the median values and ranges for feet cleaned per film cleaning machine, for machines using perchloroethylene, 1,1,1-trichloroethane, or isopropyl alcohol.

Table 3-4

BASINWIDE FEET OF FILM CLEANED, BY FILM SIZE AND TYPE OF SOLVENT

Solvent	Feet per Year			Maximum Feet per Day		
	35 mm[a]	70 mm	Total	35 mm[a]	70 mm	Total
Perchloroethylene	315,475,500	23,674,800	339,150,300	1,232,000	112,200	1,344,200
Isopropanol	41,845,150		41,845,150	177,600		177,600
1,1,1-Trichloroethane	84,321,700		84,321,700	310,200		310,200
Other VOC	44,928,000		44,928,000	192,000		192,000
HFE 7200	32,947,200		32,947,200	105,600		105,600
Total	519,517,550	23,674,800	**543,192,350**	2,017,400	112,200	**2,129,600**

[a]Includes 35 mm and 16 mm film.

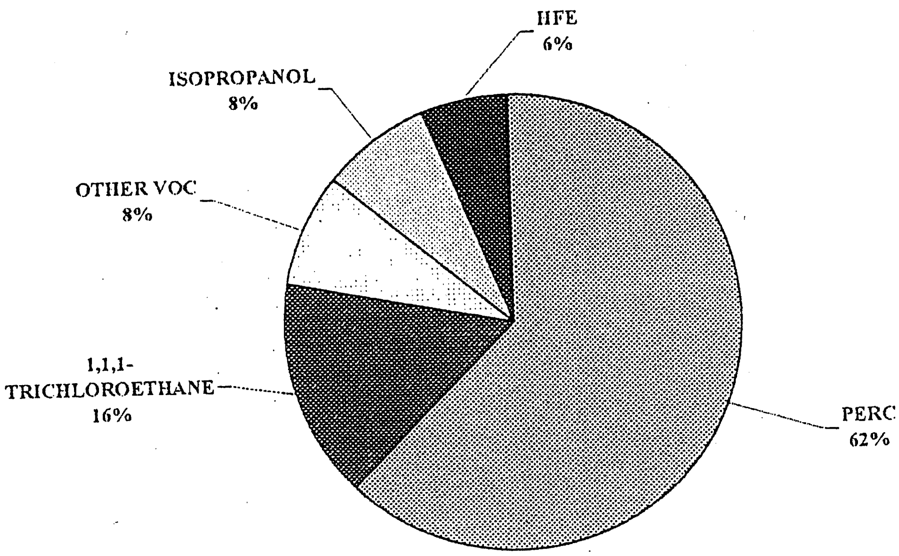

Figure 3-5. Distribution of Annual Feet of Film Cleaned, by Cleaning Solvent.

Table 3-5

ANNUAL FEET OF FILM CLEANED PER FILM CLEANING MACHINE

Film Size	Feet per Day		Feet per Year	
	Median	Range	Median	Range
16 or 35 mm	20,000	400 - 105,600	3,207,600	50,000 - 32,947,200
70 mm	20,000	6,000 - 40,400	4,000,000	90,500 - 9,138,000

3.3.2 Wet Gate Printers

Table 3-6 shows the reported feet of film printed annually and per day by wet gate printers, by film size and type of printer (contact or optical).[4] The facilities in the inventory reported printing about 200 million feet of film per year. *The actual footage printed*

[4] The one wet gate telecine machine reported is included with the optical printers to maintain confidentiality.

Table 3-6

BASINWIDE FEET OF FILM PRINTED ON WET GATE PRINTERS, BY PRINTING METHOD AND FILM SIZE

Printing Method	Feet per Year			Maximum Feet per Day		
	16 or 35 mm	70 mm	Total[b]	16 or 35 mm	70 mm	Total[b]
Contact	146,541,950	6,275,600	152,817,550	1,784,900	1,008,000	2,792,900
Optical[a]	36,383,450	239,900	36,623,350	281,100	25,800	306,900
Unknown	10,118,400		10,118,400	45,600		45,600
Total	193,043,800	6,515,500	**199,559,300**	2,111,600	1,033,800	**3,145,400**

[a]Includes one wet-gate telecine machine.

[b]Actual total footage printed is higher, because data were unavailable for 40 printers.

is most likely significantly higher, because footage data were not supplied for 40 of the 102 printers in the inventory.

For the printers for which data are available and the printing method is known, contact printing accounts for about 76 percent of the annual footage of 16- or 35-mm film and 96 percent of the annual footage of 70-mm film. The two smaller film sizes comprise about 97 percent of all film printed, regardless of the printing method.

As with film cleaning, the amount of film printed per wet gate printer varies widely. Table 3-7 shows the median values and ranges of feet printed per printer, by printing type (contact vs. optical) and film size. The data in both Tables 3-6 and 3-7 show that, although there are roughly the same number of contact and optical printers in the Basin, the contact printers have the greater workload.

Table 3-7

FOOTAGE PRINTED PER WET GATE PRINTER

	Film Size		Contact	Optical[a]
Feet per Day	16 or 35 mm	Median	22,333	6,984
		Range	200 - 252,000	226 - 48,000
	70 mm	Median	252,000	12,000
		Range	252,000 - 252,000	1,800 - 12,000
Feet per Year	16 or 35 mm	Median	2,549,261	750,000
		Range	11,765 - 28,080,000	11, 765 - 12,480,000
	70 mm	Median	1,568,902	74,710
		Range	1,568,902- 1,568,902	74,710 - 90,500

[a]Includes 35-mm wet gate telecine.

3.3.3 Wet Gate Telecine

To maintain confidentiality of data, the footage per telecine machine was combined with the values for optical motion picture film printing in determining median and ranges in Table 3-7.

3.4 MATERIAL CONSUMPTION

3.4.1 Film Cleaning Machines

The facilities in the inventory have largely made the transition from using 1,1,1-trichloroethane to using perchloroethylene and other solvents. At present, six types of motion picture film cleaning solvents are used.[5] Table 3-8 shows the annual basinwide consumption volume for each solvent formulation. Perchloroethylene is the highest-volume solvent, comprising almost half the total. Most of the rest of the cleaning solvent use is accounted for by 1,1,1-trichloroethane and a hexane/cyclohexane blend. Table 3-9 shows the annual consumption per machine for perchloroethylene, 1,1,1-trichloroethane and isopropyl alcohol.

Table 3-8

ANNUAL BASINWIDE FILM CLEANING SOLVENT CONSUMPTION, BY SOLVENT TYPE

Solvent	Gallons per Year	Percent of Total
Perchloroethylene	6,070	47
1,1,1-Trichloroethane	2,900	23
Other VOC	2,890	23
Isopropanol	600	5
HFE 7200	370	3
Total	12,830	100

Table 3-9

CLEANING SOLVENT CONSUMPTION PER MACHINE, BY SOLVENT TYPE

(Consumption in Gallons/Year)

	35 mm		70 mm	
	Median	Range	Median	Range
Perchloroethylene	83	2 - 366	52	0 - 122
1,1,1-Trichloroethane	126	0 - 1,248		
Isopropyl Alcohol	37	6 - 99		

[5] Several additional types of solvents are permitted for some facilities, but are not currently used. Also, use data were not reported for several types of solvents not reported here; their identities are not provided to preserve confidentiality.

3.4.2 Wet Gate Printing

Wet gate printing consumes about 16,400 gallons of perchloroethylene per year. Table 3-10 shows the breakdown by printing type and by film size. This volume exceeds that of the perc used in film cleaning by about 10,300 gal/yr. Table 3-11 shows how much perc is used per wet gate printer.

Table 3-10

BASINWIDE CONSUMPTION OF PERCHLOROETHYLENE IN WET GATE PRINTING (GALLONS/YEAR)

Type of Printing	16 or 35 mm	70 mm	Total
Contact	8,340	620	8,960
Optical	7,070	40	7,110
Unknown	330	0	330
Total	15,740	660	16,400

Table 3-11

PERCHLOROETHYLENE CONSUMPTION PER WET GATE PRINTER

(Consumption in Gallons/Year)

	16 or 35 mm		70 mm	
	Median	Range	Median	Range
Contact	125	<1 - 676	156	156
Optical	97	<1 - 676	16	6 - 16
Unknown	79	52 - 117	None	

3.4.3 Wet Gate Telecine

To maintain confidentiality of data, the perchloroethylene use per telecine machine was combined with the values for optical motion picture film printing in Tables 3-10 and 3-11.

3.5 EMISSION CONTROL DEVICES

The only type of "add-on" emission control device reported by the facilities in the inventory is the carbon adsorber. As will be discussed in Section 4.1, two major categories of carbon adsorbers are used in this industry. In the first, the captured pollutant is desorbed, purified, and recycled on-site. In the other, saturated carbon is removed from the premises and replaced with new adsorbent.

3.5.1 Film Cleaning

Perchloroethylene and 1,1,1-trichloroethane are the only pollutants whose film cleaning emissions are controlled. Table 3-12 shows how many film cleaning machines are controlled by each type of carbon adsorber. Figure 3-6 shows the extent of control of perchloroethylene emissions from film cleaning, by number of devices.

Table 3-12

FILM CLEANERS CONTROLLED BY CARBON ADSORBERS

Solvent Controlled	Regenerative		Disposable	
	No. of Facilities	Devices Controlled	No. of Facilities	Devices Controlled
Perchloroethylene	1	8	5	8
1,1,1-Trichloroethane	1	3	0	0
Totals	2	11	5	8

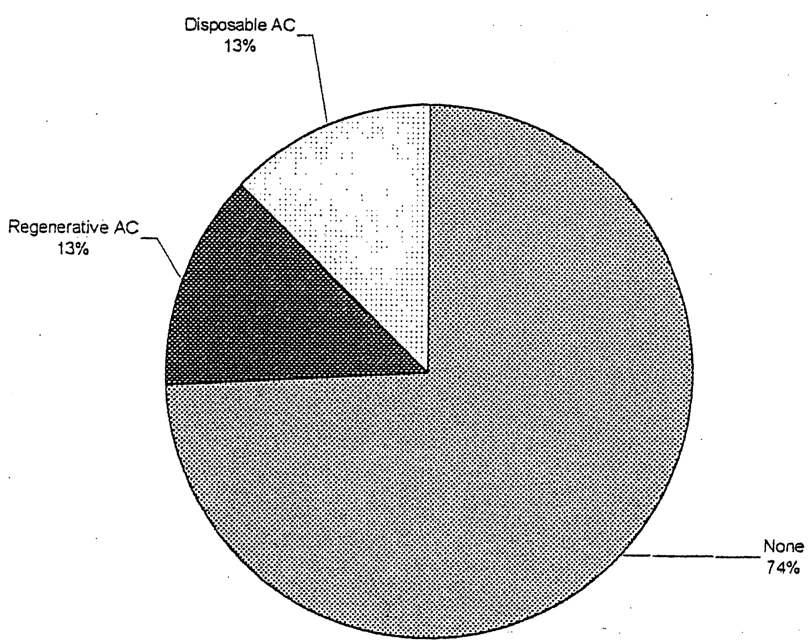

Figure 3-6. Percentages of Devices Using Carbon Adsorption to Control Perchloroethylene Emissions From Film Cleaning.

3.5.2 Film Printing

Table 3-13 shows how many wet gate printers of each type are controlled by each type of carbon adsorber. Figure 3-7 shows the extent of control of perchloroethylene emissions from wet gate printing, by number of devices. In contrast to film cleaning, almost half the wet gate printers in the inventory are served by emission control devices.

Table 3-13

WET GATE PRINTERS CONTROLLED BY CARBON ADSORBERS

Printing Type	Regenerative		Disposable	
	No. of Facilities[a]	Devices Controlled	No. of Facilities[a]	Devices Controlled
Contact	2	23	2	6
Optical	3	14	3	5
Unknown	0	0	0	0
Totals	5	37	5	11

[a]At some facilities, the same carbon adsorber serves contact and optical printers.

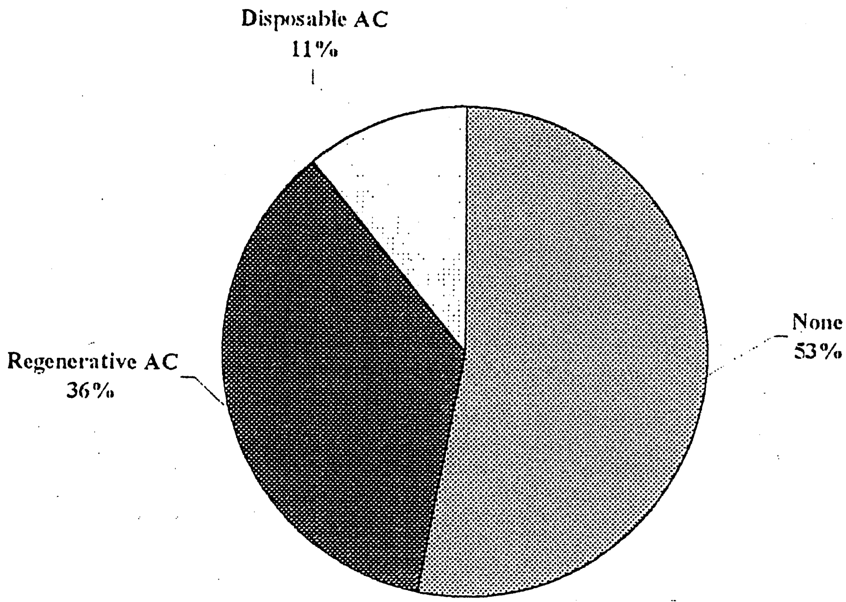

Figure 3-7. Percentages of Devices Using Carbon Adsorption to Control Perchloroethylene Emissions From Wet Gate Printing.

3.6 EMISSIONS

3.6.1 Film Cleaning

Table 3-14 shows the annual emissions of each solvent from film cleaning operations. In this table, as well as the other emission summary tables in this report, the columns are defined as follows:

> **Maximum Potential Emissions:** Total losses to the atmosphere assuming that no controls (other than internal condensation and recycling systems) are used. For equipment having external controls (e.g. carbon adsorbers), this value is the input to the emission control system.
>
> **Emissions From Uncontrolled Equipment:** Losses to the atmosphere from equipment having no external controls.
>
> **Emissions From Controlled Equipment:** Emissions downstream of external emission control equipment, such as carbon adsorbers.

Net Emissions: Emissions to the atmosphere, taking controls into account (only where applicable).[6]

Percent Control: The amount of pollutant that does not enter the atmosphere at the facility, because it is either recycled on-site or is sent off-site for disposal.[7]

Table 3-14

EMISSIONS (LB/YR) OF SOLVENTS FROM FILM CLEANING

Solvent ID	Solvent Name	Maximum Potential Emissions	Emissions From Uncontrolled Equipment	Emissions From Controlled Equipment	Net Emissions	Percent Control
71-55-6	1,1,1-Trichloroethane	32,250	20,580	120	20,700	35.8
110-82-7	Other VOC[a]	16,670	16,670	0	16,670	0.0
HFE	HFE (Ethoxy-nonafluorobutane)	4,370	4,370	0	4,370	0.0
67-63-0	Isopropyl Alcohol	3,950	3,950	0	3,950	0.0
127-18-4	Perchloroethylene	81,950	60,200	1,500	61,700	24.7

[a]VOC other than isopropyl alcohol include cyclohexane (CAS 110-82-7), hexane (CAS 110-54-3) and hydrotreated naphtha (CAS 64742-48-9).

Basinwide net emissions of perchloroethylene from film cleaning are 61,700 lb/yr and 169 lb/day (30.9 ton/yr and 0.085 ton/day). About one-quarter of the maximum potential perc emissions and about 36 percent of the maximum potential 1,1,1-trichloroethane emissions are removed by carbon adsorbers. Volatile organic compound (VOC) emissions from film cleaning total 20,620 lb/yr and 57 lb/day (10.3 tons/yr and 0.028 ton/day). None of these emissions are controlled.

Annual net emissions of perchloroethylene per facility range from 5.5 to 14,826 lb, with a median value of 732 lb/yr. Inequalities of distribution of emissions per facility can be visualized by means of Lorenz curves. The horizontal axis of these curves is the cumulative percentage of facilities. The vertical axis is the cumulative percentage of total net emissions. If all facilities had the same net emissions, the Lorenz curve would be a straight line. The more unequal the distribution, the closer the curve moves to the lower right corner.

Figure 3-8 shows the Lorenz curves for net emissions of perc and 1,1,1-trichloroethane. Relatively few facilities account for the great majority of the emissions of 1,1,1-trichloroethane; indeed two-thirds of the emissions are from one facility. Emissions of perc are more evenly distributed than those of 1,1,1-trichloroethane, but are nev-

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[6] Net Emissions = Emissions From Uncontrolled Equipment + Emissions From Controlled Equipment
[7] Percent Control = 100 x (Maximum Potential Emissions - Net Emissions)/(Maximum Potential Emissions)

ertheless concentrated among a relatively small number. About 55 percent of the net perc emissions from film cleaning are from 14 percent of the facilities.

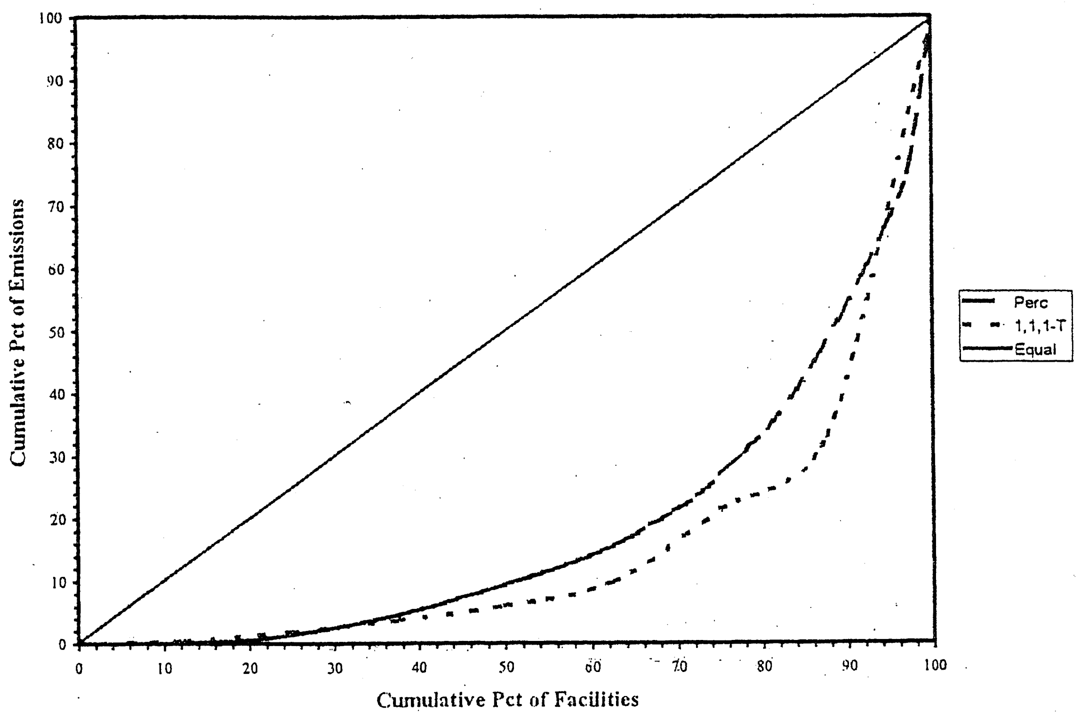

Figure 3-8. Lorenz Curves for Emissions of Perc and 1,1,1-Trichloroethane.

3.6.2 Wet Gate Printing

Tables 3-15, 3-16 and 3-17 show, respectively, the annual inventoried perchloroethylene emissions, by film size, for contact printers, optical printers, and printers whose type was not reported.

Table 3-15

ANNUAL PERCHLOROETHYLENE EMISSIONS FROM CONTACT WET GATE PRINTERS (LB/YR)

Film Size	Maximum Potential Emissions	Emissions From Uncontrolled Equipment	Emissions From Controlled Equipment	Net Emissions	Percent Control
16/35	64,050	16,470	3,640	20,110	68.6
70	8,420	0	300	310	96.3
Total	72,470	16,470	3,940	20,420	71.8

Table 3-16

ANNUAL PERCHLOROETHYLENE EMISSIONS FROM OPTICAL WET GATE PRINTERS (LB/YR)

Film Size	Maximum Potential Emissions	Emissions From Uncontrolled Equipment	Emissions From Controlled Equipment	Net Emissions	Percent Control
35	58,020	49,450	520	49,970	13.9
70	500	0	20	20	96.0
Total	58,520	49,450	540	49,990	14.6

Table 3-17

ANNUAL PERCHLOROETHYLENE EMISSIONS FROM WET GATE PRINTERS OF UNREPORTED TYPE (LB/YR)

Film Size	Maximum Potential Emissions	Emissions From Uncontrolled Equipment	Emissions From Controlled Equipment	Net Emissions	Percent Control
16/35	4,400	4,400	0	4,400	0.0
70	Not Applicable				
Total	4,400	4,400	0	4,400	0.0

For all types of wet gate printing, emissions from printing of 16 and 35 mm film far exceed those from printing of 70 mm film. This is due mainly to the fact that much more of the two smaller sizes of film is printed, but is due also to the much greater extent of use of emission controls for 70-mm printing. Although maximum potential emissions from contact printing exceed those from optical printing (72,470 vs 57,400 lb/yr), *net* emissions from contact printing are lower. This is because about 72 percent of the emissions from contact printing are controlled, while only 13 percent of those from optical printing are treated.

Annual net emissions of perchloroethylene per facility range from 0.8 to 57,283 lb, with a median value of 840 lb/yr. Figure 3-9 is a Lorenz curve for perc emissions from wet gate printing. It is clear that most of the emissions are concentrated in a few facilities. The top 25 percent of the facilities account for 88 percent of the emissions.

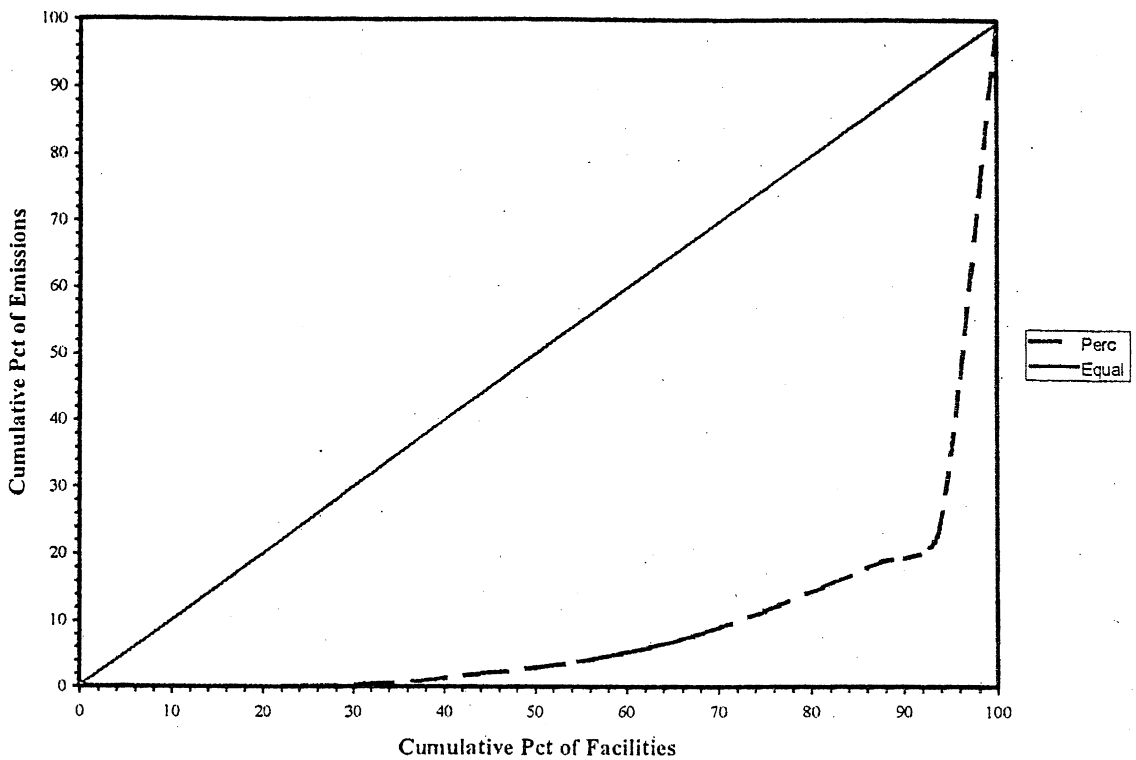

Figure 3-9. Lorenz Curve for Emissions of Perc From Wet Gate Printing.

3.6.3 Wet Gate Telecine

Estimated perchloroethylene emissions from the one wet gate telecine machine in the inventory are included with those for uncontrolled wet gate optical printing.

3.6.3 Potential for Additional Risk Reduction

Figure 3-10 shows the distribution of perchloroethylene emissions from equipment that is not served by carbon adsorbers (or any other type of pollutant removal device). These are the emissions available for reduction. Film cleaning and optical printing are responsible for about 84 percent of the emissions that are available for reduction.

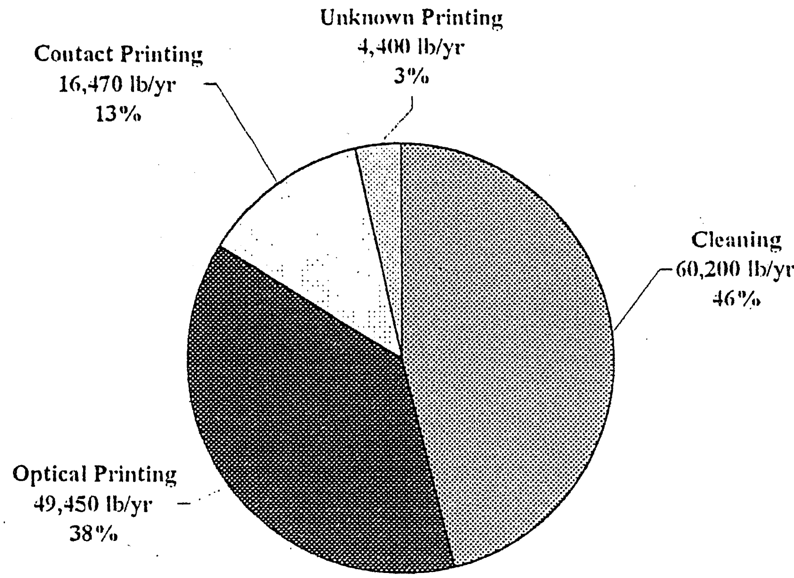

Figure 3-10. Distribution of Perchloroethylene Emissions Available for Reduction.

3.7 EMISSION FACTORS

One objective of this project was to develop useful emission factors for film cleaning and printing. The efficiency of these devices is generally expressed as "solvent mileage," or feet cleaned or printed per gallon of solvent. Various solvent mileage values have been claimed in product literature and assumed in permit applications and evaluations, but no peer-reviewed, publicly available documentation is available for any of the values used. In addition, solvent mileage may vary with film size, film processing speed, efficiency of on-board emission controls, equipment age, and other factors, some of which may not now be recognized.

It was hoped that the current project would obtain enough valid data to enable calculation of emission factors, in units of mass per length of film processed. (These units are proportional to the inverse of solvent mileage.) Good emission factors could then be multiplied by actual or estimated film processing throughput to obtain emission estimates. This project was successful only to a limited extent. It was outside the contract scope to perform laboratory or field tests to determine the emission factors, and the solvent use and film throughput values obtained through the survey were sometimes highly uncertain. Nevertheless, some of the data obtained from the laboratories were of sufficient quality to develop some useful emission factors.

3.7.1 Emission Factors Derived From Monthly Logs

Three facilities provided data from monthly in-house logs of their solvent consumption.[8] Facility A cleans 35 mm film with perchloroethylene. For one year, it kept detailed monthly records of solvent consumption and film footage. Facility B kept records of perchloroethylene consumption by a mixture of contact and optical printers, along with the corresponding footages of film printed. Unfortunately, the records do not apportion the wet gate perc consumption or the film footage between the two types of printers. Facility C uses perchloroethylene in three machines to clean 16 and 35 mm film.[9] For seven to ten months per machine, the facility recorded the amounts of makeup solvent and the corresponding operating hours. It also recorded similar information for an isopropyl alcohol film cleaner and for three wet gate contact printers.

To obtain an indication of the variability in the emission factors, each monthly record at a given plant was treated as a separate "test run." Emission factors were calculated by the following formula:

$$EF = 1000\, \rho G/F \qquad [3\text{-}1]$$

where

ρ = Solvent density (lb/gal)

G = Gallons consumed per time period

F = Feet film processed during the same time period

In Equation 3-1, 1000 converts the units of the emission factor to lb/1000 ft. The densities of perchloroethylene and isopropyl alcohol are 13.5 and 6.581 lb/gal, respectively.

Table 3-18 shows the mean emission factor for each case, along with its 95-percent confidence interval. Although the film cleaner emission factor for perchloroethylene varies somewhat from machine to machine, the differences in means are not statistically significant at the 95-percent confidence level. From this very limited data set, it does not appear that film cleaning speed influences the emission factor.

There does, however, appear to be a relationship between printing speed and the emission factor for the three contact printers at Facility C. Figure 3-11 shows the three mean emission factors, each of which has a fairly tight confidence interval. The emission factor for the group of printers at Facility B is considerably higher than the ones calculated for Facility C. Without more information on the printers at Facility B it is not possible to determine the reason for this difference.

[8] To conserve anonymity, the identities of the facilities will not be revealed.
[9] The breakdown between the two film sizes was not reported.

Table 3-18

EMISSION FACTORS CALCULATED FROM MONTHLY FACILITY DATA

Facility	Type of Device	Film Size (mm)	Process Rate (ft/min)	No. of Data Points	Emission Factor (lb/1000 ft) Mean	Lower Bound	Upper Bound
A	Film Cleaner	35	92.1	12	0.32	0.31	0.33
B	Printers	Unknown	70[a]	13	2.60	1.83	3.38
C	Contact Printer	16/35	60	14	0.18	0.13	0.23
	Contact Printer	16/35	180	14	0.032	0.022	0.043
	Contact Printer	16/35	90	14	0.083	0.059	0.11
	Film Cleaner	16/35	85	7	0.40	0.29	0.50
	Film Cleaner	16/35	150	10	0.26	0.19	0.33
	Film Cleaner	16/35	85	7	0.26	0.12	0.39
	Film Cleaner[b]	16/35	85	4	0.11	0.082	0.13

[a]Mean value estimated from facility data; 95-percent confidence interval is 58 - 82 ft/min.

[b]Emissions are of isopropyl alcohol.

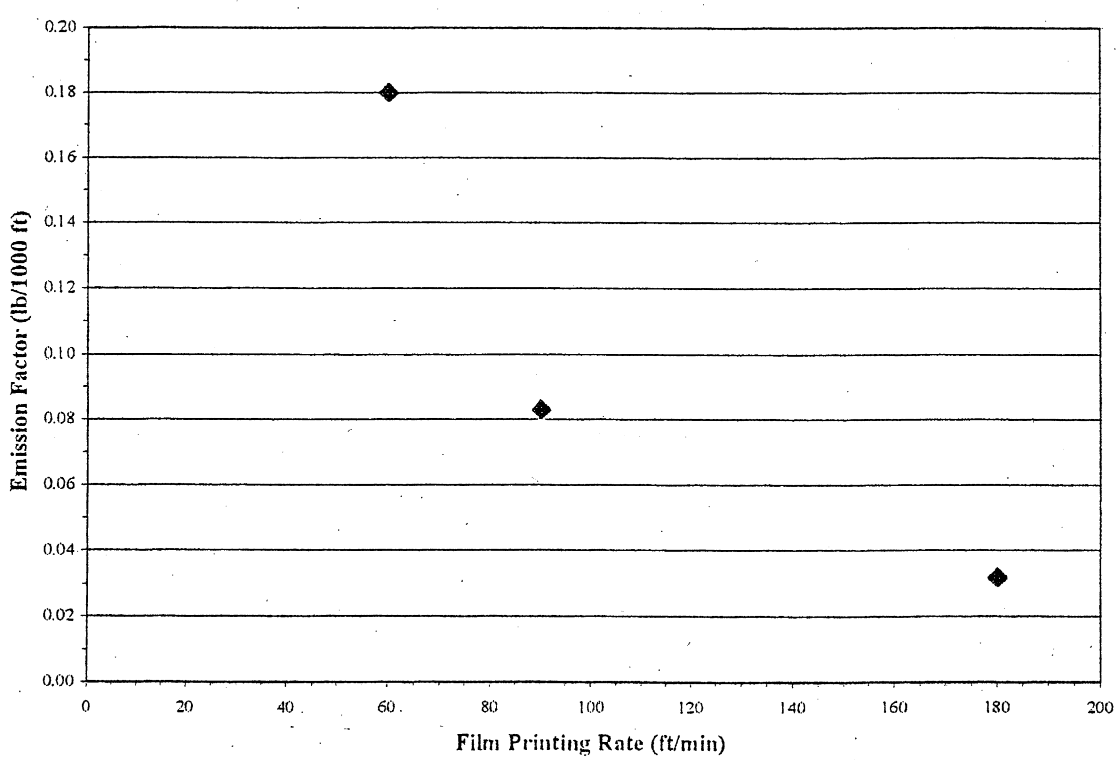

Figure 3-11. Emission Factors for Contact Printing at "Facility C."

3.7.2 Emission Factors From Annual Process Values

Emission factors were also derived from a subset of the annual film footage and solvent consumption values reported by the facilities. The analysis excluded equipment for which either the footage or the solvent consumption was unknown. It also excluded cases in which the solvent mileage had been assumed. A Grubbs test for outliers (Taylor, 1987) was applied to each data set. If the minimum was too low or the maximum was too high (with a 1-percent risk of false rejection), it was discarded. The process was continued until the Grubbs test did not indicate the need to reject any further extreme values.

Figure 3-12 shows the mean and 95-percent confidence limits for the emission factors for 35-mm contact and optical wet gate printing. A Student's t-test showed that the difference in means for the two types of printer is not statistically significant at the 95-percent confidence level ($t = 0.2999$, $t_{crit} = 2.0181$, d.f. = 42). Note that the wet gate printing emission factors determined in Section 3.7.1 are all outside the confidence limits shown in Figure 3-12. The reason for this is unknown. There were not enough usable data to determine emission factors for 70-mm wet gate printing.

Figure 3-13 shows the mean and 95-percent confidence limits for the emission factors for 35- and 70-mm film cleaning with perchloroethylene. The emission factors for 35- and 70-mm film sizes were 0.39 and 0.23 lb/1000 ft, respectively. A Student's t-test showed that the difference between these means is statistically significant at the 98-percent confidence level ($t = 2.5705$, $t_{crit} = 2.0930$, d.f. = 19). The results presented in Section 3.7.1 for film cleaners are consistent with the ranges shown in Figure 3-13.

The mean and 95-percent confidence limits of the emission factor for film cleaning with isopropyl alcohol[10] were 0.18 and 0.035 – 0.32, respectively. The emission factor developed for the one machine in Section 3.7.1 fits within these limits.

[10] All the machines cleaned 16 or 35 mm film.

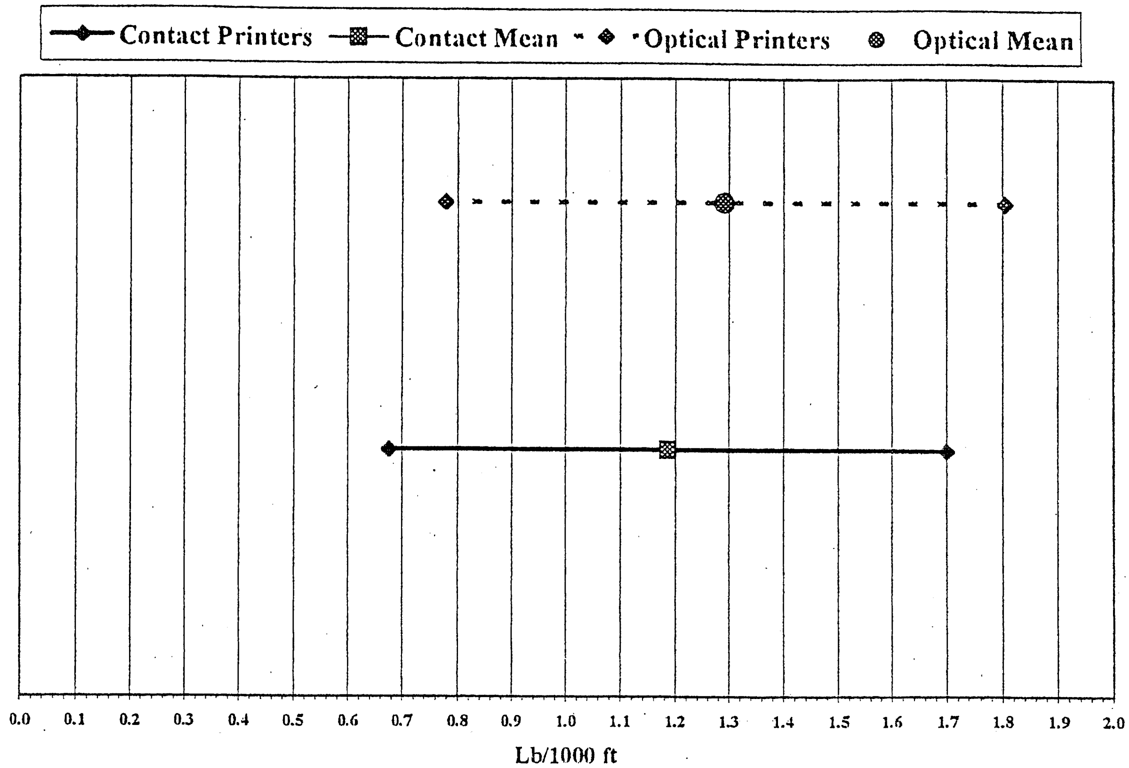

Figure 3-12. Means and 95% Confidence Limits for Emission Factors for Wet Gate Printing.

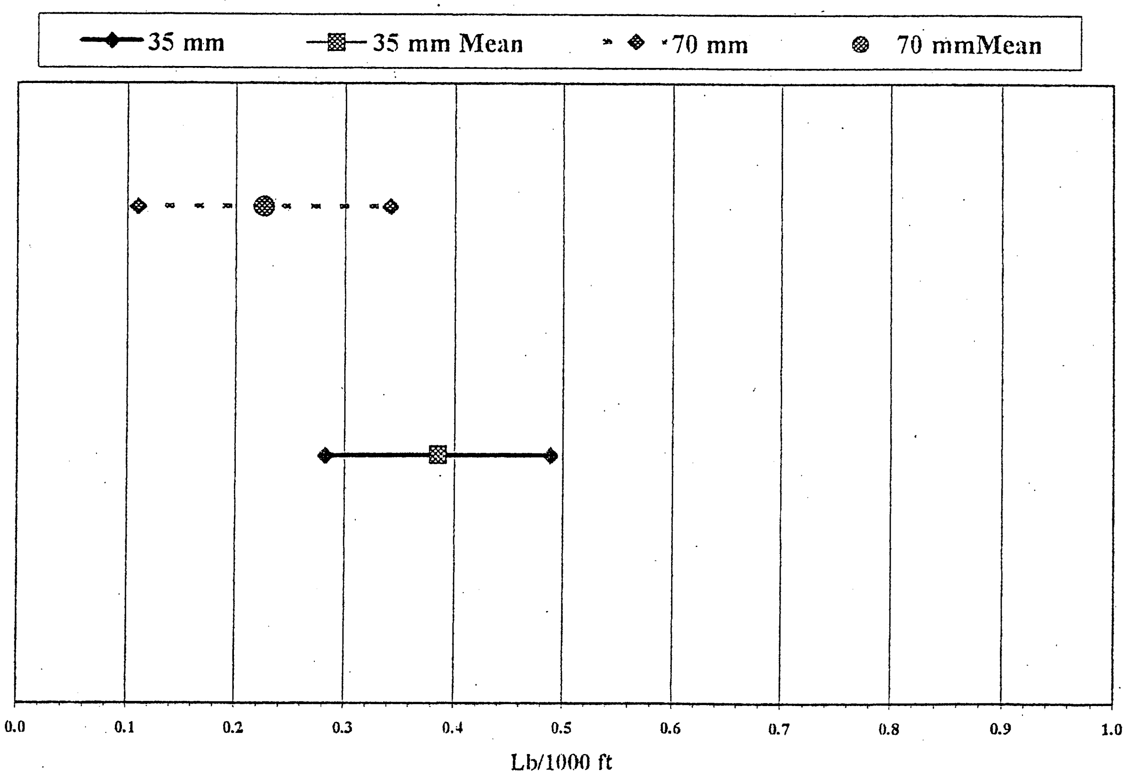

Figure 3-13. Means and 95% Confidence Limits for Emission Factors for Film Cleaning With Perchloroethylene.

3.7.3 Discussion

The means and confidence limits presented in the previous section can be used to gauge the uncertainty in emission estimates based on the emission factors developed here. The least uncertain estimates (± 27 %) would be for cleaning 35-mm film with perchloroethylene. The most uncertain estimates (± 81 %) would be for film cleaning with isopropyl alcohol.

Uncertainty in emission factors may be the product of two types of causes. First, fugitive emission rates may vary from one machine to another, as a result of differing maintenance practices, film processing speeds, performance of vapor condensing equipment, bath temperature and other factors, many of which are as yet unidentified. The other main cause of uncertainty is in the measurement or estimation of the two variables from which the emission factors are derived: volume of solvent consumed and length of film processed. Many of the estimates of annual footage were obtained by multiplying a "typical" value of feet per day by the number of operating days per year. No information about the uncertainty in the daily footage value was available. Similarly, annual solvent consumption was sometimes extrapolated to one year from a several months' actual data.

As an illustration of the consequence of uncertainty in the underlying data, supposed that the reported perc consumption and footage cleaned were 300 gallons and 10 million feet, respectively. The resulting emission factor would be $(1000)(13.5)(300)/10^8 = 0.405$ lb/1000 ft. Now suppose that the two process variables were correct within 10 percent of their reported values. The range of estimates of the emission factor would be:

$$\text{Low} = (1000)(13.5)(270)/(11 \times 10^6) = 0.331 \text{ lb/1000 ft}$$

$$\text{High} = (1000)(13.5)(330)/(9 \times 10^6) = 0.495 \text{ lb/1000 ft}$$

Given the uncertainty in the estimates of the process variables, the emission factor of 0.405 lb/1000 ft could be 18 percent low or 22 percent high.

In light of these uncertainties, the emission factors developed here should be applied with caution to the cases of individual pieces of equipment, such as in permit applications and health risk assessments. They are, however, useful for planning purposes.

4.0
RISK REDUCTION MEASURES

One of the objectives of this project was to "identify, evaluate and recommend control equipment, material substitution, process change, and other means for reducing risk due to air toxics emissions from this industry." In this report, "risk" is understood to include both cancer risk and acute and chronic noncancer health risk, to the communities near motion picture film processing facilities. As most of the facilities in the inventory are in or near residential areas, and are not likely to relocate, the only practical means of risk reduction is to decrease emissions of toxic air contaminants.

Through the survey it became evident that the industry has already adopted several means of reducing risk, including installation of emission control equipment and, to a limited extent, switching to less toxic solvents. For example, as was shown in Section 3.6, perchloroethylene emissions from wet gate printing of 70 mm film are essentially all treated by carbon adsorption. There is still, however, considerable room for improvement, especially in film cleaning and wet gate optical printing.

Section 4.1 briefly reviews current risk reduction measures. Alternative measures under active consideration (and limited application) are discussed in Section 4.2. Finally, some alternative risk reduction scenarios are presented and evaluated in Section 4.3.

4.1 REVIEW OF CURRENT RISK REDUCTION MEASURES

Whether in response to regulatory mandates or to reduce operating costs, the motion picture film laboratory industry has already implemented several types of risk reduction measures. These include:

- In-machine recovery and recycling (for film cleaning);
- "Add-on" controls;
- Solvent substitution; and
- Improved maintenance practices

4.1.1 In-Machine Recovery and Recycling

The great majority of film cleaning machines that use chlorinated solvents use built-in vapor condensation systems for primary emission control. Vapors from the heated immersion tank are condensed on refrigerated cooling coils. The condensate is later distilled, filtered, desiccated and saved for future use. The same equipment can be used to distill and recover solvent sludge. As long as the equipment is properly maintained and operated, the same solvent can be reused numerous times, reducing the need for replacement.

A similar recovery and recycling system is used for film cleaning with HFE 7200. However, only two of the twelve machines that use isopropyl alcohol are capable of recovering solvent,[1] and none of the other cleaning solvents is recycled.

The survey found only one wet gate (serving a telecine machine) whose vapors were recovered.

4.1.2 "Add-On" Controls

Except for the one wet gate telecine machine in the survey, the only type of "add-on" control device observed was the carbon adsorber. Other common organic pollutant control devices have obvious drawbacks. Incineration of chlorinated solvents can generate hydrochloric acid and other undesirable products of incomplete combustion. Additional refrigeration beyond that provided by the cleaning machines' primary controls is not likely to be economical.

Eight film cleaning machines (at five facilities) and eleven wet gate printers (at five facilities) are served by once-through, disposable canister systems. In these devices, vapors are drawn through one or more beds containing activated carbon. For a given type and granular size of activated carbon, the amount of solvent that can be adsorbed onto and retained in the carbon bed depends upon the pollutant concentration and the temperature. After the bed's capacity is reached, the solvent begins to desorb. Facilities having these devices usually monitor the pollutant's concentration in the exhaust from the carbon bed; when it reaches a given level, then a new bed is installed and the old one is taken away for regeneration. Carbon recyclers do not recover the adsorbed solvent from the carbon. They heat the carbon to reactivate it, and the heating drives off the solvent (which is treated by an afterburner).

Regenerative carbon adsorbers are used to control emissions from 11 film cleaning machines (at 2 facilities) and 37 wet gate printers (at 5 facilities). Steam is passed through the carbon to desorb the solvent. These devices require at least two beds; one is used to treat emissions while the other is being desorbed. The solvent and the steam condensate are then separated. In this industry, it is very important to remove as much water as possible, as it has a deleterious effect on film emulsions. The separation should be at as low a temperature as is practicable, because the higher the temperature, the more soluble the two compounds are in each other (Fasci, 2000).

4.1.3 Solvent Substitution

There is currently no practical substitute for perchloroethylene in wet gate printing. One facility uses a mixture of perc and a volatile organic compound[2] in its wet gates. The admixed compound does not have a favorable refractive index (see Section 4.2.2) and has other undesirable properties, but its use does reduce the consumption (and emissions) of perc.

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[1] Whether they do recover it is unknown.

[2] The identity of the compound is confidential.

As was seen in Section 3.4.1, the alternatives to perc and 1,1,1-trichloroethane that are currently used for film cleaning in the AQMD include isopropyl alcohol, hexane, hydrotreated naphtha, and HFE 7200.[3] These compounds account for about 30 percent of the total volume used. They, along with other alternative solvents, will be discussed further in Section 4.2.2.

4.1.4 Maintenance Practices

Significant fugitive emissions can occur from poor maintenance practices, including improper solvent storage and handling. However, no evidence of grossly inadequate maintenance practices (as are often seen in other industries) was observed during the site visits. Indeed, many steps are taken to minimize solvent losses. For example, perchloroethylene is typically delivered to film cleaning machines from sealed, pressurized drums. When a sensor in the cleaning machine determines that the liquid level in the machine's reservoir is too low, a solenoid valve opens and solvent flows out from the drum. When the reservoir is full, the valve closes.

Many motion picture film laboratories contract with maintenance companies to perform routine maintenance operations at fixed time intervals. The maintenance technician checks and replaces buffers and filters and sometimes performs repairs. Two potentially significant leak sources on a film cleaning machine are the spray jets and the air knife (Tisch, 1999b). Routine maintenance often includes checking and adjusting these elements.

Recordkeeping practices in the surveyed facilities range from poor (or nonexistent) to outstanding. There is generally no way to monitor solvent delivery to individual machines, since the delivery systems are not metered. The amount of solvent remaining in a drum could be determined by weighing the drum, but this is rarely done. Many cleaning machines have totalizing hour meters, which many facilities read periodically. Given the film speed (which is set by the operator) and a difference between successive hour meter readings, one can calculate the footage of film cleaned. Other facilities record the number and/or lengths of film reels cleaned on their machines.

Although recordkeeping practices in many facilities could be improved, most of the emission reductions achievable through better operating and maintenance procedures have already being realized. This approach was not explored further.

4.1.5 NESHAP Requirements

On December 3, 1999, the U.S. Environmental Protection Agency (USEPA) amended its National Emission Standards for Halogenated Solvent Cleaning (40 CFR Part 63, Subpart T) to include "continuous web cleaning machines," such as motion picture film cleaning machines. The standard applies to cleaning with one or more of six chlorinated solvents, including 1,1,1-trichloroethane and perchloroethylene. Under this

[3] Other solvents, such as AK-225 and HFE-43-10 mee, have been used by at least one laboratory in the AQMD during the past few years, but, to the best of the contractor's knowledge, are not used as of this writing.

national emission standard for hazardous air pollutants (NESHAP), "existing machines" are those placed in service before November 29, 1993 and "new" machines are those placed in service on or after that date. According to the results of this survey, most of the film cleaners in the Basin would qualify as new under the NESHAP.

The NESHAP's requirements depend upon how the machine is classified under its provisions. A film cleaning machine is considered to be a subset of "in-line solvent cleaning machines" and is not a "remote reservoir continuous web cleaning machine" (Almodovar, 2000). Because of this classification, the most important sections of the NESHAP for the purposes of this analysis are 40 CFR 63.463(g) and its alternative, 40 CFR 63.464. These will now be discussed.

Unless an alternative compliance option is chosen (see below), all "new" halogenated solvent film cleaning machines must use one of the following three emission control approaches [40 CFR 463(g)(1)(ii)]:

(A) Superheated vapor or superheated part technology, and a freeboard refrigeration device;

(B) A freeboard refrigeration device and a carbon adsorber with a capture-and-removal efficiency of at least 70 percent, and an exhaust concentration less than 100 ppm; or

(C) Superheated vapor or superheated part technology and a carbon adsorber

Because the film cleaning machines currently in use do not use superheated vapor or superheated part technology, only option B would apply. Most film cleaners using 1,1,1-trichloroethane or perchloroethylene already have freeboard refrigeration devices, but most of them are not vented to carbon adsorbers. From the contractor's review of the survey responses and the AQMD permit files for several facilities, it appears that the carbon adsorption systems currently in use satisfy the removal efficiency and exhaust concentration requirements. In addition, most facilities appear to be substantially in compliance with the operations and maintenance requirements of 40 CFR 463(g), which will not be detailed here.

A key question is whether a facility can comply with the NESHAP without needing to add a carbon adsorption system. An alternative set of standards is contained in 40 CFR 63.464. The key requirements for film cleaning machines are:

- The owner must maintain a log of solvent additions and deletions for each machine;

- The three-month rolling average emissions from the machine cannot exceed 153 kilograms per square meter per month (kg/m^2-mo) for existing machines or 99 kg/m^2-mo for new machines; and

- Exceedances of the emission limits must be reported

The owner of a film cleaning machine can also comply with the standard by demonstrating, through a method detailed in the NESHAP, that the overall cleaning system control efficiency is at least 70 percent.

Data for determining whether currently used film cleaning machines meet this alternative standard are currently unavailable.

4.2 IDENTIFICATION OF RISK REDUCTION ALTERNATIVES

4.2.1 Wet Gate Printing

Any substitute for perchloroethylene in wet gate printing must, at a minimum:

- Have an acceptable index of refraction;
- Not damage film; and
- Pose less of a community and occupational health risk than perc

The index of refraction of a substance is the ratio of the velocity of propagation of light waves in a vacuum to their velocity of propagation in the substance (Gray, 1963). Figure 4-1 shows a ray of light passing from one medium to another. Medium 1 could be the wet gate fluid and Medium 2 could be the film, or vice versa. As seen in the figure, the incident light changes direction (is "refracted") as it passes through the interface between the two media. The amount of bending is governed by Snell's law, which states (USGSA, 1996):

$$n_1 \sin \Theta_1 = n_2 \sin \Theta_2$$

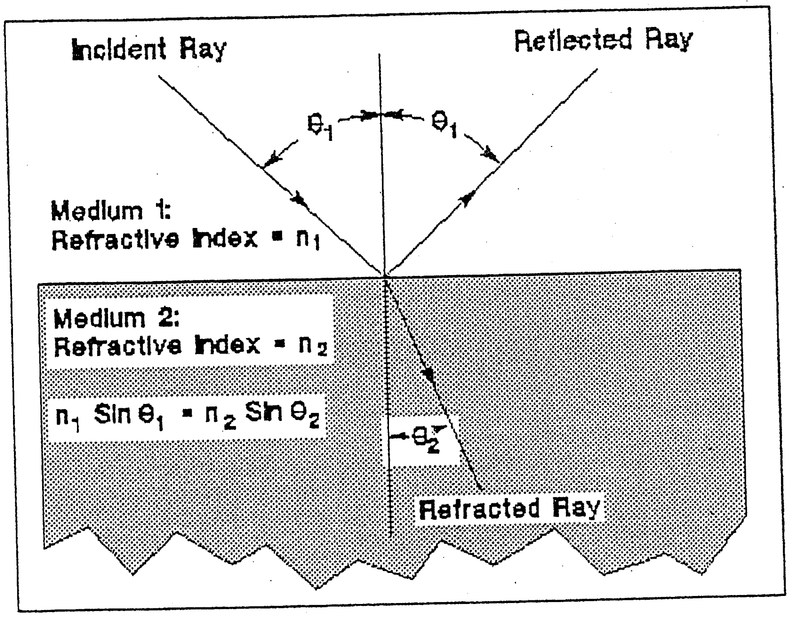
where

n_1, n_2 = Index of refraction of medium 1, medium 2

Θ_1 = Angle (with respect to the normal) at which the incident ray strikes the boundary

Θ_2 = Angle (with respect to the normal) at which the refracted ray travels

To minimize the scattering of light from scratches and other imperfections in the film, it is desirable that Θ_1 and Θ_2 be as close to each other as possible; in the ideal case, they would be equal. By Snell's law, then, the index of refraction of the wet gate medium should be as close as possible to the index of refraction of the film.



Snell's law

Figure 4-1. Refraction of Light and Snell's Law (USGSA, 1996).

The index of refraction of cellulose acetate, a common film base, is 1.46 to 1.50 (Bolz and Tuve, 1976). The index of refraction of perchloroethylene at 20°C is 1.5055 (Budavari et al., 1996). Suppose that, in an optical printer, light shines through the film into a wet gate fluid between the negative and the film to be printed. If the incident angle is 1°, and the wet gate fluid is perchloroethylene, then by Snell's Law, the refracted angle is 0.983°, a difference of only 0.017°.

To date, the only perc substitute used for commercial wet gate printing is isobutylbenzene (CAS 538-93-2). Isobutylbenzene (IBB) has a refractive index of 1.4928 (Budavari et al., 1996), which is close to that of perc. For the preceding example, the refracted angle would be 0.991° if IBB were the wet gate fluid; the difference would be 0.009°, which would be less diffraction than when perc is used.

IBB is used for printing at a laboratory in Sweden. A person familiar with the Swedish operation told the contractor that IBB works well and does not leave a residue on the film (Orhall, 1999). A Dutch film laboratory is considering switching to the compound for printing, but has not had time to modify its printing equipment and test the chemical (Treuren, 2000).

Some operational problems may be associated with use of isobutylbenzene in wet gate printing. It reportedly has a longer drying time than perc, so film must be printed at lower speeds (Pettrone, 2000; Treuren, 1999). A representative of a film cleaning machine manufacturer stated that IBB <u>does</u> leave a residue (Tisch, 1999a).

Concern over worker health and safety has been expressed. Isobutylbenzene has a National Fire Protection Association (NFPA) flammability rating of 2, indicating that it "must be moderately heated or exposed to relatively high ambient temperatures before ignition can occur" (CDC, 2000). IBB's flash point is 131°F (Sax and Lewis, 1989), while the temperature in the wet gate is normally about 85°F (Little, 2000). Concern has been expressed about the use of IBB to print highly combustible nitrate film.[4] In the one known use of IBB for wet gate printing, the local fire department found no potential fire danger (Orhall, 2000). IBB has a NFPA reactivity rating of 0, which means that it is "normally stable, even under fire conditions, and ... not reactive with water" (UK, undated). The contractor is unaware of any mechanism by which IBB could decompose in the atmosphere to benzene or other toxic air contaminants.

Exposure to isobutylbenzene may result in eye, skin, or lung irritation (Fisher Scientific, Inc., 1999). Inhalation at high doses may cause central nervous system depression and asphyxiation. However, IBB is not the subject of any Federal or State environmental or occupational exposure limitations, and has not been listed as a carcinogen by any governmental agency.

4.2.2 Film Cleaning

Some requirements for a good film cleaning solvent are (Orhall, 1995):

- Not a health or environmental hazard
- Not a fire hazard
- Colorless
- Good film wetting properties
- Not viscous
- Does not dissolve or react with the film base
- Does not react with or extract components of the emulsion
- Not corrosive to equipment
- Easily removed from the film surface
- Not too volatile
- Not exorbitantly expensive

Another consideration in evaluating alternative film cleaning solvents is the type of cleaning that is to be performed. For example, isopropyl alcohol can be (and is) substituted for perc for cleaning films contaminated with dust particles but not with large amounts of organic matter. The alcohol will not remove the organic material well enough. Isopropyl alcohol is used mainly in post production facilities, such as telecine houses.

Eastman Kodak Company has tested a variety of film cleaning solvents and has posted a summary of its findings on the Internet (Kodak, 2000). Table 4-1 contains some of the data from the most recent posting. The Kodak table was used to identify solvents for further investigation in this project. They are discussed later in this section.

[4] The identity of the laboratory expressing this concern is confidential.

Table 4-1

POTENTIAL SUBSTITUTES FOR PERCHLOROETHYLENE IN MOTION PICTURE FILM CLEANING

Trade Name	Compound	Manufacturer	Flash Point °F	Cleaning Ability[a]	Cost per Pound	Evaporation Rate	VOC	Comments
HFE 7100	Methyl nonafluorobutyl ether/ Methyl nonafluoroisobutyl ether	3M	None	Adequate	\$10 - \$20	High	No	Not an ODC[b]
HFE 7200	Ethyl perfluoroisobutyl ether/ Ethyl perfluorobutyl ether	3M	None	Adequate	\$10 - \$20	High	No	Not an ODC
Vertrel (HFC 43-10 mee)	1,1,1,2,3,4,4,5,5,5-decafluoropentane	DuPont	None	Adequate	\$10 - \$20	High	No	Low odor
ASAHI KLIN AK-225	3,3-dichloro-1,1,1,2,2-pentafluoropropane (HCFC 225ca)	Asahi	None	Good	\$10 - \$20	High	No	ODC (2015 phaseout)
Isopropanol	Isopropanol	Various	53	Good	\$1 - \$5	High	Yes	Flammable, low odor Gathers water
Isobutyl benzene	Isobutylbenzene	Various	131	Good	\$1 - \$5	Low	Yes	Combustible, persis-tent odor
ACTREL 1064 L	Hydrocarbon mixture	Exxon	147	Good	\$5 - \$10	Low	Yes	Combustible, slight ester odor
Hydrocarbon Type Film Cleaner 40	Hydrotreated naphtha	Signal Inc.	104	Excellent	\$1 - \$5	Low	Yes	Combustible

Source: Kodak, 2000.

[a]See text.

[b]ODC = Ozone-depleting compound.

Table 4-2 summarizes pertinent physical properties of existing and alternative film cleaning solvents. A few generalizations can be made about these properties. Solvents with high **boiling points** tend to have longer drying times; on the other hand, they are less volatile and easier to condense. The **density** must be taken into account when estimating mass emissions; if two solvents have the same mileage (feet per gallon), the one with lower density will have lower emissions per foot of film cleaned. Solvents with higher **surface tension** are harder to rinse from the objects being cleaned than are those with lower surface tension. The **kauri butanol** (KB) value is one measure of the ability of a solvent to dissolve organic material; the higher the KB value, the better. However, it should be pointed out that there is no ASTM method or other standard method to measure film cleaning ability. For the "Cleaning Ability" judgments in Table 4-1, Kodak prepared its own film samples with the types of contamination that it wished to test (Pettrone, 2000).

The **vapor pressure** of a solvent is a measure of its tendency to volatilize. Substances with high vapor pressure dry more quickly, and tend to leave less of a residue, than do substances with lower vapor pressures. Note that Table 4-2 gives values only for 20°C or 25°C, and that the increase in vapor pressure at higher temperatures (such as in a film cleaning machine) varies widely from compound to compound. The **solubility of water** in a solvent is of concern because of the adverse effects of water on emulsions. The **solubility in water** is a measure of the ease of separation of the water and solvent, e.g. in the condensate from steam stripping of a carbon adsorption bed. The **viscosity** affects the amount of energy needed to transport fluids; the more viscous the fluid, the higher the energy requirement. A chemical is called flammable if its **flash point** is less than 100°F and combustible if its flash point is greater than that value. The **relative evaporation rate (RER)** is the ratio of a solvent's mass emission rate (at a given temperature) to that of n-butyl acetate; the higher the RER, the faster a substance will evaporate.

The **ozone depletion potential (ODP)** is a measure of the reactivity of a compound with stratospheric ozone. For reference, the ODP of CFC-11 is 1.0. The **global warming potential (GWP)** characterizes a substance's tendency to behave as a greenhouse gas (i.e. to prevent long-wave radiation from leaving the atmosphere) over a 100-year lifetime in the atmosphere; the reference point is 1 for carbon dioxide.

Table 4-3 summarizes the regulatory status of currently used and potential alternative film cleaning solvents. Note that the AQMD requires a permit for film cleaning with any of the solvents listed.

Table 4-2

PHYSICAL PROPERTIES OF ALTERNATIVE FILM CLEANING SOLVENTS

Parameter	Units	1,1,1-Trichloroethane	Perchloroethylene	HFE 7200	AK 225	Vertrel XF	Isobutylbenzene	Hydrotreated Naptha	Isopropyl Alcohol
Boiling Point	°C	74	121	78	54	55	173	154 - 177	82.5
	°F	165	250	172	129	130	343	309 - 351	180
Density	lb/gal	11.0	13.5	11.9	12.9	13.2	7.12	6.25	6.58
Surface Tension	dynes/cm	25.1	31.7	13.6	16.2	14.1			21.7
Kauri Butanol Value		124	90	10	31	9		109	
Vapor Pressure at 25°C	mm Hg	130	18.5	109	285	176		2.3	33
Solubility of Water	ppm			92	310	490			
Solubility in Water	ppm	4,400	150	<20	330	140	Insoluble	<1,000	Miscible
Viscosity at 25°C	cps	0.83		0.61	0.59	0.67	1.05	0.80	
Flash Point	°C	None	None	None	None	None	55	40	11.7
	°F	None	None	None	None	None	131	104	53
Relative Evaporation Rate	None	12.8	0.33[a]				<1[b]	0.35	2.8
Ozone Depleting Potential		0.1		0.0	0.03	0.0	None	None	None
Global Warming Potential		110		90	370	0.25	None	None	None

[a]With respect to trichloroethylene.

[b]With respect to ethyl ether.

Table 4-3

REGULATORY STATUS OF ALTERNATIVE FILM CLEANING SOLVENTS

Regulatory Attribute	1,1,-TCA	Perc	HFE 7200	AK-225	IPA	IBB	Hydro treated Naptha
Volatile Organic Compound	No	No	No	No	Yes	Yes	Yes
Ozone Depleter	Yes	No	No	Yes	No	No	No
Global Warming Compound	Yes	No Data	Yes	Yes	No	No	No
Unit Risk Factor (Cancer)[a]	None	5.9×10^{-6}	None	None	None	None	None
Acute Non-Cancer Reference Exposure Level[b]	68,000	20,000	None	None	3,200	None	None
Chronic Non-Cancer Reference Exposure Level[c]	None	40	None	None	7,000[d]	None	None
Subject to NESHAP	Yes	Yes	No	No	No	No	No
AB 2588 Pollutant	Yes	Yes	No	No	Yes	No	No
Requires AQMD Permit	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rule 1401/1402 Compound	Yes	Yes	No	No	Yes	No	No

[a]Source: AQMD, 1999b. Units are $(\mu g/m^3)^{-1}$.

[b]Source: AQMD, 1999a. Units are $\mu g/m^3$.

[c]Source: AQMD, 1999b. Units are $\mu g/m^3$.

[d]Proposed for implementation under Rule 1401.

Some of the alternative film cleaning solvents will now be described in more detail. The intention is not to recommend any particular alternative, but rather to summarize available information.

HFE 7200

3M Company has synthesized a family of hydrofluoroethers (HFEs) for use in degreasing and other types of cleaning, and is now actively marketing the compounds (3M, 1998a, 1998b). The compounds of interest to this study are ethyl perfluoroisobutyl ether and ethyl perfluorobutyl ether, which both have the formula $C_4F_9OC_2H_5$ (CAS 163702-06-5 and 163702-05-4), and have the trade name HFE 7200. Among HFE 7200's desirable properties are:

- No ozone depletion;
- Not a VOC
- Higher boiling point than 1,1,1-trichloroethane; and
- Relatively low toxicity

Eastman Kodak Company performed tests on HFE 7200, perchloroethylene and 1,1,1-trichloroethane to examine their tendency to leach triphenylphosphate plasticizer from acetate film (Pettrone, 1999). The HFE 7200 caused the least leaching.

RTI/Lipsner Smith Company has developed a new film cleaning machine, the CF8200, specifically for use with HFE 7200 (Lipsner Smith, 1999; Tisch, 1999c). Because HFE 7200's solvent power is less than that of perchloroethylene, the new machine incorporates increased ultrasonic energy. It was also necessary to replace nylon tubing with copper and Viton gasketry with Teflon and Teflon-coated Viton, because of HFE 7200's tendency to degrade the older machine's materials. Note that it is possible to modify the Model CF3000-MKVI and the Model CF7200 for use with HFE 7200.

Tests were recently conducted by RTI/Lipsner Smith Company, 3M and Eastman Kodak Company at one of the laboratories in the inventory[5] to evaluate the performance and costs of HFE 7200. The laboratory was pleased with the results and told the contractor that film processing speed increased significantly.

HFE is considerably more expensive than perchloroethylene. Prices range from $17 to $20 per pound, although discounts for large-volume purchases are likely.

AK-225

Asahiklin AK-225 is the trade name for a mixture of two hydrochlorofluorocarbons, 3,3-dichloro-1,1,1,2,2-pentafluoropropane (CAS 422-56-0), also known as HCFC-225ca; and 1,3-dichloro-1,1,2,2,3-pentafluoropropane (CAS 507-55-1, also known as HCFC-225cb. Manufactured in Japan, the product has been marketed in the U.S. since 1994, chiefly as a replacement for CFC-113 in precision cleaning operations (Levin, 2000). Although the material is relatively expensive ($12.50 to $14.00 per pound), it can be readily recovered, distilled and recycled at the point of use.

In cleaning tests performed for the National Aeronautics and Space Administration (NASA), HCFC-225 showed better cleaning performance than trichloroethylene, perc and ethanol (Biesinger and Beeson, 1995). Eastman Kodak Company tested Asahiklin AK-225 solvent in a Lipsner Smith CF3000-Mark VI film cleaning machine. Various negative, intermediate and positive films were run through the machine up to ten times and examined for changes in dimensional and dye stability. No changes in the film stability were found (Kurz, 1995).

HCFC-225 has not been listed as a carcinogen. Asahi Glass Company has set an acceptable exposure level of 50 ppm for an 8-hour time-weighted average (AGC, 1999). The product is not considered a VOC by AQMD Rule 102. As a hydrochlorofluorocarbon, it has less ozone depletion potential than the chlorofluorocarbons it replaces, but is scheduled for phaseout by 2015. As is the case with HFE 7200, equipment using HCFC-225 must have Viton parts retrofitted with polytetrafluoroethylene (PTFE) seals, gaskets and o-rings, since the solvent swells fluorinated elastomers (AGC, Undated).

The contractor is aware of two laboratories in the Basin that may have used AK-225 for film cleaning. One laboratory recently used a solution of AK-225 and isopropyl

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[5] The identity of the laboratory is confidential.

alcohol for film cleaning for several months.[5] According to this laboratory, the mixture reportedly cleaned grease, fingerprints and other organic contaminants more effectively than HFE 7200 but not as well as 1,1,1-trichloroethane or perc. The other laboratory has a permit to use AK-225 but is not currently using it.

HFC-43-10 mee

HFC-43-10 mee is manufactured by DuPont Fluorochemicals under the trade name Vertrel® XF. It is also known as 1,1,1,2,2,3,4,5,5,5-decafluoropentane or 2,3-dihydroperfluoropentane. Used alone or in various azeotropic blends, Vertrel XF was designed as a replacement for CFC-113 in vapor degreasing. Advantages of HFC-43-10 mee are its high vapor pressure and the fact it is not a VOC, an ozone depleting compound or a hazardous air pollutant. It does have a global warming potential, however (one fourth that of carbon dioxide). The suitability of this compound for cleaning film is uncertain. Kodak rated it as "adequate," and, according to DuPont, "neat Vertrel® XF has limited solvency for many higher molecular weight materials, such as hydrocarbon oils, silicone oils, waxes and greases" (DuPont, 1998). A 90:10 mixture of HFC-43-10 mee and isopropyl alcohol is available under the trade name Vertrel® X-P10. The mixture is not an azeotrope but DuPont states that "compositional changes stabilize within the safe operating range."

The contractor is aware of one laboratory in the Basin that has a permit to use Vertrel® XF and/or Vertrel® XM (a blend with methanol) in film cleaners. The laboratory is not presently using either product.

Isobutylbenzene

Isobutylbenzene was introduced in the previous section as a potential wet gate fluid. The compound is currently being used by a laboratory in Sweden for film cleaning (Orhall, 1995). Experience in cleaning film has generally been good. Problems with IBB are an unpleasant odor and a corrosive effect on some rubber and plastic materials. Seals, gaskets and other cleaning machine components need to be replaced with Viton®, Teflon®, or Neoprene®. In addition, concern has been expressed that the temperature of the air knives in film cleaning machines is close to the flash point of IBB.[3] Note, however, that the flash point of isopropyl alcohol is lower than that of IBB, and experience has shown that it can be used safely for film cleaning.

Hydrotreated Naphtha

Hydrotreated naphtha (CAS 64742-48-9) is a mixture of aliphatic hydrocarbons. A mixture formulated specifically for motion picture film cleaning is manufactured by Signal, Inc. in Canada (Picha, 2000). As was discussed in Section 3, one film laboratory in the Basin uses the compound.[6] Favorable characteristics of the solvent, according to the manufacturer (Signal, Inc., Undated), include:

[6] The supplier of the hydrotreated naphtha used by this facility was not reported.

- Not an ozone depleter
- More stable than 1,1,1-trichloroethane; will not hydrolyze or oxidize in air;
- Not reportable under SARA Title III, Section 313;
- Does not remove plasticizers from triacetate film base;
- Not a suspected carcinogen or hazardous air pollutant; and
- No changes in dye stability in accelerated aging tests

One potential problem with hydrotreated naphtha is its low flash point. The manufacturer recommends that cleaning be conducted at 82°F or below.

Sanlab Systems in Toronto, ON (Canada) manufactures a film cleaning machine that uses hydrotreated naphtha (Wayne, 2000). The machine uses 12 particle transfer rollers (PTRs) to remove surface dirt; the wet cleaning portion is optional. After the PTRs, the film passes through a static electricity removal unit, in which radioactive polonium ionizes the surrounding air; any charge remaining on the film is neutralized. The hydrotreated naphtha is applied to the film by two buffers, then removed by two sets of two buffers each. The maximum film throughput is 125 ft/min, although the machine normally operates at about 100 ft/min. According to the manufacturer, this device can clean all but the most heavily soiled film. The cost is approximately $14,000. This year, the first sale to a U.S. laboratory was made.

No published data on solvent mileage for the Sanlab machine were available. However, the manufacturer said that one laboratory was able to clean 4,000 feet of film with less than 1 liter of solvent (Wayne, 2000). The corresponding mileage would be >15,140 ft/gal. No attempt is made to recover and recycle the solvent.

According to a laboratory in Toronto that recently purchased a Sanlab cleaning machine, hydrotreated naphtha has a slight odor, which is not nearly as unpleasant as that of perchloroethylene (Stojanovic, 2000).

N-Propyl Bromide

Several years ago, n-propyl bromide (CAS 106-94-5) was discussed as a possible alternative to perc for film cleaning (Lingelbach, 1996; Zwaneveld, 1996). The compound is produced by Albemarle Corporation under the trade name ABZOL, and is used as a drop-in replacement for 1,1,1-trichloroethane in precision cleaning and vapor degreasing (Albemarle Corporation, 1997; Chang, 1999). However, in tests at one laboratory in Burbank[7] n-propyl bromide caused triacetate film to curl, and it is expected to have similar effects on polyester (Estar) based films (Zwaneveld, 1996). In other tests, Eastman Kodak concluded that the solvent curled film and removed plasticizers, even when diluted with other materials (Pettrone, 2000). Finally, in light of reported reproductive problems associated with 2-bromopropane, a contaminant of industrial-grade n-

[7] Laboratory was not identified.

propyl bromide, the Occupational Safety and Health Administration (OSHA) has recommended that both chemical be tested under the National Toxicology Program (Anon., 2000). In conclusion, it is highly unlikely that ABZOL will be used in film cleaning.

4.3 EVALUATION OF ALTERNATIVES

At this writing it appears that, unless a laboratory in the Basin wishes to experiment with isobutylbenzene, there is no commercially available alternative to the use of perchloroethylene in wet gate printing. Some laboratories have asked chemical companies to develop a "new molecule" that would have the appropriate refractive index and other desirable features, but the manufacturers have evidently declined to do so (Pettrone, 2000). Given the apparent successful use of IBB in at least one laboratory, it should be explored further as a near-term substitute for perchloroethylene.

For film cleaning, the only two near-term risk reduction alternatives are increasing the extent to which perchloroethylene emissions are controlled by carbon adsorption, and use of alternative solvents such as HFE 7200, AK-225 or HFC-43-10 mee in new or modified film cleaning machines. These alternatives were evaluated further.

4.3.1 Definition of Scenarios

The cost analysis examined several hypothetical scenarios in which two laboratories (one small, one large) wish to expand their operations by purchasing and using new film cleaning machines. The "base case" consisted of purchasing state-of-the-art film cleaners that use perchloroethylene, with no add-on controls. The objective of the cost analysis was to estimate the *incremental* costs, i.e. the cost over and above the cost of the base case, of various alternative risk reduction strategies.

Table 4-4 defines the scenarios examined. For the small laboratory, the two risk reduction alternatives are secondary emissions treatment using a simple activated carbon

Table 4-4

SCENARIOS EXAMINED FOR COST ANALYSIS

Case No.	No. of Cleaners	Solvent	Add-On Controls
S-B	1	Perchloroethylene	None
S-1	1	Perchloroethylene	Activated carbon canister
S-2	1	HFE-7200	None
L-B	8	Perchloroethylene	None
L-1	8	Perchloroethylene	Carbon adsorption with regeneration
L-2	8	HFE-7200	None
L-3	8	HFE-7200	Carbon adsorption with regeneration

canister system (with no on-site recycling); and use of HFE 7200 in a machine with no add-on controls.[8] For the large laboratory, the choices are use of a regenerative carbon adsorption system (with on-site recycling); use of HFE 7200 in a machine with no add-on controls; and use of HFE 7200 in a machine whose emissions are treated by a regenerative carbon adsorption system. In the last case, the main purpose of the carbon adsorption system is to recover HFE 7200 for re-use, rather than pollution control *per se*.

A canister-type carbon adsorber consists of a vessel, activated carbon, inlet connection and distributor leading to the carbon bed, and an outlet connection for the purified gas stream. The carbon canisters are not intended for desorption on-site. However, the carbon may be regenerated at a central facility. Once the carbon reaches a certain VOC content, the unit is shut down, replaced with another, and disposed of or regenerated by the central facility.

The second type of carbon adsorption unit is a fixed-bed system. Fixed-bed adsorbers may be operated in either *intermittent* or *continuous* modes. In intermittent operation, the adsorber removes the organic contaminant for a specified time (the "adsorption time"), which corresponds to the time during which the controlled source is emitting the pollutant(s) to be controlled. After the adsorber and the source are shut down (*e.g.*, overnight), the unit begins the *desorption* cycle, during which the captured pollutant is removed from the carbon. This cycle, in turn, consists of three steps: (1) *regeneration* of the carbon by heating, generally by blowing steam through the bed in the direction opposite to the gas flow; (2) *drying* of the bed, with compressed air or a fan; and (3) *cooling* the bed to its operating temperature via a fan. (In most designs, the same fan can be used for both bed drying and cooling.) At the end of the desorption cycle (which usually lasts 1 to 1.5 hours), the unit sits idle until the source starts up again. In *continuous* operation, a regenerated carbon bed is always available for adsorption, so that beds can be provided: while one is adsorbing, the second is desorbing or idle. As each bed must be large enough to handle the entire gas flow while adsorbing, twice as much carbon must be provided than for an *intermittent* system handling the same flow.

4.3.2 Incremental Cost Analysis Methods

Table 4-5 lists the major assumptions used in scoping the scenarios and the cost analyses.[9] For the small laboratory scenarios, the general procedures of the USEPA's *OAQPS Control Cost Manual, 5th Edition* (Vatuvak, 1996) were followed to design a carbon canister system and estimate its capital and operating costs. Wherever possible, data from vendors of activated carbon and carbon adsorption systems were used. For the large laboratory case, a spreadsheet template from the USEPA's "CO$T-AIR" collection (Vatuvak, 1999) was used. Again, actual data from vendors were used wherever possible to replace the spreadsheet's defaults.

[8] The same analysis could be performed with AK-225 or HFC-43-10 mee. HFE 7200 was analyzed because some operating data were available.

[9] A detailed description of the cost analyses is provided in Appendix B.

Table 4-5

MAJOR ASSUMPTIONS USED IN COST ANALYSIS

Parameter	Value	Units	Comments
Solvent mileage, perc machine	54,000	ft/gal	75th percentile of values from survey
Solvent mileage, HFE machine	70,000	ft/gal	Vendor literature
Film processing rate	5,225	ft/hr	Median value from survey
Annual perc use per machine	82.5	gal/yr	Median value from survey
Exhaust air flow per machine	150	cfm	Median value from survey
Cost of new machine	80,500	$	Vendor quote (Tisch, 2000)
Interest rate for capital recovery	7	%	Vatuvak, 1999

Because the objective of the analysis was to compare incremental costs, those costs that did not vary from one alternative to another were not included.[10] For example, the analysis did not include the cost of labor and materials for operating and maintaining the film cleaning machines. Total annual costs were calculated as follows:

C = [(Capital Cost) x (Capital Recovery Factor)] + Operating Costs

Note that the costs of obtaining permits to construct (including consulting fees) were included in the capital cost and then annualized with the capital recovery factor. Note also that, for the cases involving carbon adsorption with on-site regeneration, the cost is reduced by a credit for the recovered solvent. Finally, the total annual cost for each alternative was divided by the annual film footage cleaned and multiplied by 100; the units of comparison were therefore dollars per 100 feet cleaned.

4.3.3 Results of Incremental Cost Analysis

Table 4-6 shows the results of the incremental cost analysis. For the small laboratory, it would be relatively less expensive to switch to an HFE 1200 machine without add-on controls. For the large laboratory, the cost per 100 feet of film cleaned would actually decrease if a carbon adsorber with on-site generation were used, inasmuch as 90 percent of the perchloroethylene would be recovered for re-use. The incremental cost of purchasing and using an HFE 1200 machine would be about 26 cents per 100 feet of film cleaned. Case L-3 was discarded after analysis showed that a regenerative carbon adsorption system would not be physically or economically feasible. (See Appendix B.)

[10] Except for the film cleaning machines, whose unit price did not vary among alternatives.

Table 4-6

RESULTS OF INCREMENTAL COST ANALYSIS

Case	Annualized Capital Cost			Operating Cost			Grand Total	Increment Over Base
	Equipment	Regulatory Cost	Total	O & M	Regulatory Cost	Total		
S-B	$0.26	$0.01	$0.27	$0.02	$0.01	$0.03	$0.29	
S-1	$0.28	$0.02	$0.30	$0.35	$0.02	$0.37	$0.67	**$0.38**
S-2	$0.26	$0.01	$0.27	$0.29	$0.00	$0.29	$0.56	**$0.27**
L-B	$0.26	$0.00	$0.26	$0.02	$0.01	$0.03	$0.29	
L-1	$0.30	$0.01	$0.31	$0.07	$0.01	$0.08	$0.28	**($0.01)**
L-2	$0.26	$0.00	$0.26	$0.29	$0.00	$0.29	$0.55	**$0.26**

Regulatory costs (i.e. those for permits to construction, annual permit renewal, and emission fees, plus associated consulting) account for no more than about 2 cents per 100 feet of film cleaned. They do not affect significantly the differences among the alternatives.

5.0

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

5.1.1 Motion Picture Film Processing Facilities

(1) This project determined that there are 50 facilities in the District that print motion picture film using wet gate printers, use wet gate telecine machines, and/or clean motion picture film with organic solvents.

(2) In the inventory, 20 facilities are motion picture and television studios, producers of television commercials and title houses; 13 specialize in printing and cleaning film; 11 are telecine houses; and 6 preserve and restore old films.

(3) About three quarters of the facilities in the inventory are in Hollywood, Burbank or Santa Monica.

5.1.2 Equipment Inventory

<u>Motion Picture Film Cleaning Equipment</u>

(1) The survey identified and characterized 107 motion picture film cleaning machines, most of which use perchloroethylene (perc).

(2) Seven machines are used to clean 70 mm film. The rest clean 35 and 16 mm film.[1]

(3) About one quarter of the film cleaning machines that use perc do not have permits from the AQMD.

(4) Most of the facilities have one or two film cleaning machines; the maximum per facility is ten.

<u>Wet Gate Printers</u>

(1) The survey identified 102 wet gate printers, all of which use perchloroethylene as the wet gate fluid.

(2) Roughly equal numbers of contact and optical printers use wet gates.

(3) About 80 percent of the wet gate printers have AQMD permits.

(4) The majority of facilities in the inventory do not have any wet gate printers; those that do have printers have 1 to 27.

[1] Film size was unknown for ten machines.

(5) The survey found only one facility that uses a wet gate telecine machine.

5.1.3 Film Footage

Motion Picture Film Cleaning Equipment

(1) The facilities in the inventory clean 543 million feet of film per year, and a maximum of 2.1 million feet per day. The overwhelming majority of this footage is 35 or 16 mm.

(2) Perc is used to clean all the 70 mm film and about 61 percent of the rest.

(3) The feet of film cleaned per machine per day or per year varies widely from machine to machine. The median values for 16 or 35 mm film are 20,000 ft/day and 3,207,600 ft/yr. The median values for 70 mm film are 20,000 ft/day and 4,000,000 ft/yr.

Wet Gate Printers

(1) Footage data were provided for only 62 of the 102 printers in the inventory; therefore actual footage printed is likely higher than that reported here.

(2) The facilities in the inventory print 199.6 million feet of film per year and a maximum of 3.1 million feet per day. The great majority of this footage is 35 or 16 mm.

(3) Contact and optical printing account for 152.8 million and 36.6 million ft/yr, respectively.[2] The type of printer is unknown for the rest of the footage.

(4) The amount of film printed per year per wet gate printer varies widely from device to device. The median values for 35 mm contact and optical printers are 2.5 million and 750,000 ft/yr, respectively.[2]

5.1.4 Material Consumption

Motion Picture Film Cleaning Equipment

(1) Film cleaning solvents currently used include perchloroethylene (6,070 gal/yr), 1,1,1-trichloroethane (2,900 gal/yr), other volatile organic compounds (VOC) (2,890 gal/yr), isopropyl alcohol (600 gal/yr), and HFE 7200 (a hydrofluoroether blend) (370 gal/yr).

(2) The median values of consumption per 35 mm film cleaning machine are 83 gal/yr of perchloroethylene, 126 gal/yr of 1,1,1-trichloroethane, and 37 gal/yr of isopropyl alcohol.

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[2] Transfer by wet gate telecine is included in the total for optical printing.

Wet Gate Printers

(1) Wet gate printing consumes about 16,400 gal/yr of perc

(2) The median values of consumption per contact printer and per optical printer are 125 gal/yr and 97 gal/yr, respectively.[2]

5.1.5 Emission Control Devices

(1) The only type of "add-on" emission control device reported is the carbon adsorber. In some systems, the captured pollutant is desorbed and recycled onsite. In others, saturated carbon is removed from the premises and replaced with new adsorbent.

(2) Perchloroethylene and 1,1,1-trichloroethane are the only pollutants whose film cleaning emission are controlled. Eleven devices are controlled by regenerative systems and eight are controlled by disposable canisters.

(3) Regenerative carbon adsorbers are used to treat 37 wet gate printers, while disposable canisters are used for 11 printers.

5.1.6 Emissions

In the following discussion, "maximum potential emissions" are total losses to the atmosphere assuming no carbon adsorption. "Emissions from uncontrolled equipment" are losses from equipment not served by carbon adsorbers. "Emissions from controlled equipment" are those downstream from external emission control equipment. "Net emissions" are emissions to the atmosphere, taking controls into account, where applicable.

Motion Picture Film Cleaning Equipment

(1) Basinwide net emissions of perc from film cleaning are 61,700 lb/yr and 169 lb/day (30.9 tons/yr and 0.085 ton/day).

(2) About one quarter of the maximum potential perc emissions and about 36 percent of the maximum potential 1,1,1-trichloroethane emissions are removed by carbon adsorbers.

(3) Volatile organic compound (VOC) emissions from film cleaning total 20,260 lb/yr and 56.5 lb/day (10.1 tons/yr and 0.028 ton/day). None of these emissions are controlled.

(4) The median value of net emission of perchloroethylene per facility from film cleaning is 732 lb/yr.

(5) Relatively few facilities account for the great majority of the emissions of 1,1,1-trichloroethane.

(6) Emissions of perc are more evenly distributed than those of 1,1,1-trichloroethane, but about 55 percent of the net emissions are from 14 percent of the facilities.

Wet Gate Printers

(1) Net perchloroethylene emissions from contact printers, optical printers, and printers whose type is not known are 20,420 lb/yr, 49,990 lb/yr and 4,400 lb/yr, respectively.[3]

(2) About 72 percent of the emissions from contact printing and about 15 percent of the emissions from optical printing are controlled.

(3) The median value of net emissions of perchloroethylene per facility from wet gate printing is 840 lb/yr.

(4) The top 25 percent of the facilities account for 88 percent of the emissions from wet gate printing.

Potential for Emission Reduction

About 130,000 lb/yr of perc emissions are not treated by carbon adsorption and are therefore available for reduction. Film cleaning and optical printing are responsible for 84 percent of these uncontrolled emissions.

5.1.7 Emission Factors

Emission Factors Derived From Monthly Logs

(1) Detailed monthly data useful for calculating credible emission factors were available for nine devices at three facilities.

(2) Mean perchloroethylene emission factors for film cleaning ranged from 0.11 to 0.40 lb/1000 feet of film cleaned.

(3) The mean perchloroethylene emission factor for contact printing was 2.6 lb/1000 ft printed for one facility and ranged from 0.032 to 0.18 lb/1000 ft at another.

(4) There appears to be a statistically significant inverse relationship between film printing rate and the emission factor for contact printing.

Emission Factors From Annual Process Values

(1) Emission factors were also derived from a subset of the annual film footage and solvent consumption values reported by the facilities.

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[3] Emissions from wet gate telecine are included in the total for optical printing.

(2) The 95-percent confidence intervals for the mean emission factor for contact printers and optical printers were about 0.8 – 1.8 and 0.7 – 1.7 lb/1000 ft, respectively; the difference in means was not statistically significant.

(3) The 95-percent confidence interval for the mean emission factor for 35-mm film cleaning with perchloroethylene was about 0.3 to 0.5 lb/1000 ft. The interval for 70-mm film cleaning with perchloroethylene was about 0.1 to 0.35 lb/1000 ft.

(4) Variability in emission factors is due to differences among machines in maintenance practices, film processing speeds, performance of vapor condensation equipment, solvent temperature, and other factors. Some variability is also due to uncertainty in the underlying estimates of film footage and solvent consumption.

5.1.8 Risk Reduction Measures

(1) Currently used risk reduction or minimization measures include in-machine recovery and recycling, emission capture and removal, solvent substitution, and careful housekeeping practices.

(2) In-machine recovery and recycling already goes a long way towards reducing emissions, and the technology continues to improve.

(3) Carbon adsorption is the only practical "add-on" measure for this industry.

(4) There is currently no practical substitute for perchloroethylene in wet gate printing.

(5) The alternatives to perc and 1,1,1-trichloroethane comprise about 30 percent of the total volume of film cleaning solvents.

(6) Any substitute for perchloroethylene in wet gate printing must have an acceptable index of refraction, not damage film, and pose less of a community and occupational health risk than perc.

(7) Isobutylbenzene (IBB) has been used in Sweden as a wet gate fluid with satisfactory results. Because it has a low flash point, it may pose a fire hazard in some cases. It is relatively non-toxic.

(8) Film cleaning solvent alternatives reviewed included HFE 7200, AK-225, IBB, hydrotreated naphtha, and n-propyl bromide.

(9) The only near-term alternatives for risk reduction are increasing the extent to which perchloroethylene emissions are controlled by carbon adsorption and use of HFE 7200, AK-225, or HFC-43-10 mee in new or modified film cleaning machines.

(10) The costs of these alternatives were estimated for two facility sizes, using U.S. Environmental Protection Agency methods and data from the survey and from vendors. The "base cases" were installation of one or eight new perchloroethylene film cleaning machines without add-on controls.

(11) For a small laboratory, the lowest incremental cost (over the base case) would be use of HFE 1200 and no carbon adsorption.

(12) For the case of eight machines, the lowest incremental cost (over the base case) would be use of perchloroethylene and emission control with a regenerative carbon adsorption system.

5.2 RECOMMENDATIONS

The contractor recommends the following actions.

5.2.1 Better Characterization of Emissions

The emission factors developed in this project apply only to a limited number of circumstances. For determining risk under Rule 1401/1402, better annual average and hourly emission estimates are needed. The material balance approach used for most of the survey data does not explicitly take into account the influence of process variables, such as film speed. If the District wishes to obtain better emission estimates, then they could be obtained through a systematic program of emissions testing. The purpose of the tests would be to relate mass emissions to readily observable and quantifiable operating parameters.

<u>Testing of Film Cleaning Machines</u>

Recommended features of a program to test film cleaning machines are:

- Testing a variety of film cleaning machines, of at least two generations of primary controls (e.g. the Lipsner Smith CF3000 and the CF7200);

- Continuous monitoring for perchloroethylene in the vent duct from the cleaning machine's cabinet, and from the cleaning room exhaust, using flame ionization analyzers calibrated directly with perc; and

- Careful recording of process parameters, including film size, film speed, and solvent bath temperature.

Note that the volume of perchloroethylene consumed during the test need not be recorded.

Testing of Wet Gate Printers

Testing of wet gate printer emissions poses more of a challenge, since, in many cases, the wet gates are not enclosed. Construction of a temporary total enclosure (TTE), the customary solution to this problem, may not be practical. However, some wet gate systems are enclosed during operation, and vapors are exhausted in ducts. The evaporation rate of perchloroethylene would tend to be higher in an enclosure, due to convective mass transfer. As a compromise, it might be possible to sample the exhaust ventilation from a relatively small room in which one or two printers is operating. As in the case of film cleaning machines, process parameters should be monitored continuously during each test.

5.2.2 Performance Testing of Alternative Materials

It was learned during the survey that several laboratories, including both small- and large-volume operations, have conducted in-house tests of alternative cleaning solvents. It would be to the advantage of the industry as a whole if the resources of the motion picture film laboratory industry, wet gate and cleaning machine manufacturers, the District, and solvent manufacturers could be pooled to sponsor commercial-scale testing. This testing would resolve questions such as whether isobutylbenzene leaves a residue on film, or what additives would enable various solvents to clean more effectively. At a minimum, isobutylbenzene should be tested extensively for use as wet gate fluid.

6.0

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APPENDIX A
SURVEY FORMS

A.1 NOTIFICATION PACKAGE

PACIFIC ENVIRONMENTAL SERVICES, INC.

Celebrating the Test of Time 25 1971-1996

13100 Brooks Drive, Suite 100
Baldwin Park, CA 91706
(626) 856-1400
FAX (626) 814-0820
http://www.pes.com

November 18, 1999

Dear Plant Manager:

The South Coast Air Quality Management District (SCAQMD) has selected Pacific Environmental Services, Inc. (PES) to conduct a survey of companies that have motion picture film cleaning and/or printing operations, or that transfer images from motion picture film to videotape. One purpose of the survey is to gather information that can be used to estimate emissions of air pollutants from these operations. Another purpose is to evaluate the feasibility of various ways to reduce emissions and the resulting health risk to the community.

If this plant does not clean or print motion picture film on the premises and does not use a wet-gate telecine machine, then please fill out and sign the attached exemption form and fax it or mail it back to us.

You may be assured that any information given to PES that you identify as "confidential" or "trade secret" will be held as such by PES and the SCAQMD. (Please see the attached letter from the SCAQMD for more information, including assurances of confidentiality.)

Because the number of plants involved is small, PES plans to visit each one to obtain the information in person. We will be calling you in the next few weeks to schedule an appointment for one of our air quality engineers and a representative of the SCAQMD to visit you. During the visit, we would like a tour of your operation, to see what types of equipment you have, how chemicals are stored and handled, and, where applicable, what measures you take to control your emissions. We would also like to hear your opinions about the practicality of various alternatives for reducing air pollutant emissions. Finally, we need to gather data on material use, feet of film processed, etc. so that we can estimate emissions.

Attached is a list of the specific types of information that we will need. We would appreciate it if you could have the data available for us at the time of our visit. If you have any questions about this project, please call me at (626) 856-1400 or call the SCAQMD contract manager, Tracy Goss, at (909) 396-3106.

Sincerely yours,

Pacific Environmental Services, Inc.

Michael B. Rogozen, D.Env.
Principal Investigator
SCAQMD Motion Picture Laboratory Survey

Attachments

South Coast
Air Quality Management District
21865 E. Copley Drive, Diamond Bar, CA 91765-4182
(909) 396-2000 • http://www.aqmd.gov

October 8, 1999

Dear Motion Picture Film Processing Lab Operator:

Pacific Environmental Services (PES) is under contract to conduct a research study for the South Coast Air Quality Management District (AQMD). The purpose of the study is to gather pertinent information and develop an emissions inventory and health risk reduction guidelines for motion picture film processing laboratories.

During this process, PES will be surveying all laboratories regarding their operations and use of chemicals in the cleaning and printing of film. Any information given to PES that is identified as "CONFIDENTIAL" or "TRADE SECRET" will be held as such by PES and the AQMD. The final report for this effort will not contain any facility-specific information. The information you and other companies provide will be used only in summary format and will not be distinguishable to any particular facility.

It should be noted that the AQMD is subject to the California Public Records Act (Government Code section 6250 *et seq.*) and information received may be subject to public disclosure if ordered by a court after finding the information was not properly declared trade secret. Information that is considered trade secret includes, but is not limited to, formulas, software, plan patterns, processes, tools, mechanisms, compounds, procedures, production data, or compilation of information which is not patented. Information used to calculate air emissions may be trade secret. However, emissions data are not trade secret.

We ask that you assist us with this research by meeting with PES and providing the requested information. If you have any questions, please contact the District Contract Manager for this effort, Tracy A. Goss, P.E. at (909) 396-3106.

Thank you for your assistance.

Sincerely,

Jill Whynot

Jill Whynot
Planning and Rules Manager

TG

INFORMATION NEEDS FOR EMISSION INVENTORY SURVEY OF MOTION PICTURE LABORATORIES

FACILITY DATA

Address of physical location
Mailing address
Contact name and title
SCAQMD Facility ID number (if any)
Telephone and fax numbers
SIC code
Number of employees

EQUIPMENT AND PROCESS IDENTIFICATION

Make and model of each film cleaning device
Make and model of each motion picture film printer
Type(s) of wet gate(s)
Make and model of each telecine machine
For each device, typical and maximum processing capacity (e.g. feet film per minute)

MATERIAL USE INFORMATION

MSDS for the perc used in wet gate printing or telecine
MSDS for solvent(s) used in film cleaning
Annual, maximum daily, and maximum hourly feet of film processed by each device
Amount of perc and other chemicals on hand (gallons or pounds) at start and end of 1998
Amount of perc and other chemicals purchased in 1998 (need purchase records)
Hazardous waste manifests for all perc and other solvents disposed of in 1998
Hazardous waste manifests for carbon recycled (where applicable)
Hazardous waste manifests for filters and buffers disposed of in 1998
Capital and O&M costs for cleaning, printing and pollution control equipment

OPERATING SCHEDULE

Hours/day, days/week and weeks/year that equipment is operating
Percent of annual activity that occurs in each month
Equipment maintenance schedules

EMISSION CONTROL EQUIPMENT

Type of equipment
Emission source(s) controlled
SCAQMD permit number(s)
Volume of air treated (cubic feet per minute)
Control efficiency (provide copy of source test or manufacturer's guarantee)
Percent down time for control equipment

STACK PARAMETERS

Length(s), width(s) and height(s) of the building(s) where the equipment is located
If emissions are through a stack, what are the stack's height (from the ground), diameter, temperature, and flow rate?

CONFIRMATION OF EXEMPTION FROM MOTION PICTURE LABORATORY SURVEY

This facility is exempt from Pacific Environmental Services, Inc.'s survey for the South Coast Air Quality Management District because:

✓ No motion picture film is cleaned on the premises;

and

✓ No wet-gate (liquid-gate) printing of motion picture film is done on the premises;

and

✓ No wet-gate (liquid-gate) telecine transfers are performed on the premises.

Name ____

Title ____

Company ______________________________________

Facility Address __________________________________

____

Signature ______________________ Date ______________________

Please fax your signed response to Dr. Michael Rogozen at (626) 814-0820 or mail it to:

Dr. Michael Rogozen
SCAQMD Motion Picture Laboratory Survey
Pacific Environmental Services, Inc.
13100 Brooks Drive, Suite 100
Baldwin Park, CA 91706

Thank you for your cooperation.

A.2 FIELD DATA FORMS

INSTRUCTIONS FOR INTERVIEWERS
SCAQMD MOTION PICTURE FILM PROCESSING SURVEY

1. Explain the survey project to the facility representative. Give him or her the opportunity to sign the "opt out" form if applicable.

2. Tour the facility, including:

   - All rooms that have film cleaning machines
   - All printers that have wet gates
   - Perc or other chemical reservoirs and/or drum storage areas
   - Control equipment (if applicable)

3. Make a diagram of the flow of perc through the facility, including

   - Distribution from central reservoir to intermediate reservoirs (if any)
   - Capture apparatus
   - Fugitive emission points
   - General building exhaust points
   - Control equipment (if any)

4. Fill out the field survey forms from your observations and data that the plant provides.

   - Copy information from purchase records, hazardous waste manifests, source test reports, etc. (We don't need copies of the documents themselves.)

   - Note on the forms any data that were unavailable at the time of your visit.

5. Review the facility's equipment maintenance schedule (if any) and ask if it differs from what is recommended by the manufacturer(s).

6. Discuss whatever risk reduction alternatives we have information about, including cleaning with HFE, use of IBB in wet gate printing, etc.

   - Are they aware of the alternative(s)?

   - What do <u>they</u> perceive as the pros and cons?

EQUIPMENT SUMMARY FORM

Survey ID No.		**Date**	
		Initials	

FILM CLEANING MACHINES

Device No.	Make	Model	35/70	Sol-vent Code	Permit No.	Year Placed in Service	Capacity (ft/min)

Solvent code: P = perc, I = isopropanol, * = other (specify)

WET GATE PRINTERS

Device No.	Make	Model	35/70	Sol-vent Code	Permit No.	Year Placed in Service	Capacity (ft/min)

Solvent code: P = perc, I = isopropanol, * = other (specify)

OPERATING ‿A FORM

Survey ID

Date

Type of Cleaning or Wet Gate Fluid

Initials

MSDS Provided ☐

Maintenance Schedule Provided ☐

Device Number	Feet of Film Processed			General Operating Schedule			Monthly Activity Pattern											
	Maximum Hourly	Daily	Annual	Hours/ Day	Days/ Week	Weeks/ Year	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Aug	Sep	Oct	Nov	Dec

SOLVENT IN ORY FORM

Survey ID ____ **Date** ____ **Initials** ____

Type of Cleaning or Wet Gate Fluid ____

Beginning and Ending Inventories

	Amount	Units
On Hand December 31, 1997		
On Hand January 1, 1999		

Waste Categories
1 - Solvent sludge
2 - Filters
3 - Buffers
4 - Spent carbon

Purchases in 1998
(Do not include internal recycling.)

Date	Amount	Units

Disposal in 1998 (Includes sludge, filters, buffers, spent carbon, etc.)

Date	Manifest No.	Amount	Units	Description	Disposer or Recycler

Carbon Recycler Address & Contact ____ Telephone Number ____

Other Disposer Address & Contact ____ Telephone Number ____

CONTROL AND STACK INFORMATION

Survey ID	
Date	
Initials	

CONTROL INFORMATION

Type of device			
Manufacturer			
Model			
Date Installed			
AQMD Permit No.			
Volume of air treated (cfm)			
Control efficiency (capture, control, overall)			
Percent downtime			

RELEASE PARAMETERS

	Value	Units
Building width		
Building length		
Building height		
Stack height above ground		
Stack diameter		
Stack Velocity		
Stack temperature		
Volumetric Flow Rate		

CONTROL DIAGRAM

OPERATING AND MAINTENANCE COSTS FORM

Survey ID		Date	
		Initials	

OPERATING COSTS

Film Cleaning Machines

	Units	Amount
Operating labor	Person-hrs/week	
Solvent cost	$/drum (inc. shipping)	
Power draw	Watts	
Solids disposal	$/drum	
Sludge disposal	$/drum	

Carbon Adsorption Systems

	Units	Amount
Operating labor	Person-hrs/week	
Carbon replacement frequency	Times/yr	
Carbon cost	$/replacement	
Steam price (if applicable)	$/1000 lb	
Cooling water price (if applicable)	$/1000 gal	
Electrical consumption	Kwh/yr	

MAINTENANCE COSTS

Film Cleaning Machines

	Units	Amount
Maintenance labor	Person-hrs/week	
Replacement buffers	No. per year	
Replacement buffer cost	$/each	
Replacement filters	No. per year	
Replacement filter cost	$/each	

Carbon Adsorption Systems

	Units	Amount
Maintenance labor	Person-hrs/week	
Replacement parts (other than carbon)		

APPENDIX B
COST ANALYSIS METHODS

Appendix B

COST ANALYSIS METHODS

B.1 DEFINITION OF SCENARIOS AND SCOPING OF CONTROLS

B.1.1 Case S-B: Single Film Cleaning Machine Using Perchloroethylene

This scenario consists of the purchase of one new 16/35 mm film cleaning machine that uses perchloroethylene (perc). No add-on emission controls are included. According to the survey, the 75th percentile of solvent mileage for 16- and 35-mm film cleaners using perc was **54,000 ft/gal**, and the median film cleaning speed was **5,225 ft/hr**. Finally, the median perc consumption per machine was **82.5 gal/yr**.

$$\text{Uncontrolled Emissions} = (5225\ \text{ft/hr})(\text{gal}/54000\ \text{ft})(13.5\ \text{lb/gal})(\text{hr}/60\ \text{min})$$
$$= \mathbf{0.02177\ lb/min}$$

The median exhaust flow rate for this type of film cleaning machine was **125 ft³/min**.

B.1.2 Case S-1: Single Film Cleaning Machine Using Perchloroethylene With Activated Carbon Canister

This scenario has the same operating parameters as Case S-B, except that perchloroethylene in the film cleaner's exhaust is vented to one or more removable activated carbon canisters. The mass concentration of perc in the exhaust is:

$$C_p = (0.02177\ \text{lb/min})/(125\ \text{ft}^3/\text{min}) = 0.0001742\ \text{lb/ft}^3$$

An adsorption isotherm for perc at 25°C and 1 atm on Calgon Carbon Corporation BPL4X6 activated carbon was obtained from the carbon manufacturer (Fuller, 2000). It is shown in Figure B-1. The 25°C (77°F) temperature was assumed to apply to the case of the film cleaning machine exhaust.

The density of dry air at 77°F is 0.07398 lb/ft³ and its molecular weight is 28.966 lb/lb-mole (Jorgensen, 1970). Therefore:

$$\text{Molar Concentration of perc} = (0.0001742\ \text{lb/ft}^3)/(165.85\ \text{lb/lb-mole})$$
$$= 1.0503 \times 10^{-6}\ \text{lb-moles/ft}^3$$
$$\text{Molar Concentration of air} = (0.07398\ \text{lb/ft}^3)/(28.966\ \text{lb/lb-mole})$$
$$= 2.554 \times 10^{-3}\ \text{lb-moles/ft}^3$$
$$\text{Mole fraction perc} = (1.0503 \times 10^{-6})/(1.0503 \times 10^{-6} + 2.554 \times 10^{-3})$$
$$= 0.000411 = \mathbf{411\ ppm}$$

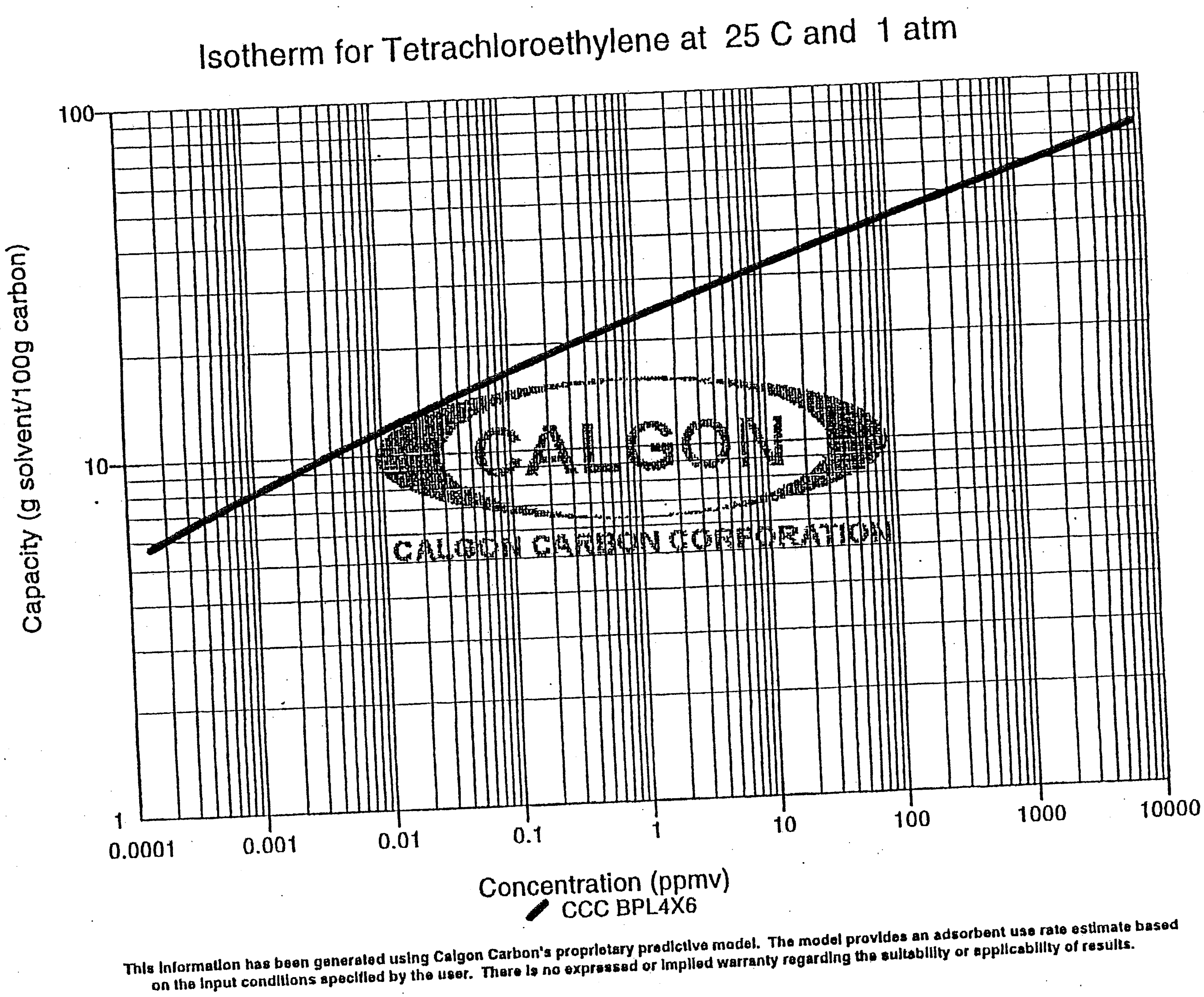

Figure B-1. Adsorption Isotherm for Perchloroethylene. (Source: Fuller, 2000).

From the adsorption isotherm, the holding capacity of the carbon at 411 ppm is 51 g perc per 100 g solvent. Using the *OAQPS Control Cost Manual's* terminology, w_e (max) = 0.51.

The mass flow rate of perc from the film cleaner is:

$$m_p = (0.02177 \text{ lb/min})(60 \text{ min/hr}) = 1.3062 \text{ lb/hr}$$

The annual hours per year during which the film cleaner is actually operating (and during which emissions must be treated) is:

$$\Theta_A = (82.5 \text{ gal/yr})(13.5 \text{ lb/gal})/(1.3062 \text{ lb/hr})$$

$$= \mathbf{852.66 \text{ hr/yr}}$$

The total annual carbon requirement, M_{CI}, is found from:

$$M_{CI} = m_p \, \Theta_A / w_c$$

Where w_c is the capacity of the carbon bed (with a safety factor). The *OAQPS Control Cost Manual* uses a safety factor of 0.5. Therefore:

$$w_c = 0.5 \, w_e \text{ (max)} = (0.5)(0.51) = 0.255 \text{ lb perc/lb carbon}$$

Therefore the amount of carbon needed for one year's operation is:

$$M_{CI} = (1.3062)(852.66)/(0.255)$$

$$= 4{,}367.6 \text{ lb carbon}$$

For an additional margin of safety, this amount was rounded up to **4,500** lb carbon. Comparable facilities maintain 200 to 400 lb of carbon on site at a given time. It was assumed that this system would have two 200-lb drums. Therefore, carbon would have to be replaced about 11 times per year.

B.1.3 Case S-2: Single Film Cleaning Machine Using HFE 7200

RTI Lipsner Smith's Model CF8200 film cleaning machine was assumed to have a solvent mileage of **70,000 ft/gal** when using HFE 7200. It was also assumed that the machine can clean **225 feet of film per minute**, while a machine using perc can clean 90 feet per minute. The hourly processing rate is therefore (5225 ft/hr)(225/90) = 13,062.5 ft/hr.

It was assumed that the HFE 7200 machine cleans the same amount of film per year as the perc machine in Case B-1. The perc machine cleans 54,000 ft per gallon of solvent.

$$\text{Annual Footage (Base)} = (82.5 \text{ gal/yr perc})(54000 \text{ ft/gal perc})$$

$$= \mathbf{4{,}455{,}000 \text{ ft/yr}}$$

HFE 7200 Consumption = (4455000 ft/yr)/(70000 ft/gal HFE)

= 63.6 gal/yr

B.1.4 Case L-B: Eight Film Cleaning Machines Using Perchloroethylene

In this scenario, the laboratory purchases eight new 16/35 mm film cleaning machines using perc. The per-machine film processing, solvent consumption and exhaust air flow rates are the same as in Case S-B.

B.1.5 Case L-1: Eight Film Cleaning Machines Using Perchloroethylene, Served By a Regenerative Carbon Adsorption System

This scenario is the same as Case L-B, except that the laboratory also constructs and uses a fixed-bed carbon adsorber, from which it recovers perc for re-use. The system was scoped using the carbon adsorption spreadsheet in the U.S. Environmental Protection Agency's "CO$T-AIR" collection (Vatuvak, 1999). A printout of a portion of the spreadsheet is in Section B.3. In general, the inputs to the spreadsheet were proportional to those developed in Section B.1.2. For example, the inlet stream flow rate was (8)(125 ft^3/min) = 1,000 ft^3/min. Table B-1 lists the key inputs to the spreadsheet. It was assumed that at least one film cleaning machine would be operating at any given time, so that cleaning would take place 24 hours per day, 5 days per week, 52 days per year (6,240 hr/yr).

It was assumed that the perc removal rate would be 90 percent. The actual removal rate would probably be higher, but the AQMD has frequently assumed 90 percent in its permit application reviews.

Table B-1

KEY INPUT VARIABLES TO COST SPREADSHEET: 8 PERC FILM CLEANING MACHINES WITH REGENERATIVE CARBON ADSORBER

Input Parameter	Units	Value
Inlet Stream Flow Rate	acfm	1000
Perc Removal Rate	%	90
Adsorption Time	hr/day	24
Desorption Time	hr/day	8
No. of Adsorbing Vessels		1
No. of Desorbing Vessels		1
Operating Hours	hr/yr	6240

B.1.6 Case L-2: Eight Film Cleaning Machines Using HFE 7200, With No Add-On Emission Controls

In this scenario, the laboratory purchases eight new 16/35 mm film cleaning machines using HFE 7200. The per-machine film processing, solvent consumption and exhaust air flow rates are the same as in Case S-2.

B.1.7 Case L-3: Eight Film Cleaning Machines Using HFE 7200, With Carbon Adsorber to Recover Solvent

In this scenario, a regenerative carbon adsorber is used solely for the purpose of recovering HFE 7200 for re-use in the eight film cleaning machines, rather than for "emission control."

As discussed in Section B.1.3, the hourly film processing rate per machine is 13,062.5 ft/hr. For 8 machines, the rate would be 104,500 ft/hr. The mass flow of HFE 7200 from the eight machines' combined exhausts would be:

$$\begin{aligned} \text{HFE 7200 Mass Flow} &= (104500\ \text{ft/hr})(\text{gal}/70000\ \text{ft})(11.93\ \text{lb/gal}) \\ &= 17.810\ \text{lb/hr} \\ &= 0.2968\ \text{lb/min} \end{aligned}$$

Assuming the same exhaust flow rate as with the perc film cleaner, the mass concentration of HFE in the exhaust is:

$$C_{HFE} = (0.2968\ \text{lb/min})/[(8)(125\ \text{ft}^3/\text{min}) = 0.0002968\ \text{lb/ft}^3$$

$$\begin{aligned} \text{Molar Concentration of HFE} &= (0.0002968\ \text{lb/ft}^3)/(264\ \text{lb/lb-mole}) \\ &= 1.1242 \times 10^{-6}\ \text{lb-moles/ft}^3 \\ \text{Mole fraction HFE} &= (1.1242 \times 10^{-6})/(1.1242 \times 10^{-6} + 2.554 \times 10^{-3}) \\ &= 0.00043997 = \mathbf{440\ ppm} \end{aligned}$$

No adsorption isotherms for HFE 7200 were available. However, 3M Performance Materials Division has developed an adsorption isotherm for HFE 7100 on Westvaco BX7540 activated carbon (Hill, 2000). Since HFE 7100 has a lower molecular weight than HFE 7200, its adsorption on activated carbon would be less efficient than for HFE 7200. The following analysis is therefore somewhat conservative. An equation fitted to experimental data for adsorption of HFE 7100 is (Hill, 2000):

$$Y = (30.925)(1.1339)\,P/(1 + 30.925\,P)$$

where

Y = Loading (g HFE 7100 per g carbon)

P = Partial pressure of HFE 7100 in the inlet stream

Letting P = 0.00043997 and substituting the value into the isotherm equation results in a predicted capacity of 0.01522 g HFE 7100 per g carbon (**0.01522 lb HFE 7100 per lb carbon**). Note that the lowest partial pressure value used to develop the curve fitting equation (other than a forced value of zero) was about 0.05. Therefore this analysis uses a value at the lowest end of the range of predictability of the isotherm equation.

The system was scoped using the same carbon adsorption spreadsheet in the U.S. Environmental Protection Agency's "CO$T-AIR" collection as was used for Case L-1 (Vatuvak, 1999). It was assumed that at least one film cleaning machine would be operating at any given time, so that cleaning would take place 24 hours per day, 5 days per week, 52 days per year (6,240 hr/yr).

It was assumed that the HFE 7200 recovery rate would be 90 percent, as was the case with perc. However, no data on the recoverability of HFE 7200 from activated carbon were available, and there is a possibility that the compound will decompose in the presence of steam.

When these and other assumptions were input to CO$T-AIR, the cost model yielded quite unrealistic design features. Apparently, an HFE recovery system of the type modeled cannot be designed. This scenario was therefore discarded.

B.2 COST ANALYSIS

B.2.1 Capital and Operating Costs

Because the objective of the analysis was to compare *incremental* costs, those costs that did not vary from one scenario to another were not included. For example, one would expect the operating labor costs for a film machine to be about the same, no matter which solvent is used. Total annual costs were calculated as follows:

C = [(Capital Cost) x (Capital Recovery Factor)] + Operating Costs

The costs of obtaining permits to construct (including consulting fees) were included in the capital costs and then annualized with the capital recovery factor.[1] The total annualized cost for each alternative was divided by the annual film footage cleaned and multiplied by 100; the units of comparison were therefore dollars per 100 feet cleaned.

Table B-2 lists some of the key unit cost assumptions. Tables B-3 and B-4 show the results of the capital and operating cost calculations, respectively. Included in Table B-4 is the total annual cost per 100 feet of film cleaned.

B.2.2 Incremental Costs

Table B-5 shows the incremental costs of the alternatives, with reference to the two baseline cases (Cases S-B and L-B).

[1] Note that the CO$T-AIR spreadsheet uses a five-year capital recovery factor for replacement carbon for the fixed beds in regenerative systems.

Table B-2

UNIT COST ASSUMPTIONS

Input Parameter	Units	Value
Film Cleaning Machine	Each	$80,500.00
Carbon Price	$/lb	$2.29
Cost of Perc	$/lb	$0.69
Cost of HFE 7200	$/lb	$17.00
Steam Price	$/1000 lb	$6.00
Cooling Water Price	$/1000 gal	$0.20
Taxes, Insurance, Administration	% of capital cost	4
Annual Interest Rate[a]	%	7

[a]The AQMD uses an interest rate of 4 percent in its analyses. The 7 percent rate is used by the U.S. Environmental Protection Agency.

Note that the use of the U.S. Environmental Protection Agency's interest rate, rather than the rate used by the AQMD, has a negligible effect on the total or incremental costs per 100 feet of film.

Table B-3

CAPITAL COSTS FOR FILM CLEANING ALTERNATIVES

Cost Category	S-B	S-1	S-2	L-B	L-1	L-2
Film Cleaner(s)	80,500.00	80,500.00	80,500.00	644,000.00	644,000.00	644,000.00
Initial Cannisters		914.29				
Other Cannister System Costs		6,553.38				
Regenerative Carbon Adsorber					114,249.00	
Permit Consulting	2,500.00	2,500.00	2,500.00	5,000.00	5,000.00	5,000.00
PTC - Film Cleaner	788.10	788.10	788.10	3,546.45	3,546.45	3,546.45
PTC - Carbon Adsorber		2,028.90			8,712.90	
Total Capital Cost	83,788.10	93,284.67	83,788.10	652,546.45	775,508.35	652,546.45

Table B-4

ANNUAL COSTS FOR FILM CLEANING ALTERNATIVES

Cost Category	S-B	S-1	S-2	L-B	L-1	L-2
Annualized Capital Cost - Equipment	11,929.54	13,281.64	11,929.54	92,907.93	110,135.45	92,907.93
Solvent Purchase	772.20	772.20	12,907.41	6,177.60	6,177.60	103,259.26
Annual Permit Renewal - Cleaner(s)	179.10	179.10	179.10	1,432.80	1,432.80	1,432.80
Annual Permit Renewal - Carbon Adsorber		641.50			1,540.30	
Toxic Emission Fee	233.89	23.39		1,871.10	187.11	
Carbon Replacement Cost		10,305.00			1,210.00	
Electricity Cost (Control Equipment)		38.29			965.00	
Spent Carbon Disposal Cost		4,500.00				
Maintenance Labor					5,148.00	
Maintenance Materials					5,148.00	
Steam					1,369.00	
Cooling Water					157.00	
Overhead					6,178.00	
Total Annualized Cost	13,114.73	29,741.12	25,016.05	102,389.43	139,648.26	197,600.00
Recovery Credits					(40,493.00)	
Total Annual Cost	$ 13,114.73	$ 29,741.12	$ 25,016.05	$ 102,389.43	$ 99,155.26	$ 197,600.00
Annual Cost Per 100 feet of film	$ 0.29	$ 0.67	$ 0.56	$ 0.29	$ 0.28	$ 0.55

Table B-5

INCREMENTAL COSTS FOR FILM CLEANING ALTERNATIVES

Case	Annualized Capital Cost			Operating Cost			Grand Total	Increment Over Base
	Equipment	Regulatory Cost	Total	O & M	Regulatory Cost	Total		
S-B	$0.26	$0.01	$0.27	$0.02	$0.01	$0.03	$0.29	
S-1	$0.28	$0.02	$0.30	$0.35	$0.02	$0.37	$0.67	**$0.38**
S-2	$0.26	$0.01	$0.27	$0.29	$0.00	$0.29	$0.56	**$0.27**
L-B	$0.26	$0.00	$0.26	$0.02	$0.01	$0.03	$0.29	
L-1	$0.30	$0.01	$0.31	$0.07	$0.01	$0.08	$0.28	**($0.01)**
L-2	$0.26	$0.00	$0.26	$0.29	$0.00	$0.29	$0.55	**$0.26**

APPENDIX C

COST CALCULATION SPREADSHEET FOR CASE L-1

Case L-1: Regenerative Carbon Adsorber Serving 8 Perc Film Cleaning Machines

TOTAL ANNUAL COST SPREADSHEET PROGRAM--CARBON ADSORBERS [1]

COST BASE DATE: Third Quarter 1989 [2]

VAPCCI (Fourth Quarter 1998--FINAL): [3]	102.5
INPUT PARAMETERS:	
-- Inlet stream flowrate (acfm):	1000
-- Inlet stream temperature (oF):	77
-- Inlet stream pressure (atm):	1
-- VOC to be condensed:	PERCHLOROETHYLENE
-- Inlet VOC flowrate (lb/hr):	10.4496
-- VOC molecular weight (lb/lb-mole):	165.85
-- VOC inlet volume fraction:	4.116519E-04
-- VOC inlet concentration (ppmv):	412
-- VOC inlet partial pressure (psia):	0.0060
-- Required VOC removal (fraction):	0.900
-- Freundlich isotherm equation constants for VOC (see Table 1 below):	
VOC number (enter Table 1 # or zero,	0
K:	0.000
M:	0.000
-- Yaws isotherm equation constants (see Table 2 below):	
VOC number (enter Table 2 #or zero,	39
	1.40596
	0.20802
	-0.02097
-- Adsorption time (hr):	24.0
-- Desorption time (hr):	8.0
-- Number of adsorbing vessels:	1
-- Superficial carbon bed velocity (ft/min):	75
-- Carbon price ($/lb):	2.29
-- Material of construction (see list below):[4]	1
DESIGN PARAMETERS:	
-- Carbon equilibrium capacity--Freundlich (lb VOC	0.0000
" " "	0.5100
-- Carbon working capacity (lb VOC/lb carbon):	0.2550
-- Number of desorbing vessels:	1
-- Total number of vessels:	2
-- Carbon requirement, total (lb):	1967
-- Carbon requirement per vessel (lb):	983
-- Gas flowrate per vessel (acfm):	1000
-- Adsorber vessel diameter (ft):	4.120
-- Adsorber vessel length (ft):	6.459
-- Adsorber vessel surface area (ft2):	110.27
-- Carbon bed thickness (ft):	2.459
-- Carbon bed pressure drop (in. w.c.): [5]	8.315

Case L-1: Regenerative Carbon Adsorber Serving 8 Perc Film Cleaning Machines

CAPITAL COSTS

Equipment Costs ($):	
-- Adsorber vessels	21,039
-- Carbon	4,504
-- Other equipment (condenser, decanter, etc.)	33,777
Total equipment cost ($)--base:	59,321
' ' ' ' --escalated:	67,431
Purchased Equipment Cost ($):	72,826
Total Capital Investment ($):	117,249
" " " ($/	117.2

ANNUAL COST INPUTS:

Operating factor (hr/yr):	6240
Operating labor rate ($/hr):	12.00
Maintenance labor rate ($/hr):	13.20
Operating labor factor (hr/sh):	0.0
Maintenance labor factor (hr/sh):	0.5
Electricity price ($/kWhr):	0.09
Recovered VOC value ($/lb):	0.6900
Steam price ($/1000 lb):	6.00
Cooling water price ($/1000 gal):	0.20
Carbon replacement labor ($/lb):	0.05
Overhead rate (fraction):	0.6
Annual interest rate (fraction):	0.07
Control system life (years):	10
Capital recovery factor (system):	0.1424
Carbon life (years):	5
Capital recovery factor (carbon):	0.2439
Taxes, insurance, admin. factor:	0.04

ANNUAL COSTS:

Item	Cost ($/yr)	Wt. Factor	W.F.(cond.)
Operating labor	0	0.000	----
Supervisory labor	0	0.000	----
Maintenance labor	5,148	0.126	----
Maintenance materials	5,148	0.126	----
Electricity	965	0.024	----
Steam	1,369	0.034	----
Cooling water	157	0.004	----
Carbon replacement	1,210	0.030	----
Overhead	6,178	0.151	0.403
Taxes, insurance, administrative	4,690	0.115	----
Capital recovery	15,987	0.391	0.506
Total Annual Cost (without credits)	40,852	1.000	0.933
Recovery credits	(40,493)		
Total Annual Cost (with credits)	360		
" " " ($	0.96		

Case L-1: Regenerative Carbon Adsorber Serving 8 Perc Film Cleaning Machines

Notes:
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[1] This program has been based on data and procedures in Chapter 4 of the OAQPS CONTROL COST MANUAL (5th edition).

[2] Base equipment costs reflect this date.

[3] VAPCCI = Vatavuk Air Pollution Control Cost Index (for carbon adsorbers) corresponding to year and quarter shown. Base equipment cost, purchased equipment cost, and total capital investment have been escalated to this date via the VAPCCI and control equipment vendor data.

[4] Enter one of the following: carbon steel--'1'; 316 stainless steel--'1.3'; Carpenter 20 (CB-3)--'1.9'; Monel-400--'2.3'; Nickel-200--'3.2'; titanium--'4.5'.

[5] This is the carbon bed pressure drop ONLY. There will be additional pressure drop through the ductwork . For estimating ductwork pressure losses, see Chapter 10 of the OAQPS CONTROL COST MANUAL (5th edition).