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Chromium Emissions from Chromium Electroplating and Chromic Acid Anodizing Operations--Background Information for Proposed Standards

Volume II

NESHAP

Office of Air Quality
Clean Air
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Planning and Standards

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Volume II

U. S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

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ABBREVIATIONS USED IN THIS DOCUMENT

A	= ampere
acfm	= actual cubic feet per minute
acmm	= actual cubic meters per minute
Ah	= ampere-hour
ANSI	= American National Standards Institute
atm	= atmospheres
BACT	= best available control technology
BID	= background information document
CAA	= Clean Air Act
cm	= centimeter
cm^2	= square centimeter
cm^3	= cubic centimeter
°C	= degrees centigrade
Cr	= chromium
Cr^2	= chromium (II)
Cr^6	= hexavalent chromium
CrO_3	= chromium anhydride, commonly known as chromic acid
ΔP	= pressure drop
dscf	= dry standard cubic foot
dscfm	= dry standard cubic feet per minute
dscm	= dry standard cubic meter
EO	= Executive Order
°F	= degrees Fahrenheit
ft	= foot
ft^2	= square foot
ft^3	= cubic foot
g	= gram
GACT	= generally available control technology
gal	= gallon
gal/min	= gallons per minute
gr	= grain
hr	= hour
hp	= horsepower
in.	= inch

in.^{2} = square inch
in. w.c. = inches of water column
kg = kilogram
kPa = kilopascal
kW = kilowatt
L = liter
L/G = liquid to gas [ratio]
LAER = lowest achievable emission rate
lb = pound
lb_f/ft = pound force per foot
m = meter
m^2 = square meter
m^3 = cubic meter
MACT = maximum available control technology
mg = milligram
Mg = megagram
mil = thousandth of an inch
min = minute
MW = megawatt
μg = microgram
μm = micrometer
NEPA = National Environmental Policy Act
NESHAP = national emission standards for hazardous air pollutants
ng = nanogram
NSPS = new source performance standard
OSHA = Occupational Safety and Health Administration
oz = ounce
P = pressure
psi = pounds per square inch
PVC = polyvinyl chloride
RACT = reasonably available control technology
RCRA = Resource Conservation and Recovery Act
RFA = Regulatory Flexibility Act
RIA = Regulatory Impact Analysis
SIC = Standard Industrial Classification (code)

TLV	=	threshold limit value
V	=	volt
wt	=	weight
yr	=	year

GLOSSARY OF ELECTROPLATING TERMS

Activation:	Process in which the conductivity of the part to be plated is increased.
Ampere:	Current flowing at a rate of one coulomb per second.
Anion:	A negatively charged ion.
Anode:	The electrode at which current enters or electrons leave the solution; also, the positive electrode at which negative ions are discharged, positive ions are formed, or at which other oxidizing reactions occur.
Anodizing:	A surface treatment of metals, particularly aluminum; the part to be plated serves as the anode and an oxide film is produced as an integral part of the base metal.
Baffle:	A device used to regulate the flow of gas by deflecting the gas.
Base metal:	The underlying metal or alloy system onto which the plated metal is deposited; for example, in the chromium electroplating of steel in the automotive industry, the steel is the base metal.
Brightener:	An agent added to electroplating baths that helps form a bright plate or improves the brightness of the deposit.
Bright plating:	Electroplating to provide a highly brilliant or polished-appearing surface; most decorative plating is done with brighteners.
Buffing:	Smoothing a surface using fine abrasive particles in liquid suspension, paste, or grease stick form.

Burnt deposit:	A rough, noncoherent, or otherwise unsatisfactory deposit produced by the application of excessive current density and usually containing oxides or other inclusions.
Bus (bus bar):	A rigid conducting section, usually copper, for carrying current to the anode and cathode bars.
Capture efficiency:	A measure of the effectiveness of a ventilation system to overcome opposing air currents and direct contaminated air from the process vessel into the ventilation hood.
Capture velocity:	Air velocity at any point in front of the ventilation hood or at the hood opening necessary to overcome opposing air currents and to capture the contaminated air at that point by causing it to flow into the hood.
Cathode:	The electrode through which current leaves or electrons enter the solution; the negative electrode. Also, the electrode at which positive ions are discharged, negative ions are formed, or other reducing reactions occur. In electroplating, the cathode typically is the workpiece to be plated.
Cathode efficiency:	The current efficiency of a specified cathodic process.
Cation:	A positively charged ion.
Chemical fume suppressants:	Surface-active compounds that reduce or suppress fumes at the surface of a solution.
Chromic acid:	The common name for chromium anhydride (CrO_3).
Cleaning:	The removal of grease or other foreign material from the surface of a part.

Alkaline: Cleaning by means of an alkaline solution.

Anodic (reverse): Electrolytic cleaning in which the workpiece is the anode.

Cathodic (direct): Electrolytic cleaning in which the workpiece is the cathode.

Emulsion: Cleaning by means of solutions containing organic solvents, water, and emulsifying agents.

Soak: Alkaline cleaning without the use of current.

Solvent: Cleaning by means of organic solvents.

Colloidal particle: An electrically charged particle, generally smaller than 200 millimicrons, dispersed in a second phase.

Coloring (color buffing): Light buffing of metal surfaces to produce a high luster.

Complexing agent: A compound capable of forming a complex ion with a metal ion.

Conversion coating: A coating produced by chemical or electrochemical treatment of a metallic surface that gives a superficial layer of a compound of the metal.

Correlation coefficient(r): A measure of interdependence of two random variables that range in value from -1 to +1. The perfect negative correlation is indicated at -1, absence of correlation at 0, and perfect positive correlation at +1.

Coulomb: The quantity of electricity which passes any section of an electric circuit in one second when the current in the circuit is one ampere.

Covering power: The ability of a plating solution to produce a deposit at very low current densities.

Current density:	A measure of the flow of ionic species at the electrodes. Expressed as amperes per square foot, this is one of several important process parameters in the control of the overall electroplating operation. Current density is equal to the total current divided by the total area of the electrode in the solution.
Current efficiency:	Percentage of applied current used to deposit metal on a part being plated; remaining current is used in side reactions.
Decorative chromium plating:	Chromium plating for decorative purposes.
Degreasing:	The removal of grease and oils from a surface.
Solvent:	Degreasing by immersion in liquid organic solvents.
Vapor:	Degreasing by solvent vapors condensing on the parts being plated.
Desmut:	The removal of soil or grease films that cleaners and etchants leave behind.
Detergent:	A surface-active agent that can clean soiled surfaces.
Anionic:	A detergent that produces aggregates of negatively charged ions with colloidal properties.
Cationic:	A detergent that produces aggregates of positively charged ions with colloidal properties.
Nonionic:	A detergent that produces aggregates of electrically neutral molecules with colloidal properties.
Dielectric:	A material or medium that does not conduct electricity and that can sustain an electrical field.

Dielectric strength:	The maximum potential gradient that a dielectric material can withstand without rupture.
Direct interception:	Collection of particles, due to their size and relative velocity, by interception with a fluid boundary around the collection surface.
Drag-in:	The water or solution that adheres to objects introduced into a bath.
Drag-out:	The water or solution that adheres to objects removed from a bath.
Dummy:	A cathode in a plating tank that is used for working the solution but that is not to be used after plating.
Dummying:	Plating with dummy cathodes.
Effluent:	Liquid which flows away from a contained space or a main waterway.
Electrochemical equivalent:	The weight of an element, compound, radical, or ion involved in a specified electrochemical reaction during the passage of a unit quantity of electricity, such as a Faraday.
Electrochemistry:	The science that deals with the use of electrical energy to bring about a chemical reaction and the use of chemical action to generate electrical energy.
Electrodeposition:	The process of depositing a substance upon an electrode by electrolysis. Includes electroplating.
Electroless plating:	Depositing of a metallic coating by a controlled chemical reduction, which is catalyzed by the metal or alloy being deposited.

Electrolyte:	A conducting medium in which the flow of current is accompanied by movement of matter. Most often an aqueous solution of acids, bases, or salts but includes many other media such as fused salts, ionized gases, some solids, etc.
Electrolysis:	Production of chemical changes by the passage of current through an electrolyte.
Electroplating:	The electrodeposition of an adherent metallic coating upon an electrode (workpiece) to obtain a surface with properties or dimensions different from those of the base metal.
Face velocity:	The velocity of the gas stream across the face (front) of a given surface.
Faraday:	The number of coulombs (96,490) required for an electrochemical reaction involving one chemical equivalent.
Faraday's Law:	(1) The amount of any substance dissolved or deposited in electrolysis is proportional to the total electric charge passed. (2) The amounts of different substances dissolved or deposited by the passage of the same electric charge are proportioned to their equivalent weights.
Frequency distribution:	A function that measures the relative frequency or probability that a variable can take on a set of values.
Grinding:	The removal of metal by means of rotating rigid wheels containing abrasives.
Hard chromium plating:	Chromium plating for engineering or functional purposes rather than decorative applications.

Heat exchanger: Any device that transfers heat from one fluid to another or to the environment.

Hexavalent chromium: The form of chromium in a valence state of +6.

Horsepower: The unit of power in the British engineering system equal to 550 foot-pounds per second, approximately 745.7 watts.

Inertial impaction: Collection of particles by their collision with and adhesion to a stationary surface.

Influent: A input stream of a fluid into a contained space or main waterway.

Inlet loading: Uncontrolled concentration of the pollutant.

Ion: An atom or group of atoms which has lost or gained one or more electrons, thereby acquiring a net electrical charge.

Kilowatt: A unit of power equal to 1,000 watts.

Kilowatt-hour: A unit of energy or work equal to 1,000 watt-hours.

Leveling action: The ability of a plating solution to produce a smoother surface than that of a base metal.

Linear regression: The straight line running among the points of a scatter diagram and about which the amount of scatter is smallest.

Liquid-to-gas ratio: A design operating parameter for scrubbers that is set at a value to optimize performance. It is the amount of liquid flow compared to the gas flow, expressed in liters per minute to 1,000 cubic meters per minute.

Mist eliminator:	A device that removes liquid mist or droplets from a gas stream via impingement, flow-direction change, velocity change, centrifugal force, filters, or coalescing packs.
Oxidation:	A reaction in which electrons are removed from a reactant.
Packed bed:	A fixed layer of small particles or objects arranged in a vessel to promote intimate contact between gases, vapors, liquids, solids, or various combinations thereof.
Passivation:	The treatment of a metal to form a protective coating on its surface and reduce its chemical activity.
Periodic reverse:	A method of plating in which the current is reversed periodically.
Polishing:	Smoothing a metal surface with abrasive particles attached by adhesive to the surface of wheels or belts.
Polypropylene:	A crystalline, thermoplastic resin made by the polymerization of propylene. The product is hard and tough; resists moisture, oils, and solvents; and withstands temperatures up to 170 degrees centigrade.
Pressure drop:	The difference in pressure between two points in a flow system, usually caused by frictional resistance to a fluid or gas flowing through a conduit, filter media, or other flow-conducting system.
Rack:	A frame for suspending articles during plating and related operations.
Rectifier:	A device which converts alternating current into direct current by permitting appreciable flow of current in one direction.

Reduction:	A chemical reaction in which electrons are added to the reactant.
Reentrainment:	Reentry into the gas stream of previously collected particles.
Reentrainment velocity:	The velocity at which particle reentry occurs.
Scrubber:	A device that removes entrained liquid droplets, dust, or an undesired gas component from the process gas stream via impaction or direct interception.
Shield:	To alter the normal current distribution on an anode or cathode by the interposition of a nonconductor.
Slot velocity:	Air velocity through the openings in a slot-type hood. It is used primarily as a means of obtaining air distribution across the face of the hood.
Smut:	Anything that fouls or soils the external surface of the base metal in electroplating processes; removal of smut is a critical initial step in the electroplating process.
Strike:	A solution used to deposit a thin initial film of metal.
Surface active agent:	A soluble or colloidal substance that affects markedly the surface energy of solutions even when present in very low concentrations.
Surface tension:	The property, due to molecular forces, that exists in the surface film of all liquids and tends to prevent liquid from spreading.
Tarnish:	Dulling, staining, or discoloration of metals due to superficial corrosion.
Thermocouple:	A device that is used to measure temperature.

Throwing power:	The improvement of the coating distribution ratio over the primary current distribution ratio on an electrode. Also, a measure of the degree of uniformity with which metal is deposited on an irregularly shaped cathode.
Trivalent chromium:	The form of chromium in a valence state of +3.
Volt:	The electromotive force that will produce a current of one ampere through a resistance of one ohm.
Watt:	The unit of power in the metric system of units, equal to one joule per second.
Wetting agent:	A substance that reduces the surface tension of a liquid, thereby causing it to spread more readily on a solid surface.
Workload:	The amount of work in the process tank at a given time.
Workpiece:	The material being plated or otherwise finished.

APPENDIX A.

EVOLUTION OF THE BACKGROUND INFORMATION DOCUMENT

APPENDIX A. EVOLUTION OF THE BACKGROUND INFORMATION DOCUMENT

The source category survey (Phase I) for chromium emissions from chromium electroplating operations was begun in October 1984 by the U. S. Environmental Protection Agency (EPA). The study to develop a national emission standard for chromium emissions from chromium electroplating and chromic acid anodizing operations was initiated in September 1985. Table A-1 lists major events and accomplishments in the evolution of the background information document (BID) for the standard.

In December 1985, an effort was begun to obtain the information needed to develop the BID (Phase II). The information gathering effort included literature surveys; canvassing of State, regional, and local air pollution control agencies; site visits; meetings with industry representatives; contact with engineering consultants and equipment vendors; industry surveys; and emission testing.

Sixty-eight sites were visited to gather background information on each type of operation and to identify test candidates. The number of operations visited within each source category was 30 hard chromium plating operations; 19 decorative chromium plating operations; and 6 chromic acid anodizing operations. Additional site visits were made to six trivalent chromium plating operations and six control device vendors. As a result of the site visits, 19 emission tests were conducted at 14 hard chromium plating, 4 decorative chromium plating, and 1 chromic acid anodizing operations to determine uncontrolled hexavalent chromium emission levels and to establish performance levels for the various systems used to control chromic acid mist.

The control systems tested were packed-bed scrubbers, chevron-blade mist eliminators, mesh-pad mist eliminators, a trivalent chromium plating process, and chemical fume suppressants.

In order to assess operating practices and existing levels of control in the industry, industry surveys were mailed to 180 electroplating operations in June 1987. The 180 electroplating operations included 60 hard and 60 decorative chromium plating operations, 30 chromic acid anodizing operations, and 30 operations where the type of plating operation was unknown. Fifteen additional surveys were mailed in October 1987 to replace those from the first mailout sent to operations that were found to be permanently closed or that no longer performed chromium plating. The overall response rate from the industry survey was 75 percent.

Chapters 3 through 5 of the draft BID, which describe the industry, emission control techniques, model plants, and regulatory alternatives (control options), were completed in February 1987 and mailed to industry for review and comment. Industry comments on the draft BID were analyzed and incorporated into a revised version that was submitted to the EPA Work Group in May 1987 for internal review. The Work Group commented on the representativeness of the model plants and the need for additional test data. In March 1988, an evaluation of the results of the industry survey and information gathered from numerous plant visits led to revisions in the model plants and emission estimating techniques. Additional site visits and source tests were conducted in the second half of 1988 and early 1989. Following the source tests, an analysis of the test data was performed and used as a basis for revisions to the control options. As a result of these changes, final revisions were made to the draft BID during the spring and summer of 1989.

In February 1989, industry surveys were mailed to six decorative chromium electroplating operations to obtain additional production cost data for use in assessing economic impacts. The response rate for this survey was 100 percent.

In late 1989 and early 1990, new control technologies became available and were installed by selected plants in an attempt to meet the strict chromium standard set by the State of California for large hard chromium electroplaters. As a result of these developments, EPA decided to obtain information on the new technologies and gather source test information on these systems to determine if a more stringent level of control for chromium emissions beyond that currently demonstrated was achievable. All information gathered on these new control technologies was compiled into a separate document entitled Technical Assessment of Innovative Emission Control Technologies Used in the Chromium Electroplating Industry. A separate document was prepared because the BID was finalized before all of the information regarding the newer control technologies was obtained.

TABLE A-1. EVOLUTION OF THE BACKGROUND INFORMATION DOCUMENT

Date	Event
10/29/84	Site visit to Greensboro Industrial Platers, Greensboro, North Carolina
12/20/84	Site visit to Gibbs Plating Company, Charlotte, North Carolina
03/07/85	Site visit to Carolina Plating Company, Greenville, South Carolina
03/07/85	Site visit to T&S Brass and Bronze Works, Travelers Rest, South Carolina
03/14/85	Site visit to C. S. Ohm Manufacturing Company, Sterling Heights, Michigan
03/14/85	Site visit to Modern Hard Chrome Service Company, Warren, Michigan
03/15/85	Site visit to Chevrolet-Pontiac-Canada Group, Livonia, Michigan
03/15/85	Site visit to General Plating Incorporated, Detroit, Michigan
04/25/85	Phase I Section 114 information requests mailed
05/15-16/85	Emission testing at Carolina Plating Company, Greenville, South Carolina
06/18-20/85	Emission testing at C. S. Ohm Manufacturing Company, Sterling Heights, Michigan
09/25/85	EPA concurrence meeting on decision to proceed to Phase II
12/06/85	Phase I technical report submitted
12/19/85	Site visit to Lufkin® Rule, Apex, North Carolina
01/07/86	Site visit to OMI International Corporation, Warren, Michigan
01/08/86	Site visit to CRECO, Incorporated, Owosso, Michigan
01/08/86	Site visit to Duall Industries, Owosso, Michigan
01/08/86	Site visit to Tri-Mer® Corporation, Owosso, Michigan
01/28/86	Site visit to Martin Marietta Aerospace, Orlando, Florida
03/13/86	Site visit to Saxonia Franke of America, Spartanburg, South Carolina
03/13/86	Site visit to Steel Heddle Company, Greenville, South Carolina
03/18-26/86	Emission testing at Greensboro Industrial Plating Company, Greensboro, North Carolina
03/21/86	Site visit to Metals Applied, Incorporated, Cleveland, Ohio
03/27/86	Site visit to Able Machine Company, Taylors, South Carolina
03/27/86	Site visit to C&R Chrome Services, Inc., Gastonia, North Carolina
05/02/86	Site visit to Consolidated Engravers Corp., Charlotte, North Carolina
05/22/86	Site visit to Diamond Chrome Plating, Inc., Howell, Michigan
05/23/86	Site visit to Maremont Corporation, Pulaski, Tennessee
05/29/86	Site visit to Piedmont Industrial Plating, Statesville, North Carolina
06/04/86	Site visit to E. F. Brewer Company, Menomonee Falls, Wisconsin
06/05/86	Site visit to Briggs and Stratton, Glendale, Wisconsin
06/05/86	Site visit to G. E. Medical Systems, Milwaukee, Wisconsin
06/05/86	Site visit to Milwaukee Plating Company, Milwaukee, Wisconsin
06/24-25/86	Emission testing at Steel Heddle, Inc., Greenville, South Carolina
06/30-07/01/86	Emission testing at Able Machine Company, Taylors, South Carolina
07/09/86	First draft of BID Chapters 3 through 5 completed
07/15/86	Preliminary model plant parameter memorandum submitted
08/02/86	Site visit to Briggs and Stratton, Glendale, Wisconsin

TABLE A-1. (Continued)

Date	Event
08/19-22/86	Emission testing at Piedmont Industrial Plating, Statesville, North Carolina
09/04/86	Site visit to Reliable Plating Works, Milwaukee, Wisconsin
09/05/86	Site visit to Chrome Craft Corporation, Highland Park, Michigan
11/10/86	Site visit to KCH Services, Inc., Forest City, North Carolina
11/10/86	Site visit to Duall Industries, Forest City, North Carolina
11/23/86	Cost enclosures mailed to scrubber and mist eliminator vendors
12/08/86	Site visit to United Metal Finishing, Inc., Greensboro, North Carolina
12/17/86	Site visit to Hamilton Standard, Windsor Locks, Connecticut
12/17/86	Site visit to Pratt and Whitney, East Hartford, Connecticut
12/18/86	Site visit to Reliable Plating and Polishing Company, Bridgeport, Connecticut
01/21/87	Site visit to Delco Products Division, Livonia, Michigan
01/22/87	Site visit to Buick-Oldsmobile-Cadillac Group, Detroit, Michigan
02/12/87	MRI presentation of test data at AES Chromium Colloquium in San Diego, California
02/12/87	Mail out of draft BID Chapters 3 through 5 to industry
03/03/87	Site visit to Consolidated Engravers Corporation, Charlotte, North Carolina
03/26/87	First draft of BID Chapter 6 completed
03/30/87	First draft of BID Chapter 7 completed
04/08/87	Site visit to Norfolk Naval Air Rework Facility, Norfolk, Virginia
04/08/87	Site visit to Norfolk Naval Shipyard, Norfolk, Virginia
04/18-19/87	Emission testing at Delco Products Division, Livonia, Michigan
05/01/87	MRI presentation on status of NESHAP development to AESF conference in Charlotte, North Carolina
05/08/87	BID Chapters 3 through 5 mailed out to Work Group
05/12-14/87	Emission testing at Consolidated Engravers Corporation, Charlotte, North Carolina
05/13/87	Cost enclosures mailed to trivalent chromium process vendors
06/15/87	Site visit to Naval Aviation Depot, Jacksonville, Florida
06/24/87	Human Exposure Model inputs submitted to Pollutant Assessment Branch
06/30/87	Phase II Section 114 information requests mailed
08/12/87	Site visit to A-1 Chrome, Newington, Connecticut
09/22-24/87	Emission testing at Roll Technology, Greenville, South Carolina
11/09/87	Site visit to Lufkin® Rule, Apex, North Carolina
11/24/87	Work Group package mailed
11/30/87	Site visit to Douglas Aircraft, Long Beach, California
11/30/87	Site visit to Universal Gym and Nissen Company, Cedar Rapids, Iowa
12/02/87	Site visit to Engelhard Corporation, Beachwood, Ohio
12/07/87	Site visit to Custom Processing Company, High Point, North Carolina
12/07/87	Site visit to Swaim Metals, Inc., High Point, North Carolina
12/17/87	First Work Group meeting on project status

TABLE A-1. (Continued)

Date	Event
01/12/88	Site visit to Pitney Bowes, Inc., Stamford, Connecticut
01/13/88	Site visit to Arlington Plating Company, Palatine, Illinois
01/13/88	Site visit to Automatic Die Casting Specialties, St. Clair Shores, Michigan
01/14/88	Site visit to LECO Plating Company, St. Joseph, Michigan
01/18/88	Site visit to Plant ABC, Southeastern United States
01/20/88	Site visit to Monroe Auto Equipment, Paragould, Arkansas
01/21/88	Site visit to Hager Hinge Company, Montgomery, Alabama
01/25/88	Site visit to Saco Defense, Inc., Saco, Maine
02/10/88	Site visit to Vermont American Corporation, Toccoa, Georgia
03/24/88	Revised model plant parameters submitted
03/31/88	Site visit to Saco Defense, Inc., Saco, Maine
04/19-26/88	Emission testing at Automatic Die Casting Specialties, St. Clair Shores, Michigan
06/13/88	Revised Human Exposure Model inputs submitted to Pollutant Assessment Branch
06/30/88	BID Chapters 3 through 7 revised per model plants and available test data
07/15/88	Revised model plant parameter memo submitted
07/29/88	First draft of BID Chapters 1 and 2 and Appendices A, B, and C completed
08/08-12/88	Emission testing at Roll Technology, Inc., Greenville, South Carolina
08/23/88	Final model plant parameters submitted
09/19-23/88	Emission testing at Precision Machine and Hydraulics, Inc., Worthington, West Virginia
10/05/88	Site visit to Saco Defense, Inc., Saco, Maine
10/11/88	Meeting with California Air Resources Board and Metal Finishing Association
12/14/88	Site visit to Piedmont Industrial Plating, Statesville, North Carolina
01/23-26/89	Monitored demonstration tests conducted by California Air Resources Board at Electronic Chrome Company, Santa Fe Springs, California
01/25/89	Site visit to Electrolyzing, Inc., Los Angeles, California
01/25/89	Site visit to Chromal Plating Company, Los Angeles, California
01/30-02/01/89	Emission testing at Hard Chromium Specialists, York, Pennsylvania
01/31/89	BID Chapters 3 and 4 and Appendix C updated with available test data
02/14/89	Section 114 cost data information requests mailed
03/14/89	Site visit to Precise Products, Waco, Texas
03/14/89	Site visit to Fusion, Inc., Houston, Texas
04/05/89	Draft of BID Appendix C submitted
05/01-02/89	Site visit to Fusion, Inc., Houston, Texas
05/17-24/89	Emission testing at Fusion, Inc., Houston, Texas
05/17/89	Final regulatory alternative (control option) memo submitted
06/14/89	Draft of BID Chapter 4 submitted
06/20/89	Drafts of BID Chapters 3, 5, and 6 submitted

TABLE A-1. (Continued)

Date	Event
06/29/89	Draft of BID Chapter 7 submitted
06/30/89	Obtained ISB/SDB concurrence on regulatory alternatives (control options)
07/07/89	Draft of BID Appendix B submitted
07/18/89	First draft of BID Appendix G submitted
07/20/89	First draft of BID Appendix H submitted
08/24/89	First draft of BID Appendices F and G submitted
08/30-31/89	Site visit to Remco Hydraulics, Willits, California
09/06/89	Cost enclosures mailed to fiber-bed mist eliminator and ChromeScrub™ vendors
01/04/90	Draft of emerging technology assessment document submitted
06/06/90	Work Group Package mailout
05/13/90	Work Group meeting on project status
08/17/90	Mailed out cost enclosures to advanced mesh-pad mist eliminator and extended packed-bed scrubber vendors
08/18/90	Final trivalent chromium annual cost memo submitted
09/14,17/90	Emission Standards Division Briefing on project status
09/26/90	Work Group meeting on project status
12/13/90	Draft of BID submitted
01/14/91	Docket sent to Washington, D.C.
01/30/91	NAPCTAC meeting
02/01/91	Site visit to Remco Hydraulics, Willits, California
03/20/91	Site visit to OMI/Udylite, Warren, Michigan
03/21/91	Site visit to Harshaw/M&T, Beachwood, Ohio
04/24/91	Site visit to Naval Aviation Depot, Alameda, California
04/25/91	Site visit to Remco Hydraulics, Willits, California
06/14/91	Work Group meeting
06/19-21/91	Emission testing at Remco Hydraulics, Willits, California
09/24-27/91	Test demonstration for trivalent chromium plating process at True Temper Sports, Seneca, South Carolina
10/30/91	Site visit to Electronic Chrome and Grinding Company, Santa Fe Springs, California
10/31/91	Site visit to Precision Engineering, Seattle, Washington
11/19/91	NAPCTAC meeting
12/16-20/91	Test demonstration at Precision Engineering, Seattle, Washington
02/18-20/92	Test demonstration for fume suppressant at Electronic Chrome and Grinding Company, Santa Fe Springs, California

APPENDIX B.

INDEX TO ENVIRONMENTAL IMPACT CONSIDERATIONS

APPENDIX B. INDEX TO ENVIRONMENTAL IMPACT CONSIDERATIONS

This appendix provides a cross reference between the Agency guidelines for preparation of environmental impact statements presented in the October 21, 1979, Federal Register (39 FR 37419), and the location of pertinent information in this document.

TABLE B-1. INDEX TO ENVIRONMENTAL IMPACT CONSIDERATIONS

Agency guidelines for preparing regulatory action environmental impact statements (39 FR 37419)	Location within the background information document
1. Background and description	
a. Summary of control options	The control options and their associated impacts are summarized in Chapter 1; a detailed description of the control options is provided in Chapter 5, Section 5.3.
b. Statutory basis for proposing standards	The statutory basis for proposing standards is summarized in Chapter 2.
c. Relationship to other regulatory agency actions	The various relationships with other regulatory agency actions are discussed actions in Chapter 3, Section 3.4; Chapter 6, Sections 6.4 through 6.7; and Chapter 7, Section 7.7.
d. Industry affected by the control options	A discussion of the industry affected by the control options is options presented in Chapter 3, Section 3.1. Further details covering the "business/economic" nature of the industry are presented in Chapter 8.
e. Specific processes affected by the control options	The specific processes and operations affected by the control options are summarized in Chapter 5, Section 5.3. A detailed technical discussion of the processes and operations affected by the control options is presented in Chapter 3, Section 3.2.
2. Impacts of the control options	
a. Air pollution	The air pollution impacts of the control options are discussed in Chapter 6, Section 6.2. Supplementary information regarding emission measurements and estimates is presented in Appendix C. The methodology used during emission testing is discussed in Appendix D.
b. Water pollution	The water pollution impacts of the control options are discussed in Chapter 6, Section 6.4 and Chapter 7, Section 7.7.
c. Solid waste disposal	The impact of the control options on solid waste disposal is discussed in Chapter 6, Section 6.5 and Chapter 7, Section 7.7.
d. Energy impact	The energy impacts are discussed in Chapter 6, Section 6.3.
e. Economic impact	The cost of control options and the economic impacts of the control options are discussed in Chapters 7 and 8. Supplementary information regarding the bases for costs of emission control techniques is presented in Appendix F and Appendix G.

APPENDIX C.

SUMMARY OF TEST DATA

APPENDIX C. SUMMARY OF TEST DATA

The results of 11 EPA-conducted chromium emissions tests for 9 hard and 2 decorative chromium electroplating operations are presented in this appendix. Information about the processes and air pollution control techniques evaluated and operating conditions during each test are presented in Section C.1. Tabular summaries of the emissions test data are presented in Section C.2. Test methodologies are described in Appendix D. In addition, the results of an engineering analysis to determine the amount of hexavalent chromium emissions from chromic acid anodizing operations are presented in Section C.3.

C.1 DESCRIPTION OF SOURCES

A description of the emissions source, data on operating conditions of the process and control equipment, and a schematic of the system tested are presented in this section for each hard and decorative chromium plating facility tested. All information has been obtained from the EPA-conducted tests cited in Chapters 3 and 4.

C.1.1 Hard Chromium Electroplating Test Facilities

C.1.1.1 Plant A--EPA Test.[1] Plant A is Greensboro Industrial Platers in Greensboro, North Carolina. Greensboro Industrial Platers is a medium-size job shop that performs hard chromium electroplating of textile, hydraulic, woodworking, and laundry machine parts.

C.1.1.1.1 Process description. The hard chromium plating facility consists of six tanks; however, emissions testing was conducted only on the chevron-blade mist eliminator controlling chromium emissions from Tank 6. This tank is 6.4 m (21 ft) long, 0.9 m (3 ft) wide, and 1.8 m (6 ft) deep and has a capacity of

9,800 L (2,590 gal). Based on size, chromic acid concentration, and operating parameters such as current, voltage, and plating time, Tank 6 is typical of hard chromium plating tanks in the electroplating industry. The plating solution used in Tank 6 is a conventional chromic acid solution containing chromic acid in a concentration of 255 g/L (34 oz/gal) of plating solution. Sulfuric acid in a concentration of about 2.55 g/L (0.34 oz/gal) of solution is added as a catalyst. About 5,500 kg (12,000 lb) of chromic acid are consumed by the plant per year.

C.1.1.1.2 Air pollution control. As shown in Figure C-1, two lateral exhaust hoods are installed, one on each side of Tank 6. Emissions are captured by the exhaust system and then vented to a chevron-blade mist eliminator with a single set of sinusoidal-wave-type blades. The mist eliminator was manufactured and installed in 1980 by KCH Services, Incorporated. The design parameters of the mist eliminator include a gas flow rate of 280 standard m^3/min (10,000 standard ft^3/min), cross sectional velocity of 270 m/min (900 ft/min), and a pressure drop of 0.19 kPa (0.75 in. w.c.). The mist eliminator contains 31 chevron blades spaced 3.18 cm (1.25 in.) apart. The blades are approximately 1.2 m (4.0 ft) in height, cover an area of about 1.2 m (4.0 ft) in width, and extend 0.2 m (0.8 ft) back into the unit. The blades are arranged to change the direction of the gas flow four times at 30° angles. The mist eliminator is periodically washed with water, which drains into the plating tank.

C.1.1.1.3 Process conditions during testing. Four emissions tests were conducted at the inlet and outlet of the mist eliminator to characterize uncontrolled chromium emissions from Tank 6 and the performance of the mist eliminator. Test run No. 1 was interrupted three times, run No. 2 was interrupted one time, and run Nos. 3 and 4 were interrupted two times each to unload and reload the tank.

The process was operating normally during the tests. Process operating parameters such as the voltage, current, and temperature were monitored and recorded during each test run.

The maximum operating voltage during testing was 10.5 V, and a direct current ranging from 1,750 to 8,000 A was applied during the tests. The gas flow rate to the mist eliminator was 230 m^3/min (7,970 ft^3/min) during the mass emissions tests. Average operating parameters recorded during the test runs are presented in Table C-1. The total amount of current supplied to the tank during each test run is calculated in terms of ampere-hours. A summary of the total current values is presented in Table C-2.

Grab samples were taken from Tank 6 to determine the chromium concentration of the plating solution during each mass emissions test run. Grab samples of the mist eliminator washdown water also were taken to be analyzed for chromium concentration. The mist eliminator was washed down after each mass emissions test run. The chromic acid concentration of the grab samples is presented in Table C-3.

C.1.1.2 Plant B--EPA Test.[2] Plant B is Consolidated Engravers Corporation located in Charlotte, North Carolina. The plant manufactures and refurbishes industrial rolls for the packing and textile industries. The plant operates six hard chromium plating tanks. Hard chromium plate is applied to the industrial rolls as the final, finishing stage to provide a wear-resistant surface and protection from corrosion.

C.1.1.2.1 Process description. The facility tested consists of two hard chromium plating tanks that are controlled by a chevron-blade mist eliminator with a single set of blades. Emissions tests were performed at the inlet and outlet of the mist eliminator. The tanks are operated from 8 to 10 hours per day, 5 days per week, 51 weeks per year. The chromic acid consumption for the two tanks is about 65 kg (140 lb) per month.

Tank 1 is 1.5 m (5.0 ft) long, 0.7 m (2.3 ft) wide, and 1.8 m (6.0 ft) deep and holds about 1,780 L (470 gal) of plating solution. Tank 2 is 1.8 m (6.0 ft) long, 0.8 m (2.5 ft) wide, and 1.8 m (6.0 ft) deep and holds about 2,350 L (620 gal) of plating solution. The chromic acid concentration of the plating baths is 210 g/L (28 oz/gal) of solution. The normal operating temperature of the plating baths ranges from 43° to 54°C (110° to 130°F). Both tanks are equipped with a circulating water cooling system.

Tank 1 contains two work stations, each of which is equipped with a 3,000-A rectifier. Tank 2 is equipped with one 5,000-A rectifier. Typically, one industrial roll can be plated at a time in each tank. The operating voltage and current for each roll typically range from 10 to 15 V and 1,200 to 1,600 A. About 13 μm (0.5 mil) of chromium plate is applied to each roll.

C.1.1.2.2 Air pollution control. The ventilation system and chevron-blade mist eliminator were manufactured and installed by Duall Industries, Inc., in January 1987 to control chromic acid emissions from the two hard chromium plating tanks tested. A diagram of the capture and control system for the two tanks is presented in Figure C-2.

Both tanks are equipped with double-sided lateral exhaust hoods. The hoods on each side of Tank 1 have one slot that is 1.5 m (4.8 ft) long and 8.9 cm (3.5 in.) wide. The hoods on each side of Tank 2 have three slots. Each slot is 0.4 m (1.3 ft) long and 5.1 cm (2.0 in.) wide.

Exhaust gases from both tanks are ducted together and vented to a horizontal-flow chevron-blade mist eliminator. The mist eliminator contains a single set of overlapping-type blades and is located on the roof of the plating shop. The overlapping-type blade design changes the direction of the gas flow four times, causing chromic acid droplets to impinge on the blades by inertial force. The overlapping edges of the blades act as collection troughs that provide a central location for droplet collection and facilitate drainage of the droplets into the collection sump at the bottom of the mist eliminator. The blades are approximately 1.1 m (3.5 ft) in height, cover an area of about 1.1 m (3.3 ft) in width, and extend 0.2 m (0.8 ft) back into the unit. Design parameters of the mist eliminator include a gas flow rate of 230 standard m^3/min (8,000 standard ft^3/min), gas stream velocity through the blade section of about 190 m/min (520 ft/min), and pressure drop of 0.19 kPa (0.75 in. w.c.).

A moisture extractor is installed in the stack to control chromium emissions that may be drawn through the mist eliminator. The mist eliminator and moisture extractor are equipped with a spray washdown system. The washdown water is drained into a 340-L (90-gal) holding tank and then into the plating tanks to make up for plating solution evaporation losses. The mist eliminator and moisture extractor are washed down one or two times per day depending on the amount of plating solution makeup needed.

C.1.1.2.3 Process conditions during testing. Three emissions tests were conducted at the inlet and outlet of the mist eliminator to characterize uncontrolled emissions and the performance of the mist eliminator. Inlet and outlet testing was conducted simultaneously. The emissions tests were conducted for 180 minutes each.

The gas flow rate to the mist eliminator averaged 150 m^3/min (5,390 ft^3/min). Process operating parameters such as the voltage, current, and plating solution temperature were monitored and recorded during each test. A description (dimension and surface area) and the plating time of each roll plated also was recorded during each test. The average operating conditions recorded during each emissions test run are presented in Table C-4. The total amount of current supplied to the tanks during each emissions test run is calculated in ampere-hours. A tabular summary of the total current values is presented in Table C-5.

Grab samples of the plating solution in each tank and the mist eliminator washdown water were taken to determine the concentration of chromic acid in each. Grab samples of the plating solution in each tank were taken at the beginning, middle, and end of each test run to obtain a composite sample for each tank. The mist eliminator was washed down with about 230 L (60 gal) of water each morning after testing began. Grab samples of the mist eliminator washdown water were taken from the holding tank after the mist eliminator was washed down. The chromic acid concentration of each grab sample is presented in Table C-6.

Industrial rolls used in the textile and packaging industries were chromium plated during testing. Typically, the time required to plate one roll in each work station ranged from 45 to 60 minutes.

During testing, the bath temperature of both plating tanks was higher than normal. The temperature of Tank 1 ranged from 54°C (130°F) to more than 71°C (160°F), and the temperature of Tank 2 ranged from 50° to 64°C (122° to 148°F). The cooling systems for the tanks were unable to maintain the normal operating temperatures when the tanks were operated at full capacity. Although the bath temperatures were higher than normal, the higher temperatures did not adversely affect the plating process.

The emissions test runs were stopped approximately 15 to 20 minutes to change test ports.

C.1.1.3 Plant D--EPA Test.[3] Plant D is Able Machine Company in Taylors, South Carolina. Able Machine Company is a small-size job shop that performs hard chromium electroplating of industrial rolls.

C.1.1.3.1 Process description. Emissions tests were performed on the inlet and outlet of a chevron-blade mist eliminator controlling chromium emissions from one hard chromium plating tank. Figure C-3 shows a schematic of the process tested. The tank is 4.3 m (14.0 ft) long, 1.2 m (4.0 ft) wide, and 3.0 m (10.0 ft) deep and holds about 15,100 L (3,980 gal) of plating solution. The plating bath used is a conventional hard chromium plating solution with a chromic acid concentration of 210 gal/L (28 oz/gal) of solution and a sulfuric acid catalyst concentration of 1.3 g/L (0.18 oz/gal) of solution. The chromic acid consumption for the plant is 270 kg (600 lb) per year. The tank is equipped with a transformer/rectifier rated at 12 V and 12,000 A. The operating temperature of the plating bath ranges from 43° to 60°C (110° to 140°F).

C.1.1.3.2 Air pollution control. As shown in Figure C-3, the plating tank is equipped with a push-pull capture system and a chevron-blade mist eliminator that were manufactured and installed in July 1985 by Duall Industries, Inc. Removable panels are placed over the top of the tank during plating to enclose the surface of the plating solution to maximize capture efficiency. The mist eliminator contains two sets of overlapping-type blades. The blades are approximately 1.0 m (3.1 ft) in height, cover an average of about 0.9 m (3.0 ft) in width, and each set of blades extends 0.2 m (0.8 ft) back into the unit. The design parameters of the mist eliminator include a gas flow rate of 170 standard m^3/min (6,000 standard ft^3/min), a cross sectional velocity of 190 m/min (630 ft/min), and a pressure drop of 0.5 kPa (2 in. w.c.). A moisture extractor is installed in the stack downstream of the mist eliminator. The moisture extractor consists of a stationary set of blades that force acid mist or droplets entrained in the exhaust gas to impinge against the sides of the extractor wall. The droplets drain down the sides of the extractor into collection areas.

The mist eliminator and moisture extractor are washed down with an average of 280 L (75 gal) of water at the end of each work day and at the beginning of the work day if the tank was operated overnight. Washdown water is drained into a 610-L (160-gal) holding tank inside the plating shop. The plating tank is equipped with a float that regulates the flow of makeup water from the holding tank to the plating tank.

C.1.1.3.3 Process conditions during testing. Three mass emissions test runs were conducted at the inlet and outlet of the mist eliminator. Process operating parameters such as the voltage, current, and plating solution temperature were recorded and monitored during each mass emissions test run. Data on the average operating parameters recorded during the mass emissions test runs are presented in Table C-7. The total amount of current supplied to the tank during each test run is presented in Table C-8.

Grab samples were taken from the tank to determine the chromic acid concentration of the plating solution during each mass emissions test run. Grab samples of the mist eliminator and moisture extractor washdown water also were taken at the end of the day. The mist eliminator and moisture extractor were washed down with about 320 L (85 gal) of water after the first mass emissions test run and with about 250 L (70 gal) of water after the third mass emissions test run. The chromic acid concentration of the grab samples is reported in Table C-9. Test run Nos. 1, 2, and 3 were each interrupted for approximately 45 minutes to unload and reload the tank.

C.1.1.4 Plant E--EPA Test.[4] Plant E is Roll Technology, Inc., in Greenville, South Carolina. The plant is a job shop specializing in precision finishing and refinishing of industrial rolls. Operations performed at this facility include hard chromium plating, sulfamate nickel plating, machining, grinding, and mirror finishing. The plant plates rolls that are used primarily in the paper manufacturing, roofing, laminating, and coating industries.

C.1.1.4.1 Process description. There are seven hard chromium plating tanks at this facility, arranged as shown in Figure C-4. On the average, the tanks are charged for a total of 20 hours per day. Approximately 4 hours per day are required for the change-over of rolls. During a change-over, the roll that has been plated is raised out of the plating tank, rinsed with water from a hose, and transferred to the grinding area. Then, the roll to be plated is cleaned with an abrasive cleanser and lowered into the plating solution. Plating times range from 1 to 36 hours, depending on the surface area of the roll and the plate thickness required. Rolls that require longer plating times typically are plated overnight, and rolls that require shorter plating times are plated during the day when personnel are available to perform the change-over.

Tests were conducted across the mist eliminator unit used to control emissions from Tank 6. This tank is used to plate small industrial rolls, aircraft engine pistons, and rotary pumps. The tank is 3.7 m (12.0 ft) long, 0.91 m (3.0 ft) wide, and 2.9 m (9.6 ft) deep and holds approximately 9,270 L (2,450 gal) of plating solution. The plating solution contains chromic acid in a bath concentration of 250 g/L (33 oz/gal). Sulfuric acid is used as a catalyst at a bath concentration of 2.5 g/L (0.33 oz/gal). The temperature of the plating solution is maintained between 57° and 60°C (135° and 140°F). The typical current and voltage applied to Tank 6 is 8,000 A and 12 V.

Tank 6 is typical of other hard chromium plating tanks used in the electroplating industry, based on operating parameters such as current, voltage, plating time, temperature, and chromic acid concentration. Although the composition of the plating solution remains constant, the operating voltage and current vary with each roll that is plated.

C.1.1.4.2 Air pollution control. The capture and control system on Tank 6 consists of a double-sided lateral hood ducted to a moisture extractor followed by a mist eliminator unit containing two sets of overlapping-type blades and two mesh pads. Figure C-5 presents a schematic of the capture and control system on Tank 6. The fan used in the ventilation system is rated at 260 m^3/min (9,000 ft^3/min).

The four-stage mist eliminator unit was fabricated and installed by KCH Services, Inc., in June 1988. This unit replaced the scrubber that was previously used to control chromic acid mist from the plating tank. Figure C-6 presents a cross-sectional view of the mist eliminator unit. This unit has a design airflow rate of 280 standard m^3/min (10,000 standard ft^3/min) and a design pressure drop of 0.62 kPa (2.5 in. w.c.). at a velocity of 140 m/min (450 ft/min). The blade section consists of two sets of overlapping-type blades. The blades are approximately 1.3 m (4.4 ft) in height, cover an area of about 1.2 m (4.0 ft) in width, and each set of blades extends 0.2 m (0.8 ft) back into the unit. Catchments are located along the overlapping edges of the blades and act as collection troughs, providing a central location for droplet collection and facilitating gravitational drainage of the droplets into a collection sump. Figure C-7 presents a schematic of this type of blade design. Two sets of spray nozzles (three nozzles per set) are located in front of each set of blades and are activated periodically to wash down the blades. The washdown water is drained to a holding tank and recirculated to the plating tank to replace plating solution evaporation losses. The mesh pad section consists of two mesh pads in series. The mesh pads are manufactured by Kimre, Inc. Each mesh pad is about 1.4 m (4.5 ft) high, 1.5 m (4.8 ft) wide, and 0.15 m (0.5 ft) deep. Each pad consists of eight layers of mesh. Each layer consists of interlocked polypropylene filaments 0.094 cm (0.037 in.) in diameter. The first two layers of each pad have a void space of 97 percent, and the remaining six layers have a void space of 94 percent.

The 22-inch-diameter moisture extractor is located in the ductwork near the ceiling of the plating shop. Because moisture extractors are designed for the removal of large droplets that also would be collected in the first stage of the mist eliminator unit, the overall performance measured during testing is considered to be representative of the average performance of the mist eliminator unit alone.

During testing, the airflow rate at the outlet of the mist eliminator averaged 195 m^3/min (6,880 ft^3/min), and the pressure drop was measured at 0.84 kPa (3.4 in. of w.c.).

C.1.1.4.3 <u>Process conditions during testing</u>. Mass emission tests were conducted at the following locations to characterize the performance of the control devices independently and in series: (1) the inlet of the moisture extractor, (2) between the moisture extractor and mist eliminator unit, and (3) the outlet of the mist eliminator unit. These locations are identified in Figure C-8 as IA, IB, and O, respectively.

Process parameters recorded during each test run were the plating solution temperature, operating voltage, and operating current. Data on the average operating parameters recorded for each test run are presented in Table C-10. The process was operating normally during emissions testing. The plating tank was plating two industrial rolls during each source test. The two rolls were identical in size. Each roll measured 69 cm (27 in.) long with a diameter of 41 cm (16 in.). A summary of the total current values is presented in Table C-11.

Grab samples from the plating tank were taken during each test run to determine the chromic acid concentration of the plating solution during emissions testing. The mist eliminator was washed down with clean water at the beginning of each day, and grab samples of the mist eliminator washdown water were collected. The chromic acid concentration of the grab samples are reported in Table C-12.

Test run No. 1 was 3.2 hours in duration, and two subsequent runs were each 2 hours in duration. Each test run was interrupted 10 to 15 minutes to change test ports. Test run No. 1 was interrupted for 14 minutes because of a power loss to the meter boxes. However, no other process interruptions occurred during the test runs.

C.1.1.5 Plant F--EPA Test.[5] Plant F is Precision Machine and Hydraulic, Inc., in Worthington, West Virginia. Precision Machine and Hydraulics, Inc., is a small job shop specializing in precision finishing of hydraulic cylinders.

C.1.1.5.1 Process description. The plant operates one hard chromium plating tank approximately 8 hours per day, 5 days per week. Typical plating times range from 1.5 to 15.0 hours. Cylinders plated for more than 8 hours are plated over a 2-day period.

The plating tank is 2.4 m (8.0 ft) long, 0.76 m (2.5 ft) wide, and 2.7 m (9.0 ft) deep, and holds approximately 4,810 L (1,270 gal) of plating solution. The plating solution contains chromic acid in a concentration of about 210 g/L (28 oz/gal). Sulfuric acid is used as a catalyst at a bath concentration of 2.1 g/L (0.28 oz/gal). The temperature of the plating solution is maintained at about 54°C (130°F). The tank is divided into two plating cells. Each plating cell is equipped with a rectifier. The typical current and voltage applied to each cell ranges from 2,500 to 3,000 A and from 4.5 to 6.0 V, respectively.

C.1.1.5.2 Air pollution control. The capture and control system on the plating tank consists of a single-sided lateral hood ducted to a mesh-pad mist eliminator. Figure C-9 presents a side view of the capture and control system on the plating tank.

The design airflow rate of the ventilation system is 140 standard m^3/min (5,100 standard ft^3/min). The measured flow rate was 125 m^3/min (4,430 ft^3/min).

The mesh-pad mist eliminator was fabricated and installed in May 1988 by ChromeTech, Inc., Bedford, Ohio. Figure C-10 presents a detailed schematic of the mesh-pad mist eliminator. The unit has a design pressure drop of 0.62 kPa (2.5 in. w.c.) at a velocity of 150 to 210 m/min (500 to 700 ft/min). The mist eliminator consists of two mesh pads spaced approximately 10 cm (4 in.) apart. Each mesh pad is 79 cm (31 in.) in diameter. The primary mesh pad at the inlet of the unit is 6.4 to 7.6 cm (2.5 to 3.0 in.) thick, and the secondary mesh pad at the outlet is 3.2 to 3.8 cm (1.25 to 1.5 in.) thick. Each mesh pad consists of layers of interlocked polypropylene filaments 0.051 cm (0.020 in.) in diameter. The thread count is 4.3 by 3.3 per cm^2 (28 by 21 per $in.^2$) and the weave type is honeycomb.

The unit is equipped with two spray nozzles that are activated periodically to wash down the pads. One spray nozzle is located at the inlet of the unit prior to the primary mesh pad and the other spray nozzle is located at the outlet of the unit behind the secondary mesh pad. The first nozzle sprays into the primary mesh pad in the direction of airflow, and the second spray nozzle sprays into the secondary mesh pad countercurrent to the airflow. At the end of each day, the ventilation system is shut off and the spray nozzles are activated to wash down the mesh pads. During each washdown, the mesh pads are flooded with 38 L (10 gal) of water at a pressure of 1.7 to 2.0 atm (25 to 30 psi). In addition, the unit has a removable cover that allows the mesh pads to be removed and cleaned by immersion in the plating bath. Immersion cleaning is performed once a month.

C.1.1.5.3 <u>Process conditions during testing</u>. Mass emissions tests were conducted simultaneously at the inlet and outlet of the mist eliminator unit to characterize the performance of the control device in controlling chromic acid mist.

Process parameters recorded during each test run were plating solution temperature, operating voltage, and operating current. In addition, the number and surface area of parts plated during each test run were recorded. Average values for the operating parameters recorded for each test run are presented in Table C-13. The process was operating normally during testing. The total current supplied to the tanks during each test run was calculated in terms of ampere-hours. A summary of the total current values is presented in Table C-14.

Grab samples of the plating solution were taken during each test run to determine the chromic acid concentration of the plating solution during emissions testing. The chromic acid concentrations of the grab samples are reported in Table C-15.

The mesh pads were cleaned by immersion in the plating tank prior to the first test run. The mist eliminator washdown system was activated at the end of test run Nos. 1 and 5. The mesh pads were removed and washed with water at the end of test run No. 3. No grab samples of the washdown water were obtained because of the location of the drain pipe outlet, which was 25.4 cm (10 in.) below the surface of the plating solution.

Test run No. 1 was 3.2 hours in duration, and the four subsequent runs were each 2 hours in duration. Each test run was interrupted 20 to 30 minutes to change test ports.

C.1.1.6 Plant G--EPA Test.[6] Plant G is Hard Chrome Specialists, Inc., located in York, Pennsylvania. The plant is a job shop that plates industrial rolls, hydraulic components, dies, and molds.

C.1.1.6.1 Process description. The hard chromium plating line at this facility consists of an alkaline strip tank to clean the parts prior to plating, two alkaline rinse tanks, an alkaline scrub tank, and the hard chromium plating tank followed by a spray rinse tank and by three countercurrent rinse tanks. A floor plan of the facility is presented in Figure C-11. The plating tank usually operates 8 hours per day, 5 days per week. Typical plating times for each part range from 0.5 to 20 hours.

For parts that require a plating time in excess of 8 hours, the parts are plated over 2 days.

Emissions testing was conducted on the mesh-pad mist eliminator controlling chromium emissions from the hard chromium plating tank. This tank is 1.8 m (6.0 ft) long, 0.76 m (2.5 ft) wide, and 4.3 m (14.0 ft) deep and has a capacity of 5,720 L (1,510 gal) of plating solution. The plating solution contains chromic acid in a bath concentration of about 210 g/L (28 oz/gal). Sulfuric acid is used as a catalyst at a bath concentration of 2.1 g/L (0.28 oz/gal). The temperature of the solution is maintained between 54° and 60°C (130° and 140°F). The plating tank is equipped with an air agitation system to maintain uniform bath temperature and chromic acid concentration. The maximum current and voltage of the rectifier is 8,000 A and 9 V.

C.1.1.6.2 <u>Air pollution control</u>. The capture and control system on the plating tank consists of a single-sided lateral hood ducted to a mesh-pad mist eliminator. Figure C-12 presents a schematic of the capture and control system on the hard chromium plating tank.

The mesh-pad mist eliminator was fabricated and installed in November 1988 by ChromeTech, Inc., Bedford, Ohio. Figure C-13 presents a detailed schematic of the mesh-pad mist eliminator. The design airflow rate of the ventilation system is 110 standard m^3/min (3,800 standard ft^3/min). The mesh-pad mist eliminator unit has a design pressure drop of 0.62 kPa (2.5 in. w.c.) at a gas velocity of 150 to 210 m/min (500 to 700 ft/min). The mist eliminator consists of two mesh pads spaced approximately 10 cm (4 in.) apart. Each mesh pad is 79 cm (31 in.) in diameter. The primary mesh pad at the inlet of the unit is 6.4 to 7.6 cm (2.5 to 3.0 in.) thick, and the secondary mesh pad is 3.2 to 3.8 cm (1.25 to 1.5 in.) thick. Each mesh pad consists of interlocked polypropylene filaments 0.051 cm (0.020 in.) in diameter. The thread count is 4.3 by 3.3 per square centimeter (28 by 21 per square inch) and the weave type is honeycomb. Removal of chromic acid mist is accomplished by direct interception or impaction of the chromic acid mist on the mesh pads. The collected droplets then coalesce along the fibers and drain down the pads into the drain pipe located at the bottom of the unit.

The mist eliminator unit is equipped with two spray nozzles to clean the pads. One spray nozzle is located at the inlet of the unit prior to the first mesh pad, and the other spray nozzle is located behind the second mesh pad. The first nozzle sprays into the first mesh pad in the direction of the airflow, and the second nozzle sprays into the second mesh pad countercurrent to the airflow. The first spray nozzle uses rinse water from the first rinse tank following the plating tank, and the second spray nozzle uses clean tap water. At the end of each day, the ventilation system is shut off and the spray nozzles are activated for approximately 30 seconds to wash down the mesh pads. Typically, 20 to 35 L (6 to 10 gal) of water are used each time the pads are cleaned. The washdown water is drained to the plating tank. In addition, the unit is designed so that the mesh pads can be easily removed and cleaned by immersion in the plating bath. The immersion cleaning is performed once a month.

C.1.1.6.3 <u>Process conditions during testing</u>. Five mass emissions test runs were conducted at the inlet and outlet of the mesh-pad mist eliminator. During this source test program, the plating tank was operated with and without polypropylene balls covering the surface of the plating solution. The first three test runs were done without any polypropylene balls on the plating tank surface to determine the effectiveness of the mesh-pad mist eliminator. The two subsequent test runs were conducted while polypropylene balls covered the surface of the plating solution to determine their effectiveness in controlling chromic acid mist. During test run Nos. 4 and 5, polypropylene balls covered the entire surface of the plating solution. The ball coverage was two to three layers thick in most places. Each polypropylene ball was 3.8 cm (1.5 in.) in diameter. There was no observed dispersion of polypropylene balls away from the cathode area during plating because of the relatively thick coverage supplied by the balls. In typical industrial applications, coverage is not usually as complete as that tested.

Process parameters recorded during each test run were the operating current, the operating voltage, and the plating solution temperature. In addition, the pressure drop across the mesh-pad mist eliminator unit was recorded. Average values for the parameters recorded for each test run are presented in Table C-16. One or two hydraulic cylinders were plated during each test run. A single, 18-cm (7-in.)-diameter roll, 175 cm (69 in.) long, was plated during run Nos. 1, 2, 4, and 5. This cylinder and another hydraulic cylinder, which had a diameter of 14 cm (5.5 in.) and was 170 cm (68 in.) long, were plated during test run No. 3. During plating, no visible misting was observed escaping the plating tank's ventilation system. During test run Nos. 4 and 5, visible misting was observed above the polypropylene balls; however, the mist was captured by the ventilation system. A summary of the total current values is presented in Table C-17.

The fan speed was increased after test run No. 1, on the recommendation of the control system vendor, ChromeTech, Inc. The vendor felt that increasing the airflow was necessary to operate closer to the design condition. The inlet gas flow rate during testing ranged from 88 to 93 dscm/min (3,100 to 3,300 dscf/min). The outlet flow rates ranged from 99 to 105 dscm/min (3,500 to 3,700 dscf/min). The outlet flow rate was 12 to 13 percent greater than the inlet flow rate. The larger outlet flow rate resulted from an inadequate seal around the mesh pads which allowed ambient air to be drawn into the system.

Grab samples from the plating tank were taken during each test run to determine the chromic acid concentration of the plating solution during emissions testing. The mist eliminator was washed down at the end of each day, and grab samples of the washdown water were collected. The chromic acid concentrations of the grab samples are reported in Table C-18.

Test run Nos. 1 and 4 were 3 hours in duration, and the remaining test runs were each 2 hours in duration. A slightly larger sampling nozzle was used during test run Nos. 4 and 5, which resulted in a larger sample volume collected. The larger nozzle was used to ensure adequate sample collection for the test runs where polypropylene balls were in the tank. Each test run was interrupted for 5 to 15 minutes to change test ports. Run No. 4 was also interrupted for approximately 4 minutes when the scaffolding supporting the sampling train at the inlet fell, pulling the probe from the test port. However, no other process interruptions occurred during the test runs.

C.1.1.7 Plant I--EPA Test.[7] Plant I is Piedmont Industrial Plating in Statesville, North Carolina. Piedmont Industrial Plating is a job shop that performs hard chromium plating of industrial machine parts, industrial rolls, and steel tubing.

C.1.1.7.1 Process description. The facility consists of three plating tanks arranged as shown in Figure C-14. During the source test, only the tanks designated as the 23-ft and 10-ft tanks were operated. The dimensions and operating parameters for these two tanks are presented in Table C-19. The plating solution used in the tanks is a conventional hard chromium plating solution with a chromic acid concentration of 250 g/L (32 oz/gal) and a sulfuric acid concentration of 2.52 g/L (0.32 oz/gal). The chromic acid consumption for the two tanks is about 1,630 kg (3,600 lb) per year.

The 23-ft tank is used to plate long industrial rolls and tubing as well as smaller parts. The tank is equipped with one 6,000-A and three 1,000-A rectifiers. When industrial rolls or tubing are plated, the 6,000-A rectifier is used, and when smaller and different types of parts are plated, up to four work stations can be set up in the tank. Three of the work stations are charged with the 1,000-A rectifiers, and one work station is charged with the 6,000-A rectifier. The 10-ft tank contains up to five work stations, each of which is charged with a separate 1,000-A rectifier. During this source test program the 23-ft and 10-ft tanks were divided into two and five work stations, respectively.

The concentration of trivalent chromium ions increases to levels that contaminate the plating baths when the surface area of the cathodes plated is substantially larger than the surface area of the anodes. Porous ceramic pots are used to reduce trivalent chromium contamination of the plating baths. The ceramic pots contain pores ranging from 0.5 to 1.0 μm (0.002 to 0.004 mil) in diameter. The ceramic material acts as a selective membrane that prevents the hexavalent chromium anions in the bath from flowing to the cathode, where they would be reduced and deposited. Several anodes are placed around the outside, and a cathode is placed inside each pot. The anodes and cathode are both formed from lead-antimony alloy. About 9 V and 300 A of direct current are applied to the anodes surrounding each pot. Trivalent chromium ions present in the bath migrate to the anodes, where they react with oxygen to form chromic acid.

C.1.1.7.2 Air pollution control. All three tanks are equipped with double-sided draft hoods that are installed along the length of each tank. The three tanks are ducted together and vented to a fume scrubber located outside the building. The scrubber is a horizontal-flow single packed-bed unit that is equipped with a self-contained recirculation system. The scrubber was manufactured by Duall Industries, Inc. (Duall) (Model No. F-101). The scrubber was purchased as used equipment and was installed at the plant in 1984. Duall personnel inspected the scrubber in July 1986 and made the following recommendations to ensure normal scrubber operating conditions: (1) the angle of the ductwork entry at the inlet transition of the scrubber should be repositioned to direct the gas flow toward the center of the packed bed and to prevent scrubber water from entering the ductwork, (2) the spray nozzles should be cleaned and the nozzle velocity should be upgraded to design specifications, and (3) minor cracks in the scrubber housing should be sealed. The plant corrected these problems before emissions testing was performed.

The gas flow rate to the scrubber during testing was 290 m^3/min (10,300 ft^3/min), and the water flow rate was about

130 L/min (35 gal/min). The pressure drop across the scrubber was 0.5 kPa (2 in. w.c.). The velocity of the inlet gas stream at the packed bed was about 150 m/min (500 ft/min). The packed bed is 142 cm (56 in.) in height and width and 30 cm (12 in.) in depth and contains polypropylene, spherical-type mass packing that is continuously washed with water. Water is sprayed through six nozzles countercurrent to the flow of the gas stream. Behind the packed bed is a chevron-blade mist elimination section. If wetting appears on the back side of mist elimination section, the packed bed is reconditioned to prevent the breakthrough of droplets.

The scrubber water drains into a sump in the bottom of the scrubber and is recirculated by a 0.75-horsepower pump. A sensor is used to monitor the water level in the sump, which contains about 380 L (100 gal) of water. About four times per day, 95 L (25 gal) of clean water are automatically added over the packed bed when the sensor indicates that water is needed to replace evaporation losses. The scrubber water is drained to the plating tanks approximately once per day to replace plating solution evaporation losses. The scrubber is then recharged with clean water. Grab samples of the scrubber water in the sump, taken 1 month before emissions testing was conducted, showed that the chromic acid concentration of the scrubber water under normal conditions is about 1.5 g/L (0.2 oz/gal).

C.1.1.7.3 Process conditions during testing. Hard chromium plating facilities that use scrubbers typically recirculate the scrubber water continuously to reduce both water consumption and wastewater treatment costs and to recover chromic acid for use as plating solution makeup. The purpose of this emission test was to assess the effect on scrubber performance of increasing chromic acid concentrations in the scrubber water.

The target level scrubber water chromic acid concentrations selected for testing were 0, 30, 60, and 120 g/L (0, 4, 8, and 16 oz/gal). These four target level concentrations were selected to represent the range of concentrations that could potentially occur under normal operating conditions. The target level of 120 g/L (16 oz/gal) was selected to represent worst-case conditions.

Three mass emissions test runs were conducted at the inlet and outlet of the scrubber for each of the four target level concentrations. Each test run was conducted for 2 hours. The scrubber operated normally throughout the test runs. The plant manager spiked the scrubber water with plating solution taken from the 23-ft plating tank to achieve the target levels. Grab samples of the scrubber water were taken from the scrubber recirculation sump at the beginning, middle, and end of each test run and analyzed by spectrophotometer at the test site to monitor chromic acid concentrations. The target and actual scrubber water concentrations observed during testing are presented in Table C-20.

The process was operating normally during the tests. Process operating parameters such as the voltage, current, and plating solution temperature were monitored and recorded during each mass emission test run. Data on the average operating parameters during testing are presented in Table C-21. The total amount of current supplied to the work stations during each test run is calculated in terms of ampere-hours, and a summary of the total current values is presented in Table C-22. Because the third tank was not in operation during the test, the ventilation hood for the tank was dampered off to increase the ventilation rates for the 23-ft and 10-ft tanks.

As shown in Table C-22, the total amount of current supplied to the tanks during emission test run Nos. 1 through 3 ranged from 12,000 to 13,000 Ah. For test run Nos. 4 through 6, the total current values were 30 to 40 percent lower (8,000 to 9,000 Ah) and for test run Nos. 7 through 12 the total current values were 50 to 60 percent lower (5,500 to 6,500 Ah) than the total current values for test run Nos. 1 through 3. The plant manager stated that a typical work load for the two tanks is about 6,000 Ah.

The amount and type of work plated during the emissions test runs varied depending on the plant's scheduled work load. For the 23-ft tank, Work Stations 7 and 10 were operated simultaneously during test run Nos. 1 through 6. Parts plated during these test runs included a cast iron part, lease bars for warp knitting machines, and angle iron. Only Work Station 10 was operated during test run Nos. 7 through 12. One steel tube (6.0 m [19.75 ft] in length) was plated during each of these six test runs. Plating was stopped for about 5 minutes in the middle of each test run to rotate the tube.

For the 10-ft tank, five work stations were operated for part or all of the test runs except for test run Nos. 6 and 9. Work Station 1 was not operated during test run No. 6, and Work Stations 3 and 4 were not operated during test run No. 9. The work plated during emissions testing included steel shafts and gears for engine components and steel pins and latches for packaging machines.

Grab samples were taken from both plating tanks during each mass emissions test run to monitor the chromic acid concentration of the plating solution. The chromic acid concentration of the grab samples is presented in Table C-23. The plating solution in the 23-ft tank was air-agitated for test run Nos. 3 through 12 to maintain a uniform chromic acid concentration throughout the plating solution. The plant manager considered air-agitation of the plating solution to be normal operating procedure. The tank freeboard space was maintained at about 15 cm (6 in.), which prevented plating solution from splashing into the ventilation hoods.

Sampling at the inlet and outlet was interrupted only once to change test ports except for test run No. 11, which was interrupted four times. Test run No. 11 was first interrupted after 3 minutes of testing for 38 minutes to increase the chromic acid concentration of the scrubber water, a second and third time for a total of 12 minutes at the inlet and 8 minutes at the outlet during the first hour of testing, and a fourth time to change test ports between the first and second hour of testing. Test run No. 11 was not interrupted during the second hour of testing. Port changes at the inlet took from 3 to 8 minutes except for those during test run Nos. 2 and 3, which took 17 and 39 minutes, respectively. Port changes at the outlet took from 2 to 8 minutes.

C.1.1.8 Plant K--EPA Test.[8] Plant K is Steel Heddle Company, in Greenville, South Carolina. Steel Heddle is an original equipment manufacturer of steel heddles for textile looms. The plating facility is operated both on a captive and a job shop basis. Reeds and combs for textile looms and miscellaneous parts from outside customers undergo hard chromium plating.

C.1.1.8.1 Process description. The chromium plating facility consists of four tanks, arranged as shown in Figure C-15. Based on size; operating parameters such as current, voltage, and plating time; and chromic acid concentrations, all four tanks are typical of other hard chromium plating tanks used in the electroplating industry. During this source test, Tanks 1, 2, and 4 were operated. The dimensions and operating parameters for these tanks are presented in Table C-24. The plating solution used in the tanks is a conventional hard chromium plating solution with a chromic acid concentration of 250 g/L (33 oz/gal) and a sulfuric acid catalyst concentration of 2.5 g/L (0.33 oz/gal). The chromic acid consumption for the plant is 1,500 kg (3,300 lb) per year.

C.1.1.8.2 Air pollution control. Tanks 1 and 4 are equipped with push-pull emission capture systems, and Tank 2 is equipped with a single-sided draft hood. Emissions from all three tanks are ducted to a scrubber system that is located on the roof of the plating shop. The scrubber is a horizontal-flow, double packed-bed unit manufactured by KCH Services, Inc. (Model No. H-200D). The scrubber was installed in 1981. The design gas flow rate of the scrubber is 540 standard m^3/min (19,000 standard ft^3/min). The design pressure drop is 0.75 kPa (3 in. w.c.). Six nozzles located in front of each packed bed spray water continuously countercurrent to the flow of the gas stream. Chromic acid mist that impinges on the packing material is washed to the bottom of the scrubber. The packed beds are 30.5 cm

(12 in.) deep and are filled with polypropylene, spherical-type mass packing. The scrubber also contains a chevron-blade mist elimination section located downstream of the second packed bed.

The scrubber water flows by gravity from the scrubber to a 910-L (240-gal) recirculation tank located inside the plating shop. Clean water is used to replace evaporation losses from the system. The ductwork is washed down once per month with water that subsequently drains into the plating tanks.

C.1.1.8.3 Process conditions during testing. Three mass emissions tests were conducted at the inlet and outlet of the scrubber to characterize the uncontrolled emissions from the three hard chromium plating tanks and the performance of the scrubber. The process was operating normally during the tests. Process operating parameters such as the voltage, current, and plating solution temperature were monitored and recorded during each mass emission test run. Data on the average operating parameters recorded are presented in Table C-25. The total amount of current supplied to the tanks during each test run is calculated in terms of ampere-hours, and a summary of the total current values is presented in Table C-26. In addition, the pressure drop across the scrubber was monitored and averaged 0.7 kPa (2.9 in. w.c.) during test run No. 1 and 0.8 kPa (3.2 in. w.c.) during test run Nos. 2 and 3. Sampling interruptions during the test runs were minor. All three test runs were interrupted for 15 to 20 minutes for port changes. Test run Nos. 2 and 3 were interrupted one additional time for 30 and 45 minutes, respectively, during shift changes.

Grab samples were taken from each tank tested and from the scrubber recirculation tank to determine the chromium concentration of the plating solution and recirculation water during each test run. The chromic acid concentration of the grab samples is reported in Table C-27.

C.1.1.9 Plant L--EPA Test.[9] Plant L is Fusion, Inc., in Houston, Texas. It is a job shop that specializes in hard chromium electroplating of crankshafts.

C.1.1.9.1 Process description. The plating shop consists of five hard chromium plating tanks that are operated 24 hours per day, 7 days per week, and 52 weeks per year. The plating tank (No. 1) tested during this source test program is 9.1 m (30 ft) long, 1.1 m (3.5 ft) wide, and 1.2 m (4.0 ft) deep, and holds approximately 10,400 L (2,750 gal) of plating solution. The plating tank is equipped with a single rectifier rated at 15 V and 8,000 A. The tank contains a conventional hard chromium plating solution consisting of 240 g/L (32 oz/gal) of chromic acid and 2.4 g/L (0.32 oz/gal) of sulfuric acid. The plating solution is maintained at 54°C (130°F).

The only portions of the crankshafts that are plated are the cams. The crankshafts contained from 5 to 15 cams. Semicircular-shaped anodes are positioned over each cam on the crankshaft. The crankshaft is then lowered by hoist into the plating tank. The anodes are connected to the electrical circuit, and the current and voltage are applied stepwise until the current density reaches 3,100 A/m^2 (2 $A/in.^2$). During plating, each crankshaft is rotated continuously in the tank to ensure that an even plate thickness is applied over the entire surface area of each cam. Typically, two to three crankshafts are plated simultaneously over a 24-hour period at a current loading of 3,000 to 4,000 A.

The plating tank tested is typical of other hard chromium plating tanks used in the electroplating industry with regard to size; operating parameters such as current, voltage, and plating time; and chromic acid concentration of the plating bath.

C.1.1.9.2 Air pollution control. The capture and control system on the plating tank consists of a double-sided draft hood that is vented to a horizontal-flow single packed-bed scrubber. Figure C-16 presents a schematic of the capture and control system on the plating tank.

The scrubber was manufactured by Duall Industries, Inc., (Model No. F-101) and installed in 1988. The design gas flow rate to the scrubber is 450 m^3/min (16,000 ft^3/min). The scrubbing water flow rate is approximately 180 L/min

(50 gal/min). The design pressure drop across the scrubber is 0.5 kPa (2.0 in. w.c.).

Within the scrubber system, the velocity of the gas stream is reduced to approximately 130 m/min (440 ft/min), and the gas stream is humidified by a spray of water. Water is sprayed countercurrent to the flow of the gas stream through 10 spray nozzles. The saturated gas stream then passes through a packed bed of polypropylene, spherical-type mass packing. The packed bed is wetted continuously with scrubbing water supplied by the series of spray nozzles in front of the bed. The packed bed is approximately 2.0 m (6.4 ft) high, 1.9 m (6.2 ft) wide, and 0.30 m (1.0 ft) deep. Entrained mist and water droplets impinge on the packing and drain into the sump. Behind the packed bed is a two-stage mist elimination section that removes entrained water droplets. The first stage allows large droplets to settle by gravity to the bottom of the scrubber. The second stage contains a series of vertically mounted chevron blades that change the direction of the gas flow four times at 30° angles, which causes any entrained droplets to impinge on the blades. The mist eliminator is not washed down.

The scrubber water drains into a sump in the bottom of the scrubber and is recirculated by a pump. A level indicator (sight gauge) is used to monitor the water level in the sump, which holds approximately 450 L (120 gal) of water. Once a week, the water in the sump is drained into a 5,680-L (1,500-gal) holding tank and the sump is recharged with fresh water. During testing, the chromic acid concentration of the water samples taken from the sump averaged 0.08 g/L (0.01 oz/gal). Although the plating tank is operated 24 hours per day, the recirculation system on the scrubber is turned off from 11:30 p.m. to 7:30 a.m., when there are no plant employees onsite.

Prior to emissions testing, the scrubber was retrofitted with an overhead weir so that the scrubber could be operated with and without periodic washdown of the scrubber packing with fresh water. The scrubber was also moved back approximately 1.5 m (5.0 ft) and a section of duct was inserted between the plating tank exhaust plenum and the inlet of the scrubber to accommodate inlet testing. A stack was also added to the fan to accommodate outlet testing. Figure C-17 presents a schematic of the capture and control system on the plating tank after modifications. Duall Industries, Inc., the manufacturer of the scrubber, performed the modifications on the ventilation system and scrubber in addition to inspecting the scrubber to ensure proper operation.

C.1.1.9.3 Process conditions during testing. The primary purpose of this source test was to determine if the periodic flooding action provided by the scrubber overhead weir system could significantly improve the scrubber performance. Therefore, three mass emissions test runs were conducted at the inlet and outlet of the scrubber at each of the following conditions: (1) the scrubber recirculation system was in operation and any required makeup water was supplied by a hose through one of the scrubber's inspection doors, and (2) the scrubber recirculation system was in operation and all required makeup water was supplied through a pipe that extended out about 10 to 13 cm (4 to 5 in.) over the top of the packed bed. Two subsequent test runs were conducted at the inlet and outlet of the scrubber with the scrubber recirculation system in operation and a continuous flow of fresh water supplied through the overhead weir at a rate of 7.6 L/min (2.0 gal/min).

Prior to test run Nos. 1 and 3, the sump in the bottom of the scrubber was drained to the holding tank and the sump was recharged with fresh water supplied by a hose through one of the scrubber's inspection doors. During test run Nos. 1 through 3, makeup water required by the scrubber to replace evaporation losses was added through the inspection doors with a water hose. Prior to test run No. 4, the scrubber was inspected and found to contain a heavy buildup of chromic acid resulting from the overnight shutdown of the recirculation system. Therefore, the scrubber was thoroughly cleaned by draining the sump and washing down the inside walls, packing media, and mist elimination section with a pressurized water hose. During test run Nos. 4

through 6, makeup water required by the scrubber to replace evaporation losses was supplied through the pipe located over the top of the packed bed. Prior to test run No. 7, the scrubber was cleaned again. During test run Nos. 7 and 8, makeup water was added continuously over the top of the packed bed through the overhead weir at a flow rate of 7.6 L/min (2.0 gal/min).

The scrubber parameters monitored during testing were the pressure drop across the scrubber, the frequency, and, if possible, the amount of makeup water added, the chromic acid concentration of the scrubber water, and, when applicable, the overhead water flow rate. The actual inlet gas flow rate to the scrubber during testing averaged 575 m^3/min (20,300 ft^3/min), and the monitored pressure drop was close to the design pressure drop of 0.5 kPa (2.0 in. w.c.). The average scrubber parameters monitored during each test run are presented in Table C-28. Grab samples of the scrubber water were taken from the sump at the end of each test run. Grab samples of the plating solution were taken at the beginning, middle, and end of each test run to determine the chromic acid concentration of the solution during testing. The chromic acid concentrations of the scrubber water samples and the composite plating solution samples are presented in Table C-29.

The process was operating normally during the test. Process operating parameters such as the voltage, current, and plating solution temperature were monitored and recorded during each test run. Also recorded were the number and approximate size of the crankshafts in the plating tank during each test run. Averages for the operating parameters recorded are presented in Table C-30. The total amount of current supplied to the plating tank during each test run is calculated in terms of ampere-hours based on the duration of sampling at the inlet and outlet test locations. Information on the total ampere-hours supplied to the plating tank during each test run is presented in Table C-31.

The emissions test runs were interrupted for 10 to 25 minutes to change test ports. Test run No. 1 was interrupted for approximately 3 hours because of an electrical problem in the plating line, which resulted from a current overload. Test run No. 2 was interrupted for 8 minutes because of a problem with maintaining the isokinetic sampling rate at the outlet test location.

C.1.2 Decorative Chromium Electroplating Test Facilities

C.1.2.1 Plant M--EPA Test.[10] Plant M is Delco Products Division, General Motors Corporation, located in Livonia, Michigan. The facility is a large captive shop that performs decorative chromium electroplating of automobile bumpers.

C.1.2.1.1 Process description. The plating facility consists of five decorative chromium plating lines, but only three lines (Nos. 2, 4, and 5) were being operated at the time of the tests. Each plating line consists of about 20 tanks containing various cleaning and plating solutions. The lines are serviced by automatically controlled overhead conveyors that transfer racks of up to 14 bumpers to each tank in a programmed sequence. The chromium plating segment of each line consists of a plating tank and several rinse tanks.

The chromium plating tank on Line No. 4 was tested to characterize uncontrolled emissions. Based on size; operating parameters such as current, voltage, and plating time; and chromic acid concentration, the tank is typical of other large decorative chromium plating tanks used in the electroplating industry. The chromium plating tank is 6.1 m (20 ft) long, 3.7 m (12 ft) wide, and 2.7 m (9 ft) deep and is divided into three cells that are each 2.0 m (6.7 ft) long. The tank holds approximately 61,170 L (16,160 gal) of plating solution, which contains chromic acid in a bath concentration ranging from 247 to 374 g/L (33 to 50 oz/gal). Sulfuric acid is used as a catalyst in a chromic acid-to-sulfuric acid ratio of 180:1.

Line No. 4 is operated 16 hours per day, 5 days per week. Typically, two or three cells are operated at a time. One rack of bumpers is plated per cell for about 2.25 minutes. Each bumper receives a chromium plate that is 0.305 μm (0.012 mil) thick. Two separate transformer/rectifiers charge the electrodes in each cell. For the first 15 seconds of plating, the surface of the bumpers is activated. During activation, each rectifier is set at 5 to 6 V and 2,500 to 3,000 A. After activation, the actual plating phase of the cycle begins. During plating, each rectifier is set at 16 to 17 V and 8,500 to 10,000 A. The electrical settings are determined by the required current density for a particular rack of bumpers. Typical current densities range from 1,615 to 2,150 A/m^2 (150 to 200 A/ft^2) of surface area.

C.1.2.1.2 Air pollution control. The chromium plating tank on Line No. 4 is equipped with single-sided draft hoods on each end and double-sided draft hoods between each cell (see Figure C-18). The hoods on the tank are connected to a common duct that leads to an extensive evaporator/scrubber system. The total ventilation rate is about 990 m^3/min (35,000 ft^3/min).

C.1.2.1.3 Process conditions during testing. Three test runs were conducted at the inlet of the evaporator/scrubber to characterize the uncontrolled emissions from the decorative chromium plating tank. The process was operated within normal limits during each test run.

Process operating parameters such as voltage, current, and plating solution temperature were monitored and recorded during each test run. The number of plating cycles and the number of bumpers plated also were recorded for each test run. Average values for the operating conditions recorded during each emission test run are presented in Table C-32.

In addition, grab samples of the plating solution were taken from each cell in the tank during the course of each test run to determine the chromic acid concentration. The chromic acid concentrations of the grab samples are presented in Table C-33.

Test run No. 1 was interrupted for 13 minutes for electrical repairs on the plating line. Test run No. 2 was interrupted three times for 51, 3, and 11 minutes. The 3-minute interruption was caused by delays at the racking station where bumpers are mounted on the racks. The other two interruptions occurred when the process was stopped for repair. Test run No. 3 was interrupted three times for 3, 5, and 165 minutes. The interruptions were a result of malfunctions with the overhead conveyor.

The total amount of current supplied to the tank during each test run is calculated in terms of ampere-hours. A tabular summary of the total current values is presented in Table C-34.

C.1.2.2 Plant N--EPA Test.[11] Plant N is Automatic Die Casting Specialties, Inc., St. Clair Shores, Michigan. The plant is a small job shop that performs decorative chromium electroplating of automotive trim. The plating facility consists of two decorative chromium plating lines: the main plating line and a rework plating line.

C.1.2.2.1 Process description. The chromium plating tank in the main plating line was tested to evaluate the performance of fume suppressants in reducing chromic acid mist. A process flow diagram for the main plating line is shown in Figure C-19. The main plating line consists of a series of tanks used for cleaning and plating the parts. Parts are plated with layers of copper and nickel before they are chromium plated. The chromium plating segment of the line consists of a chromium predip, a plating tank, a chromium saver tank, and three bisulfite rinse tanks. The plating line is serviced by an automatically controlled overhead conveyor that transfers racks of parts to each tank in a programmed sequence.

The chromium plating tank is 3.4 m (11.0 ft) long, 0.85 m (2.8 ft) wide, and 1.5 m (5.0 ft) deep and is divided into six cells that are each 0.55 m (1.8 ft) long. The plating tank holds approximately 3,940 L (1,040 gal) of plating solution, which contains chromic acid in a bath concentration of 280 g/L (37 oz/gal). The plating solution contains both fluoride and sulfuric acid catalysts. The temperature of the plating bath is maintained between 43° and 47°C (110° and 116°F).

The plating line operates 20 hours per day, 4 days per week. Six racks of parts are plated in the chromium plating tank at a time with a retention time of 3 minutes and 35 seconds for each rack. The tank is equipped with three rectifiers. For the first 15 seconds of plating, the parts are activated. During activation, the rectifier connected to Cell No. 1 is operated at 0 to 5 V and 0 to 200 A. After activation, the racks are automatically moved toward the center of the plating tank. During plating, the rectifier connected to Cell Nos. 2 through 5 is set at 5.2 V and 3,000 A. The rectifier connected to Cell No. 6 is set at 3.0 V and minimal to no current.

C.1.2.2.2 Air pollution control. The chromium plating tank is equipped with a single-sided draft hood. The exhaust gases captured by the hood are ducted to a vertical-flow, single packed-bed scrubber manufactured and installed by Duall Industries, Inc., in 1979. Two other tanks, the alkaline soak tank in the main plating line and the chromium plating tank in the rework plating line, are also vented to the scrubber through a common duct. Figure C-20 presents a diagram of the ventilation and control system. The total airflow rate to the scrubber from the three hoods is 130 m^3/min (4,700 ft^3/min). The hood on the alkaline soak tank was blocked off during testing to increase the airflow rate through the hood on the chromium plating tank.

A fume suppressant, Quin-Tec Cam Nos. 3 and 4, manufactured by 3M Corporation and sold by Quin-Tec, Inc., in Warren, Michigan, is normally used to reduce chromic acid mist from the chromium plating tank. During the source test, the chromium plating tank was operated under three different conditions: (1) without a fume suppressant, (2) with a foam blanket, and (3) with a "combination" fume suppressant consisting of a foam blanket and a wetting agent. The foam blanket forms a layer of foam approximately 2.5 cm (1.0 in.) thick over the plating solution when the plating tank is charged. The foam blanket reduces chromic acid mist by entrapping the mist in the foam layer. The "combination" fume suppressant forms a layer of foam 2.5 cm (1.0 in.) thick over the surface of the plating solution and lowers the surface tension of the plating solution from 70 dynes/cm (4.8×10^{-3} lb_f/ft) to below 40 dynes/cm (2.7×10^{-3} lb_f/ft). Because the surface tension of the bath is lower, the gases escape with less of a "bursting" effect at the surface and, thus, less mist is formed. The foam layer captures any mist that is formed.

The foam blanket and the "combination" fume suppressant used in the plating tank during the source test were Zero-Mist™ HT and Zero-Mist™ HT-2, respectively. Both of these fume suppressants are manufactured and sold by OMI/Udylite® International Corporation in Warren, Michigan. These fume suppressants were selected for use during the source test because they are representative of the types and brands of fume suppressants widely used in the decorative chromium electroplating industry.

C.1.2.2.3 Process conditions during testing. Nine test runs were conducted to characterize uncontrolled emissions from a decorative chromium plating tank and to evaluate the performance of fume suppressants in controlling chromic acid mist. Three test runs were performed under each of the following conditions: (1) no chemical fume suppressant in the plating bath (uncontrolled); (2) a foam blanket, Zero-Mist™ HT, maintained in the plating bath; and (3) a "combination" fume suppressant, Zero-Mist™ HT-2, maintained in the plating bath. The test port was located in the main duct prior to the entrance of the duct from the rework plating tank.

The process was maintained within normal operating limits during each test run. The operating voltage, operating current, and plating solution temperature were monitored and recorded during each test run. The number of racks processed and the type of parts plated also were recorded during each test run. The operating conditions (average values) for each emission test run are presented in Table C-35. In addition, grab samples of the plating solution were taken during each test run to determine the chromic acid concentration. The chromic acid concentrations of the grab samples are presented in Table C-36.

During the test, the initial addition (makeup) and maintenance additions of the fume suppressants were made according to vendor recommendations on the use of each fume suppressant. The makeup addition of the foam blanket, Zero-Mist™ HT, was 910 g (2.0 lb), and the makeup addition of the "combination" fume suppressant, Zero-Mist™ HT-2, was 1,800 g (4.0 lb). For both fume suppressants, visual observation of the foam over the surface of the plating solution was used to determine when a maintenance addition was required. A foam blanket approximately 2.5 cm (1.0 in.) thick was maintained over the entire surface of the bath. For the "combination" fume suppressant, stalagmometer measurements to determine the surface tension of the plating bath were used in conjunction with visual observations to monitor depletion of the fume suppressant. A surface tension measurement above 40 dynes/cm (2.7×10^{-3} lb_f/ft) was specified as an indication of the need for maintenance additions of the fume suppressant. When signs of depletion were evident, a maintenance addition of the fume suppressant was made to the plating tank. The normal maintenance addition consisted of between 90 and 100 g (0.2 and 0.3 lb) for both types of fume suppressants. Visual observations were made at 10 to 15 minute intervals for each test run. Surface tension measurements were performed on the plating solution composite samples at the end of test run Nos. 1 through 9 and at the beginning of test run Nos. 7 through 9. The measured surface tension (average) and the makeup and maintenance additions of fume suppressant for each test run are presented in Table C-37.

All test runs were completed without a process interruption except test run No. 2, which was interrupted for 4 minutes because of downtime in the process line. All test runs were stopped for 15 to 20 minutes to change test ports.

The total amount of current supplied to the tank during each test run is calculated in terms of ampere-hours. A tabular summary of the total current values is presented in Table C-38.

C.2 SUMMARY OF TEST DATA

The EPA-conducted and EPA-approved test data are summarized in Tables C-39 through C-63. Metric/English conversions and test series averages may not convert exactly because the data were rounded independently. Test data collected at each plant are presented in the following tables:

Plant A: Tables C-39 and C-40
Plant B: Tables C-41 and C-42
Plant D: Tables C-43 and C-44
Plant E: Tables C-45, C-46, and C-47
Plant F: Tables C-48 and C-49
Plant G: Tables C-50, C-51, C-52, and C-53
Plant I: Tables C-54 and C-55
Plant K: Tables C-56 and C-57
Plant L: Tables C-58 and C-59
Plant M: Table C-60
Plant N: Tables C-61, C-62, and C-63

C.3 CHROMIC ACID ANODIZING FACILITIES

C.3.1 Plant O--Engineering Analysis[12]

Plant O is Reliable Plating and Polishing Company in Bridgeport, Connecticut. Reliable Plating and Polishing Company is a small job shop engaged primarily in chromic acid anodizing of aircraft and miscellaneous parts.

C.3.1.1 Process Description. The one chromic acid anodizing tank at this facility is 3.5 m (11.5 ft) long, 0.61 m (2.0 ft) wide, and 0.91 m (3.0 ft) deep and has a capacity of approximately 1,893 L (500 gal) of anodizing solution. The chromic acid anodizing process consists of the following steps: alkaline cleaning, cold water rinse, nitric acid dip, cold water rinse, anodizing, and nickel acetate sealing and/or hot water sealing. The aluminum parts are frequently dyed after sealing. The anodizing line is equipped with an automatic hoist to transfer parts into and out of process tanks.

The anodizing solution contains chromic acid in a concentration of approximately 60 to 75 g/L (8 to 10 oz/gal) of water. The operating temperature ranges from 35° to 38°C (95° to 100°F). The tank is equipped with a 4,000-A rectifier. The voltage is applied stepwise until a level of 40 V is reached. This level is applied for the remainder of the anodizing time. The current typically ranges from 200 to 300 A, and the anodizing time is 1 hr.

C.3.1.2 Air Pollution Control. The anodizing tank is equipped with a double-sided draft hood to capture the chromic acid mist. The ventilation hood is ducted to a wet scrubber manufactured by Niehaus Brothers, Inc. The scrubber is located adjacent to the anodizing tank.

The Niehaus scrubber is a fume exhaust and separating unit developed primarily for the electroplating and chemical industries. The scrubbing action is achieved by a combination of water adsorption and centrifugal separation. Figure C-21 is a schematic of the Niehaus scrubber. Its operation is described by Niehaus as follows:

> . . . contaminated air is drawn in through the intake duct into which sprays of water are introduced. These sprays, upon impinging on the high speed blower wheel, are reduced to fog which intimately mix with the contaminated air, dissolving the contaminants. The blower wheel being axially located within the separating chamber also acts as an impeller of a centrifuge, thereby separating the water entrained contaminants which are drained at the bottom of the unit. The cleaned air spirals out the discharge located at the top.[13]

The design gas flow rate is 85 m^3/min (3,000 ft^3/min). The design water flow rate ranges from 7.6 to 11.4 L/min (2 to 3 gal/min). The scrubber water is not recycled and the scrubber is continuously sprayed with fresh water.

C.3.1.3 Engineering Analysis. During April 1987, testing was conducted on the scrubber at Plant O to estimate the amount of uncontrolled emissions from the process. Plant O was selected for testing because the scrubber water was not recycled so that a grab sample analysis of the scrubber water would determine the amount of chromium collected in the scrubber. A mass balance was then performed on the scrubber to obtain an estimate for the amount of uncontrolled chromium emissions.

C.3.1.3.1 Sampling procedures. The testing consisted of obtaining composite samples representative of the scrubber influent, scrubber effluent, and anodizing solution for each of four 1-hour anodizing cycles. Each sample consisted of four grab samples that were collected approximately 15, 30, 45, and 60 minutes into each anodizing cycle. The sampling locations are shown in Figure C-22 and are designated as letters A, B, and C. The composite samples obtained during the tests were analyzed for both hexavalent and total chromium.

The scrubber water flow rate also was measured periodically by placing an 18.9-L (5-gal) container in the outlet stream and recording the amount of time required to fill the container. The temperature, operating voltage, and operating current of the anodizing solution; the number and types of parts anodizing during each anodizing cycle; and the outlet water flow rate of the scrubber were recorded during each test run. The average values of the monitored parameters are given in Table C-64.

C.3.1.3.2 Results of mass balance. The results of the sample analyses were used to perform a chromium mass balance around the scrubber to estimate uncontrolled chromium emissions. The analytical results for each composite sample are presented in Table C-65. The analytical results show that all of the chromium in the outlet scrubber water was in the hexavalent state.

The following equation was used to solve for the uncontrolled chromium mass emission rate:

$$M = [(Q_w)(C_w)]/E$$

where:

M = uncontrolled chromium mass emission rate, kg/hr (lb/hr);

Q_w = outlet water flow rate of scrubber, L/hr (gal/hr);

C_w = chromium concentration of outlet water stream, kg/L (lb/gal); and

E = efficiency of the scrubber, 90 percent.

The uncontrolled chromium emission rate was calculated using a scrubber efficiency of 90 percent. Previous source tests at chromium electroplating facilities showed that the efficiency of packed-bed scrubbers ranged from 93 to 99 percent. The vendor of the Niehaus fume scrubber states that it can achieve an efficiency of 95 to 99 percent. However, the conservative estimate of 90 percent efficiency was used in these analyses because it is expected that the fume scrubber is less efficient than a packed-bed scrubber.

The estimated uncontrolled chromium emission results and workload descriptions for each test run are presented in Table C-66. The uncontrolled chromium emission rate ranged from 1.5×10^{-4} kg/hr (3.3×10^{-4} lb/hr) to 2.5×10^{-3} kg/hr (5.5×10^{-3} lb/hr). The variation in the estimated uncontrolled emission rates is directly related to the total surface area and configuration of the parts anodized during each test run. The same type of aircraft parts was anodized during run Nos. 2 and 3 with 22 parts anodized during run No. 2 and 16 parts anodized during run No. 3. The workload decreased 27 percent from run No. 2 to run No. 3 with a subsequent decrease of 61 percent in the uncontrolled emission rate. The types of parts anodized during both run Nos. 1 and 4 were similar and consisted of racks of small aircraft and electronic parts with 14 racks of parts anodized during run No. 1 and 17 racks of parts anodized during run No. 4. The workload increased 18 percent from run No. 1 to run No. 4 with a subsequent increase of 24 percent in the uncontrolled chromium emission rate.

The average uncontrolled emission rate for run Nos. 2 and 3 is 2.7×10^{-4} kg/hr (5.9×10^{-4} lb/hr), and the average uncontrolled emission rate for run Nos. 1 and 4 is 2.2×10^{-3} kg/hr (4.9×10^{-3} lb/hr). The average of run Nos. 2 and 3 is only 12 percent of the average of run Nos. 1 and 4, which suggests that both total surface area and configuration of parts substantially affect the amount of uncontrolled chromium emissions.

The average uncontrolled chromium emission rate for all runs was 1.2×10^{-3} kg/hr (2.6×10^{-3} lb/hr). Even though the data show a wide range of uncontrolled emission rates due to the different workloads during each run, it is reasonable to average the estimated emissions because workload variations are common in the industry.

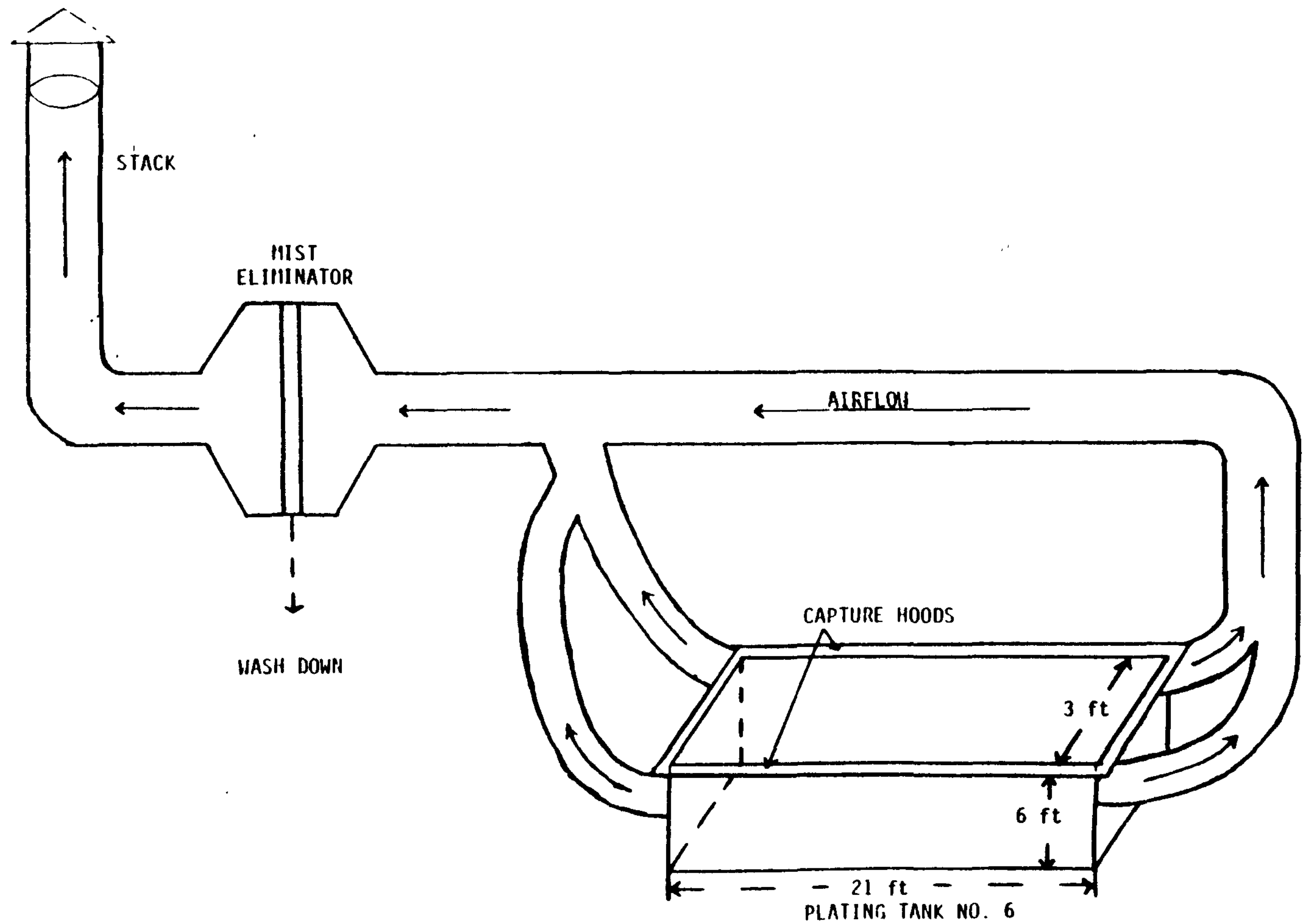


Figure C-1. Schematic of hard chromium plating Tank 6 tested at Greensboro Industrial Platers, Greensboro, North Carolina.

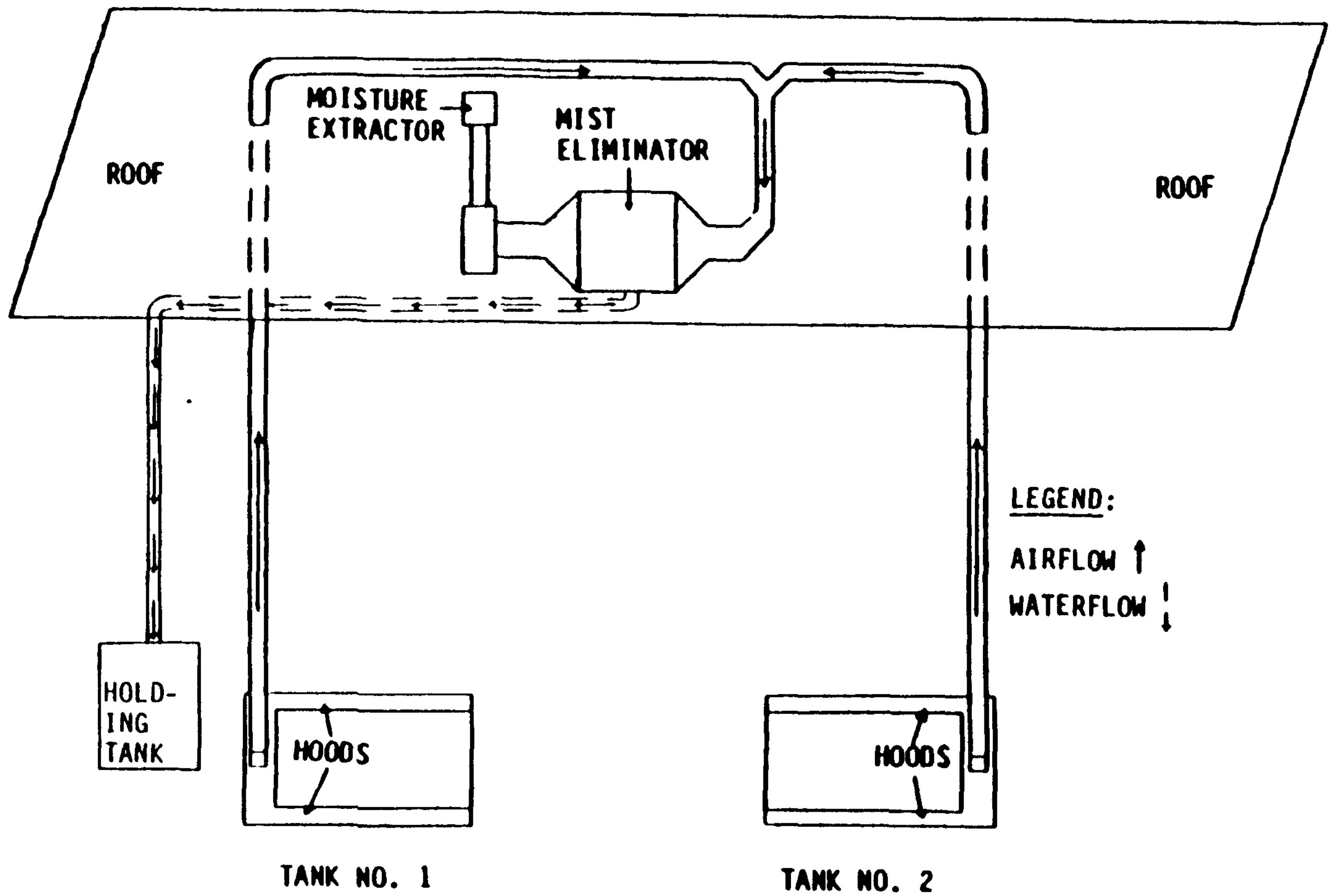


Figure C-2. Diagram of capture and control system for two hard chromium plating tanks tested at Consolidated Engravers, Charlotte, North Carolina.

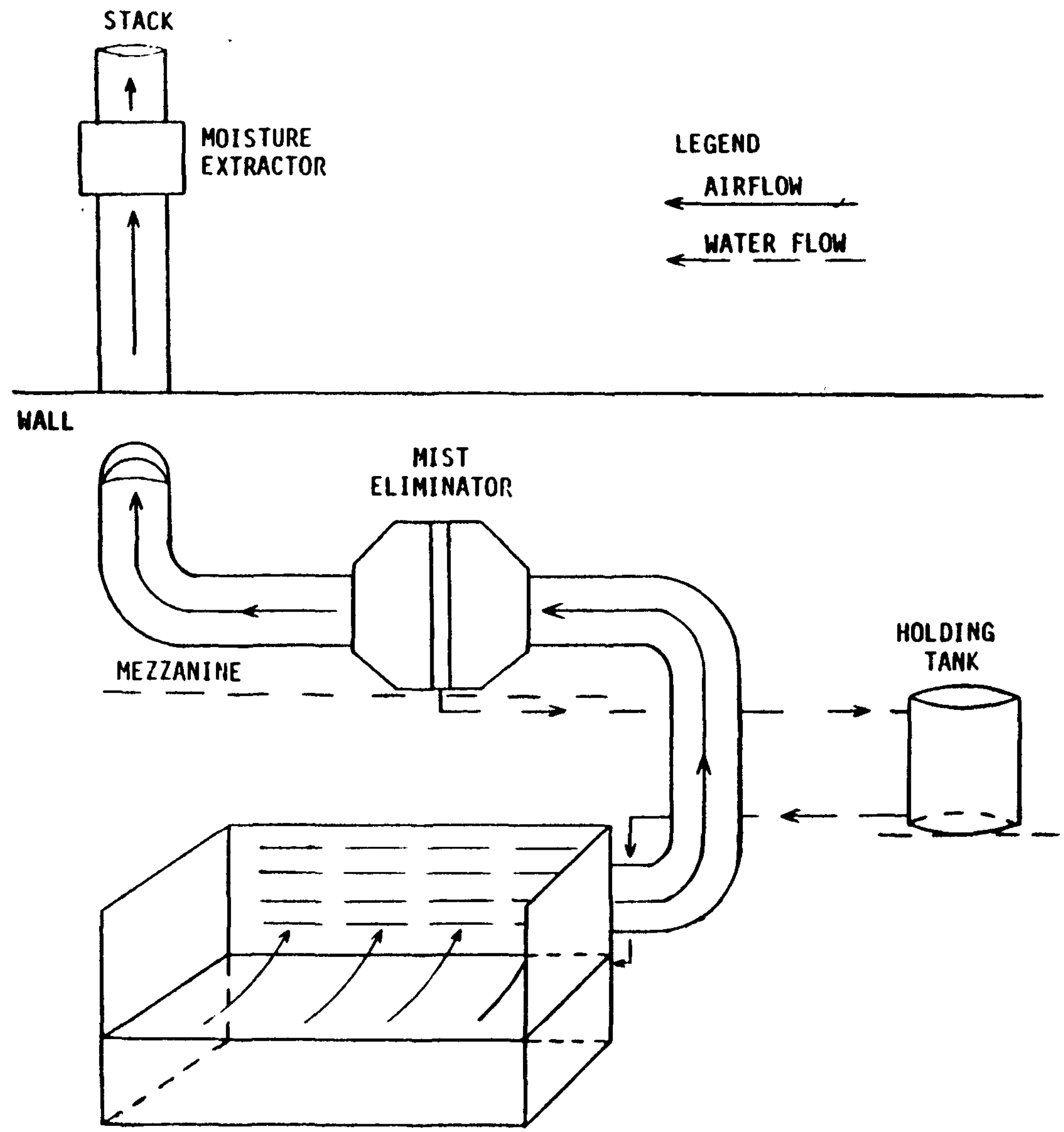


Figure C-3. Schematic of hard chromium plating operation tested at Able Machine Company, Taylors, South Carolina.

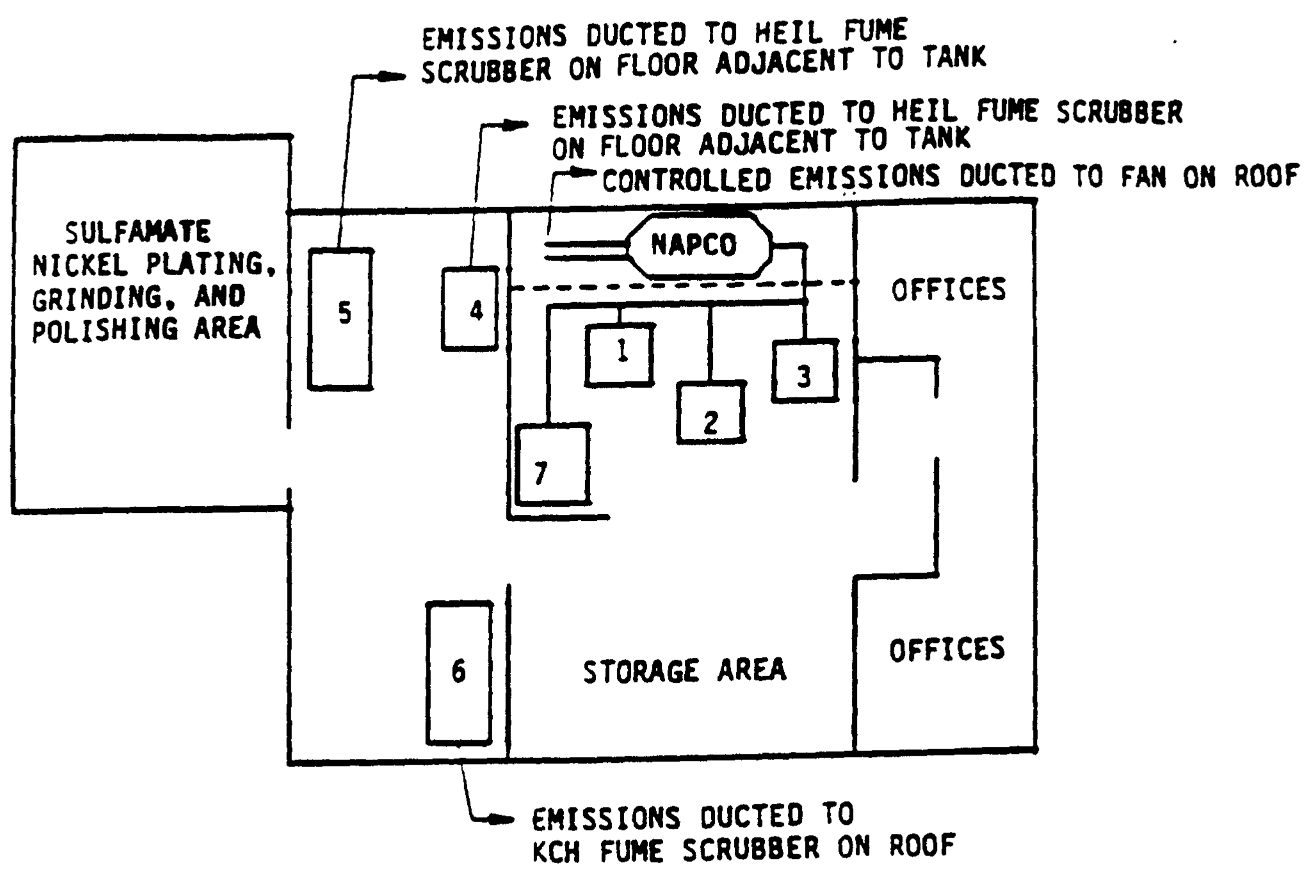


Figure C-4. Plan view of Roll Technology Inc., Greenville, South Carolina.

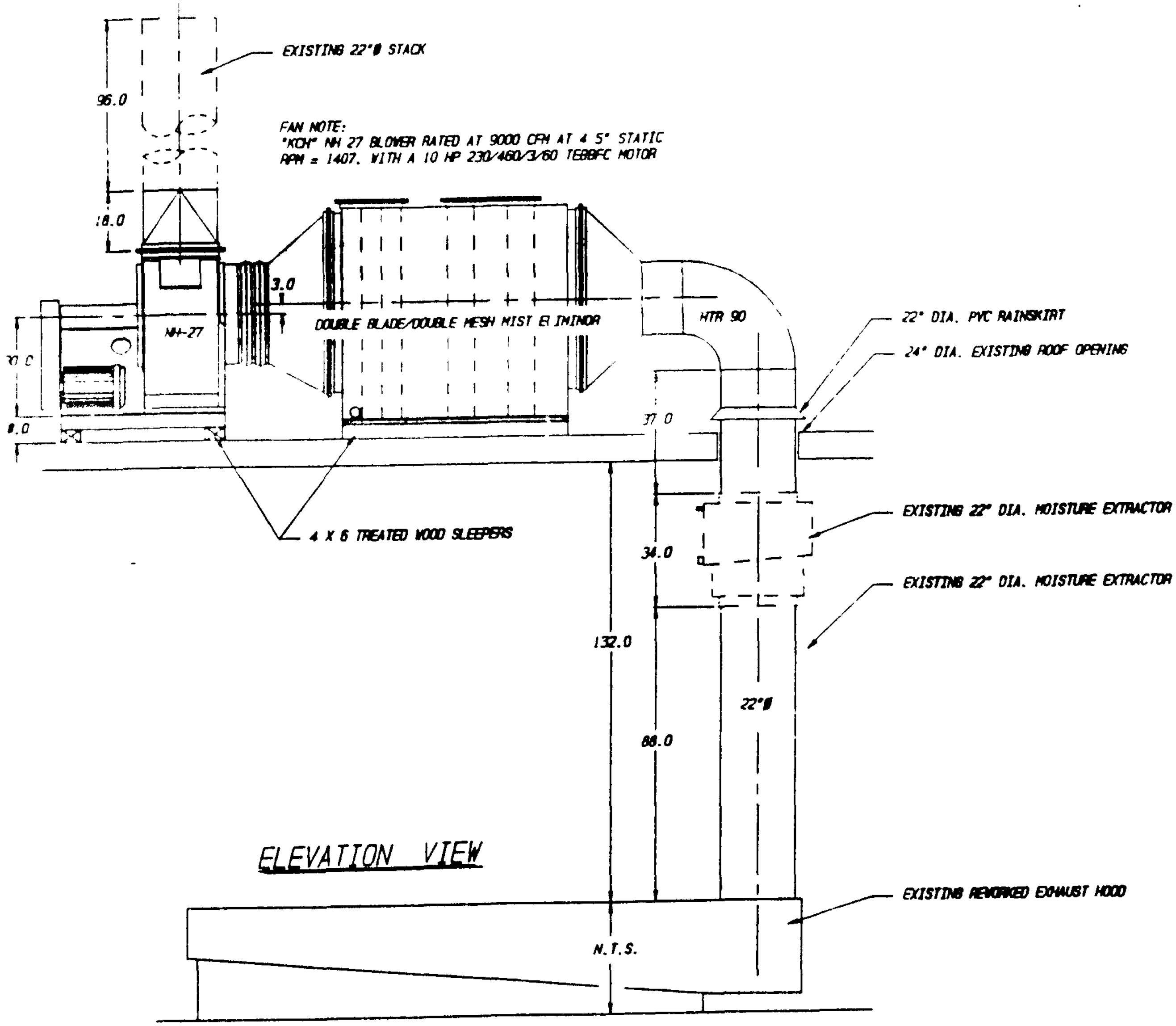


Figure C-5. Schematic of the control device system on Tank 6 at Roll Technology, Greenville, South Carolina.

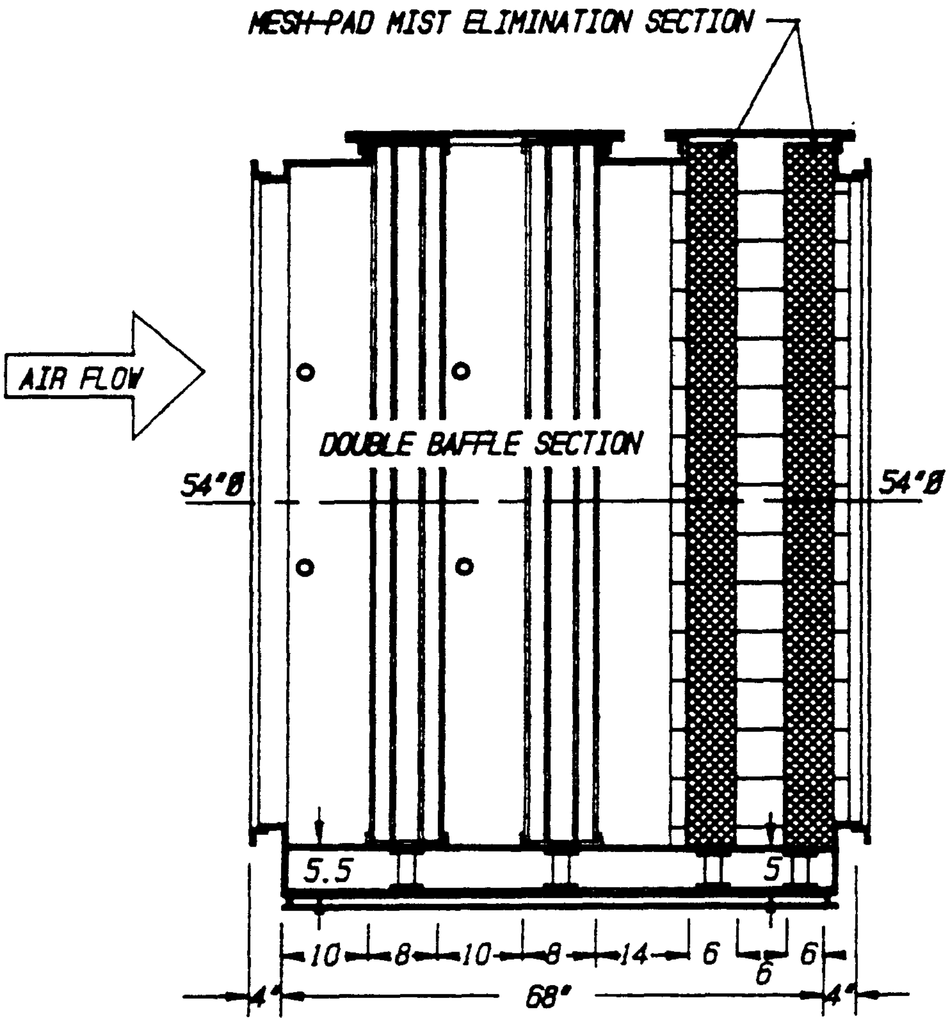


Figure C-6. Cross section of mist eliminator at Roll Technology, Greenville, South Carolina.

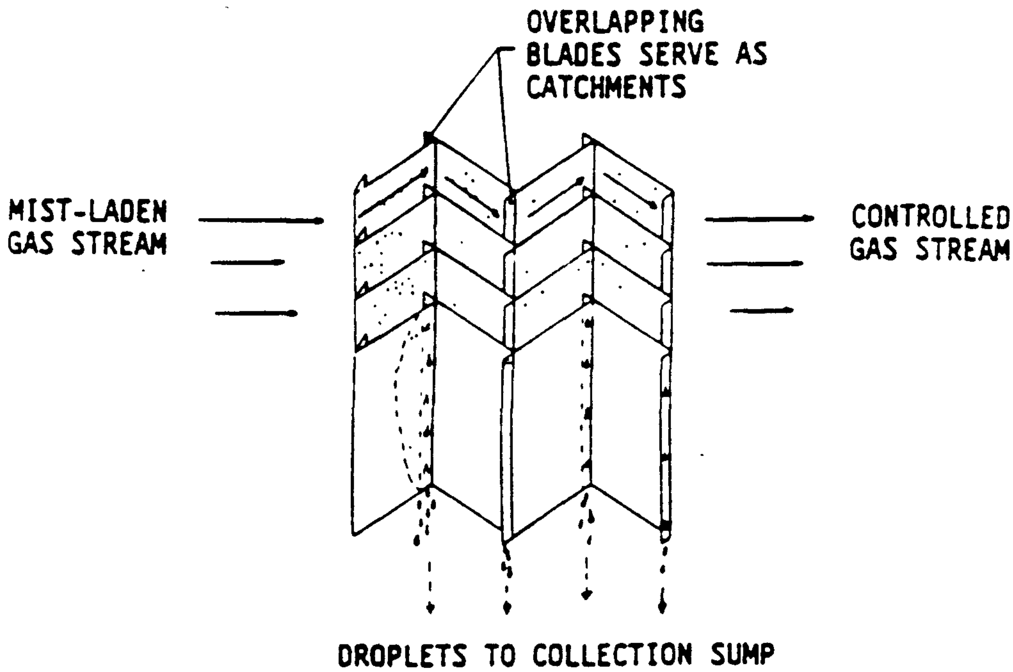


Figure C-7. Overlapping-type blade design for chevron-blade mist eliminators.

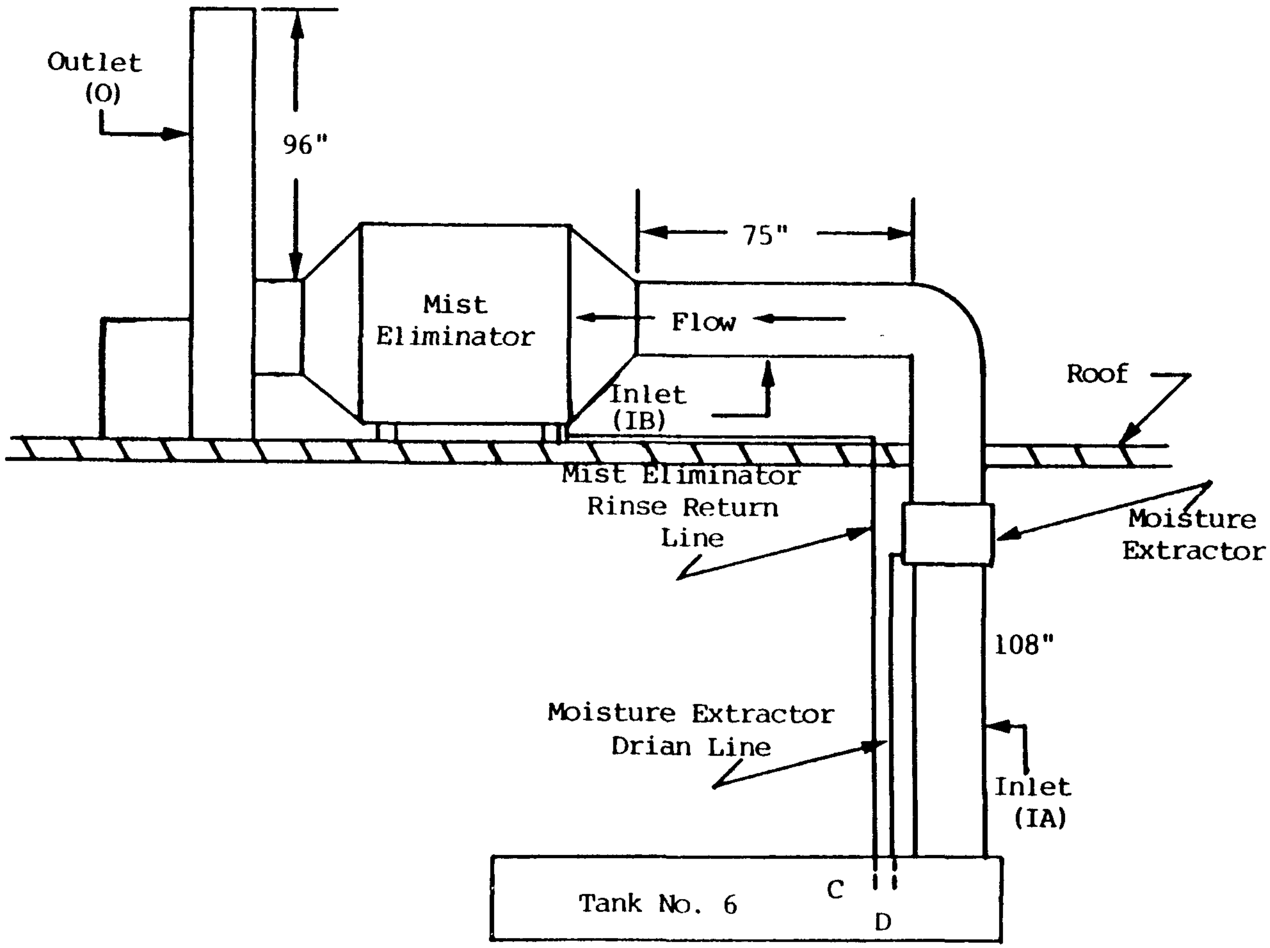


Figure C-8. Location of sample sites at Roll Technology, Greenville, South Carolina.

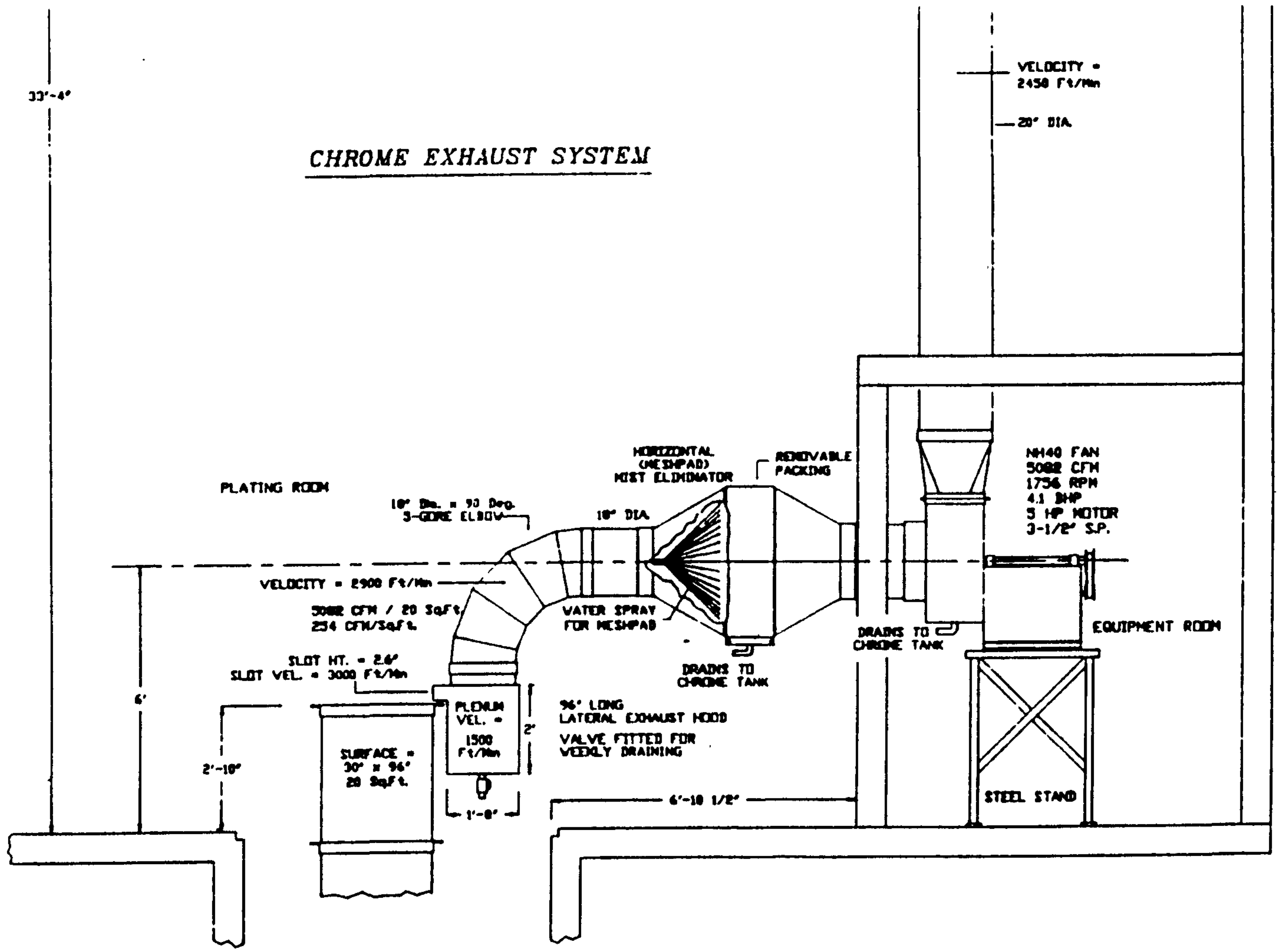


Figure C-9. Side view of capture and control system at Precision Machine and Hydraulic, Inc., Worthington, West Virginia.

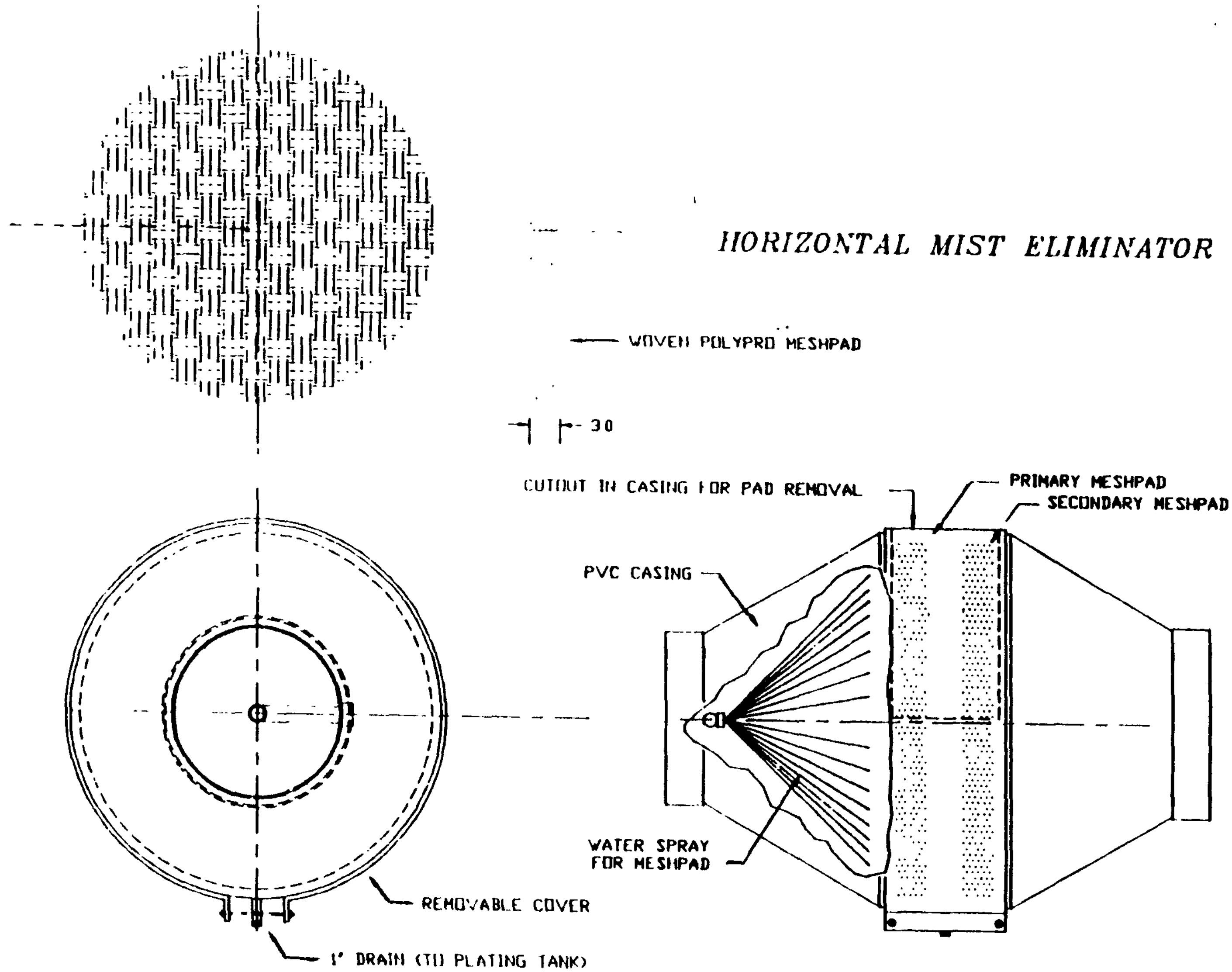


Figure C-10. Cross-sectional view of mesh-pad mist eliminator at Precision Machine and Hydraulic, Inc., Worthington, West Virginia.

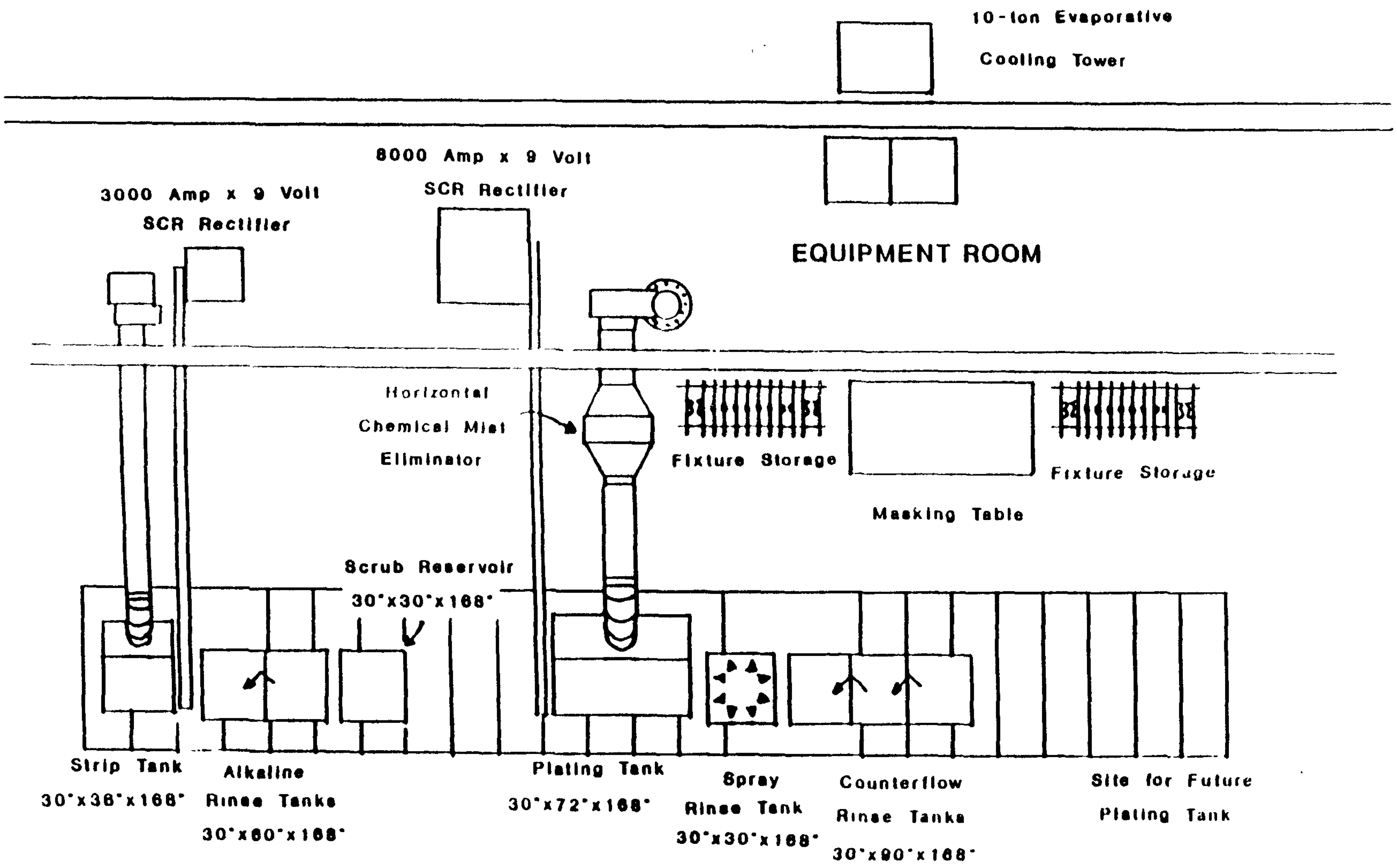


Figure C-11. Floor plan of Hard Chrome Specialists, Inc., York, Pennsylvania.

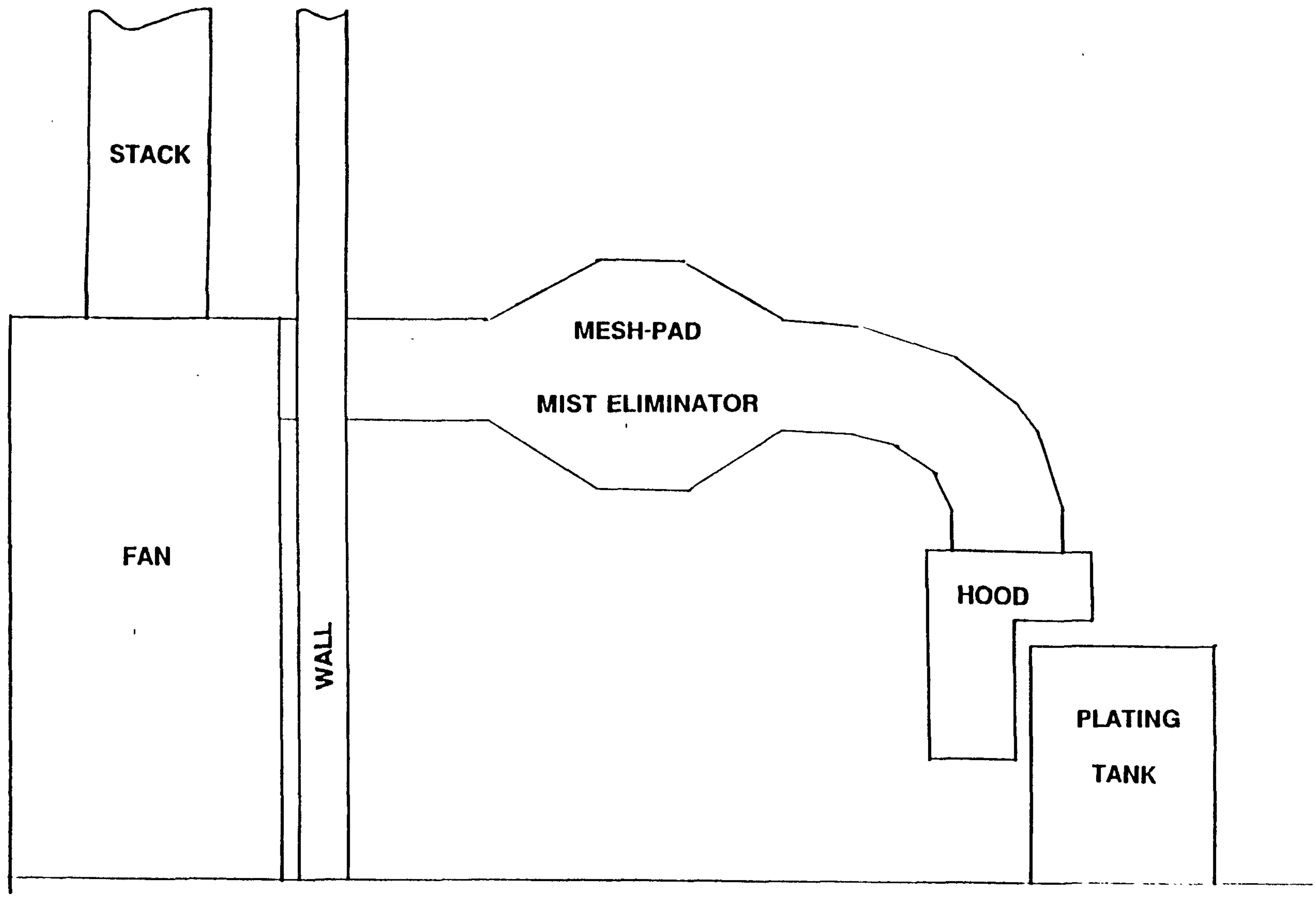


Figure C-12. Air pollution control system at Hard Chrome Specialists, York, Pennsylvania.

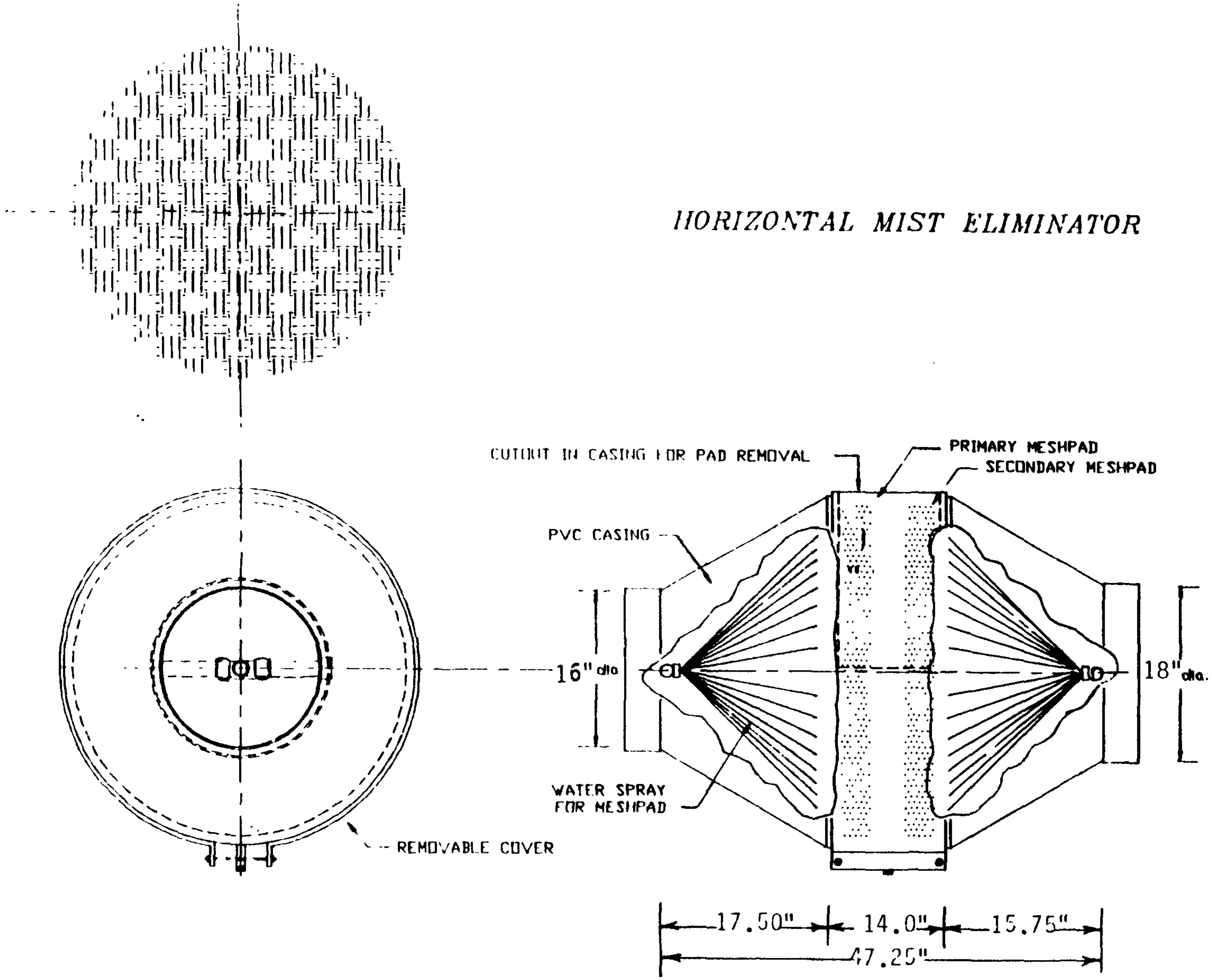


Figure C-13. Detailed schematic of mesh-pad mist eliminator at Hard Chrome Specialists, York, Pennsylvania.

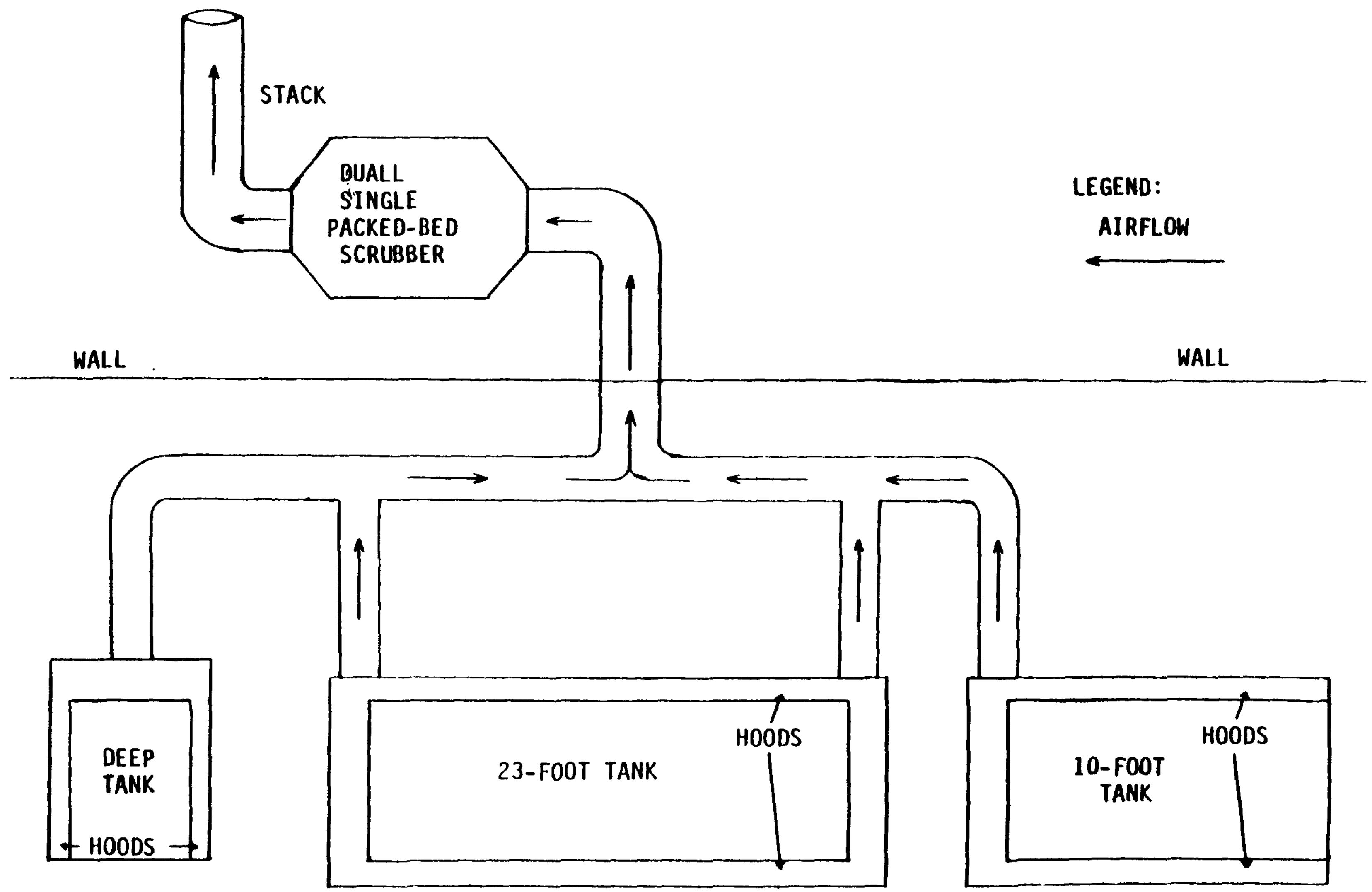


Figure C-14. Schematic of hard chromium plating operation tested at Piedmont Industrial Plating, Statesville, North Carolina.

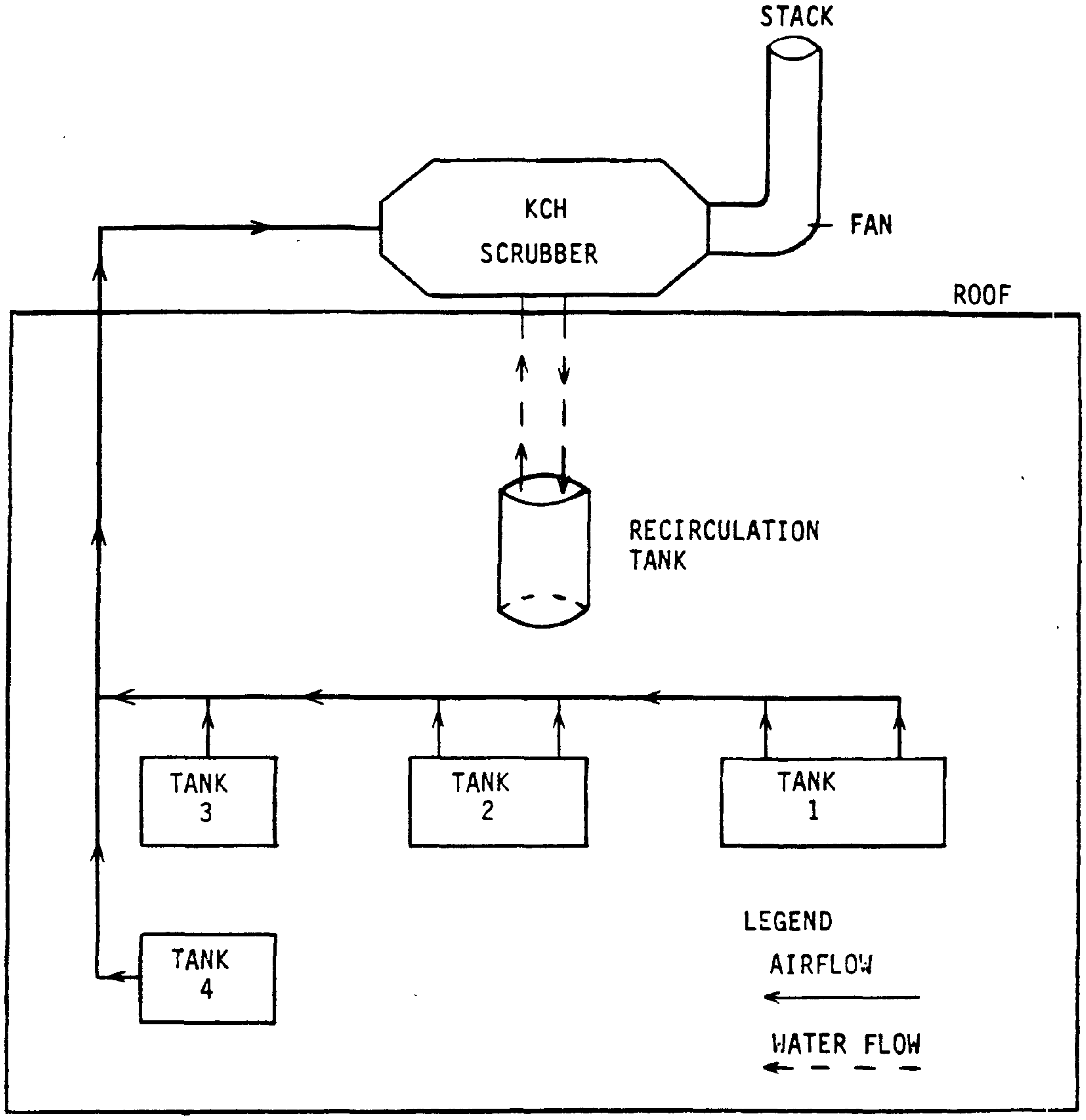


Figure C-15. Schematic of hard chromium plating operation tested at Steel Heddle Company, Greenville, South Carolina.

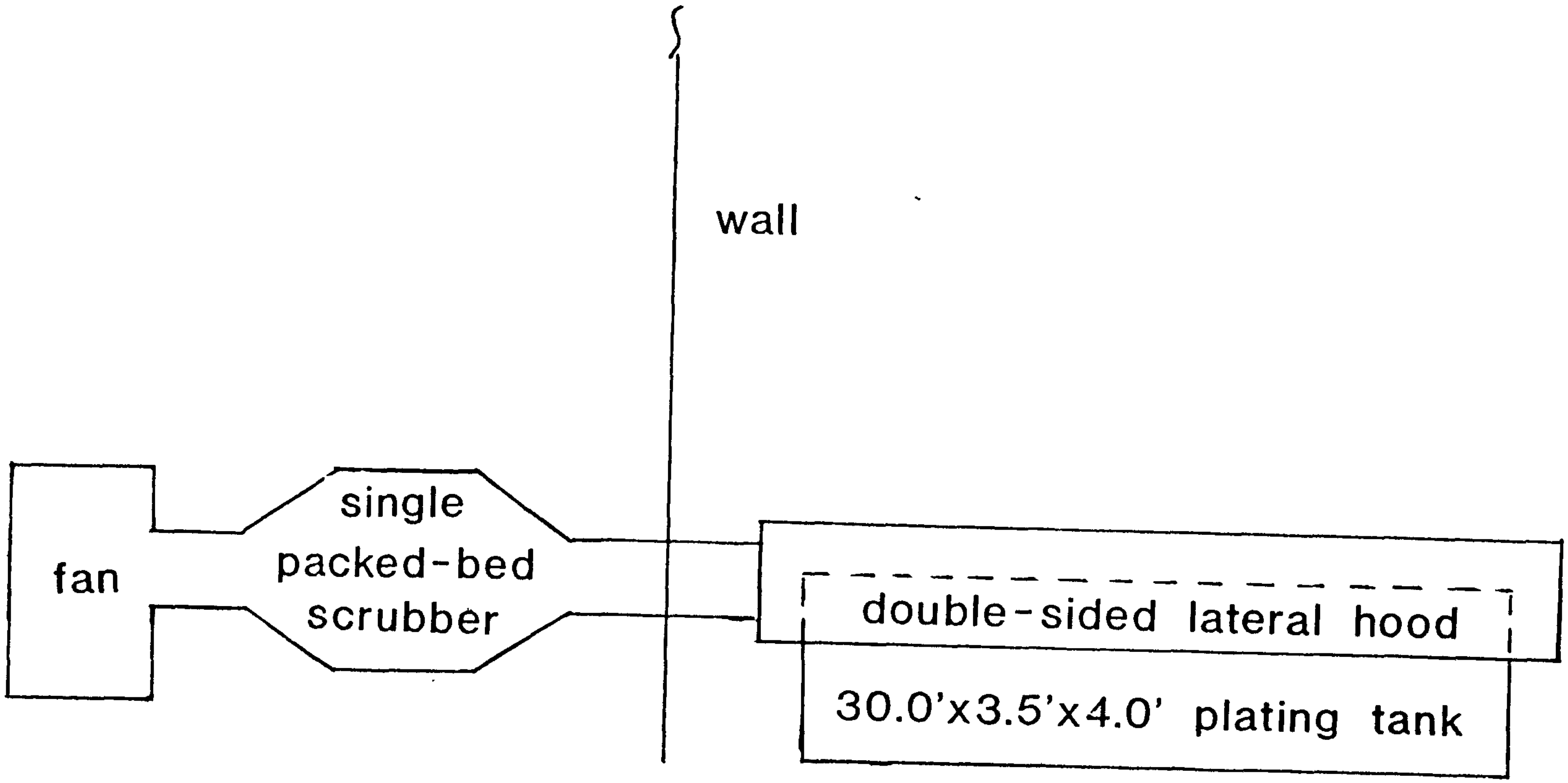


Figure C-16. Capture and control system at Fusion, Inc., Houston, Texas.

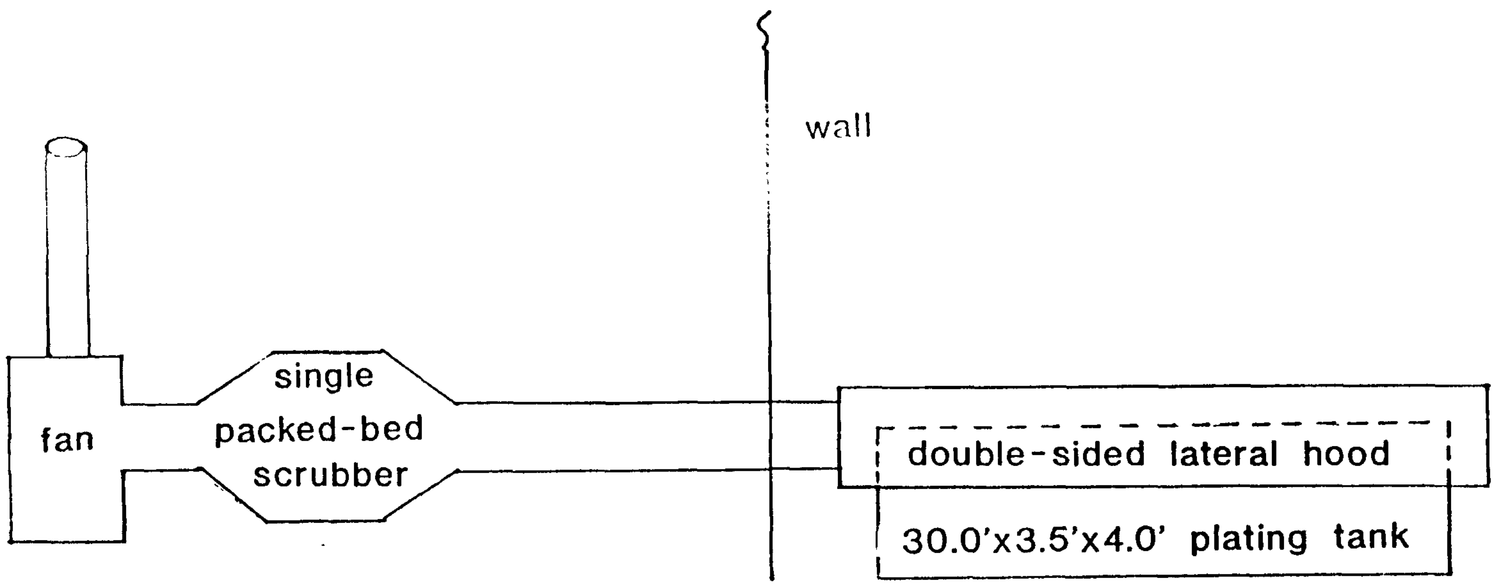


Figure C-17. Capture and control system at Fusion, Inc., Houston, Texas, after modifications.

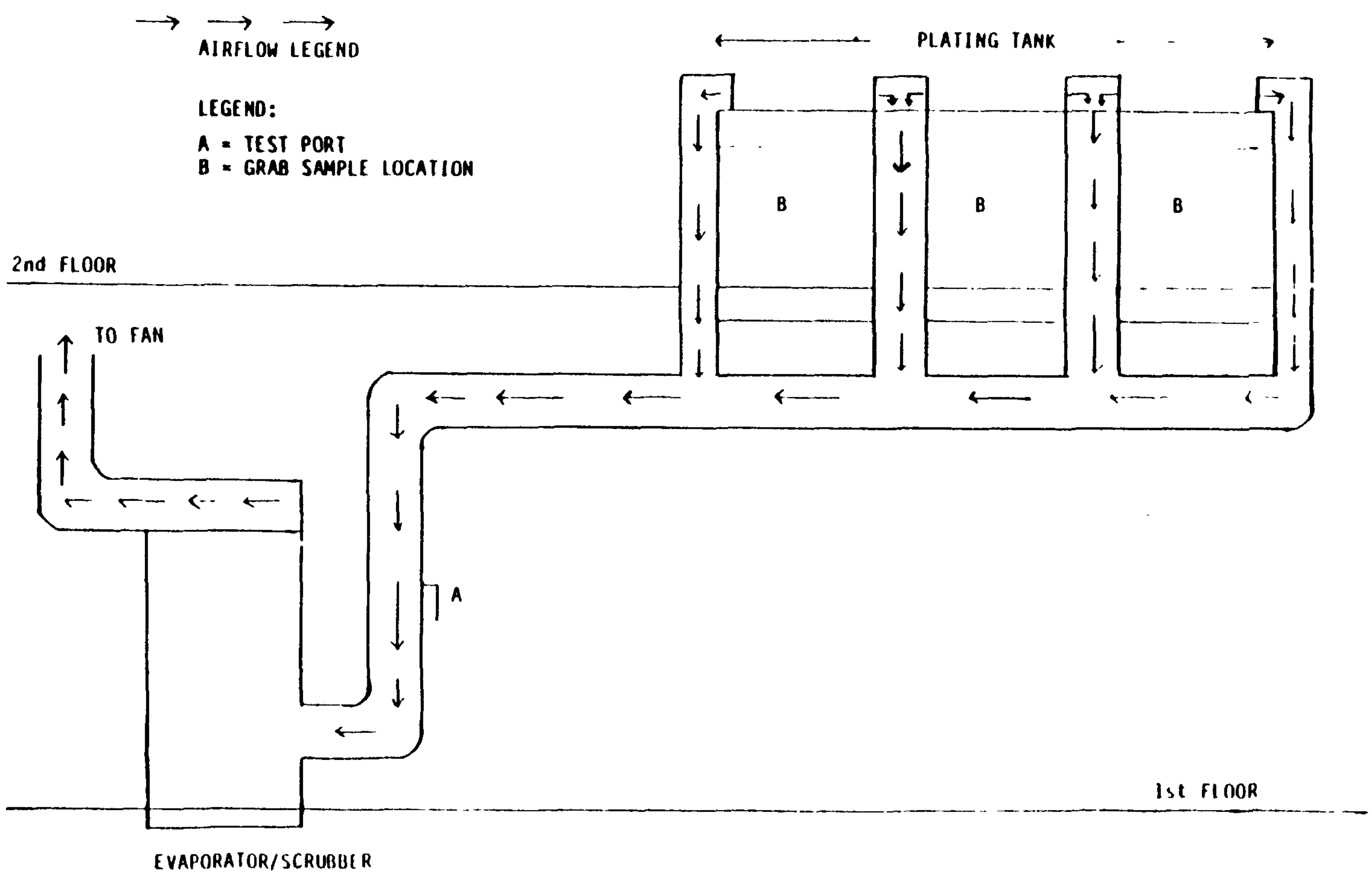
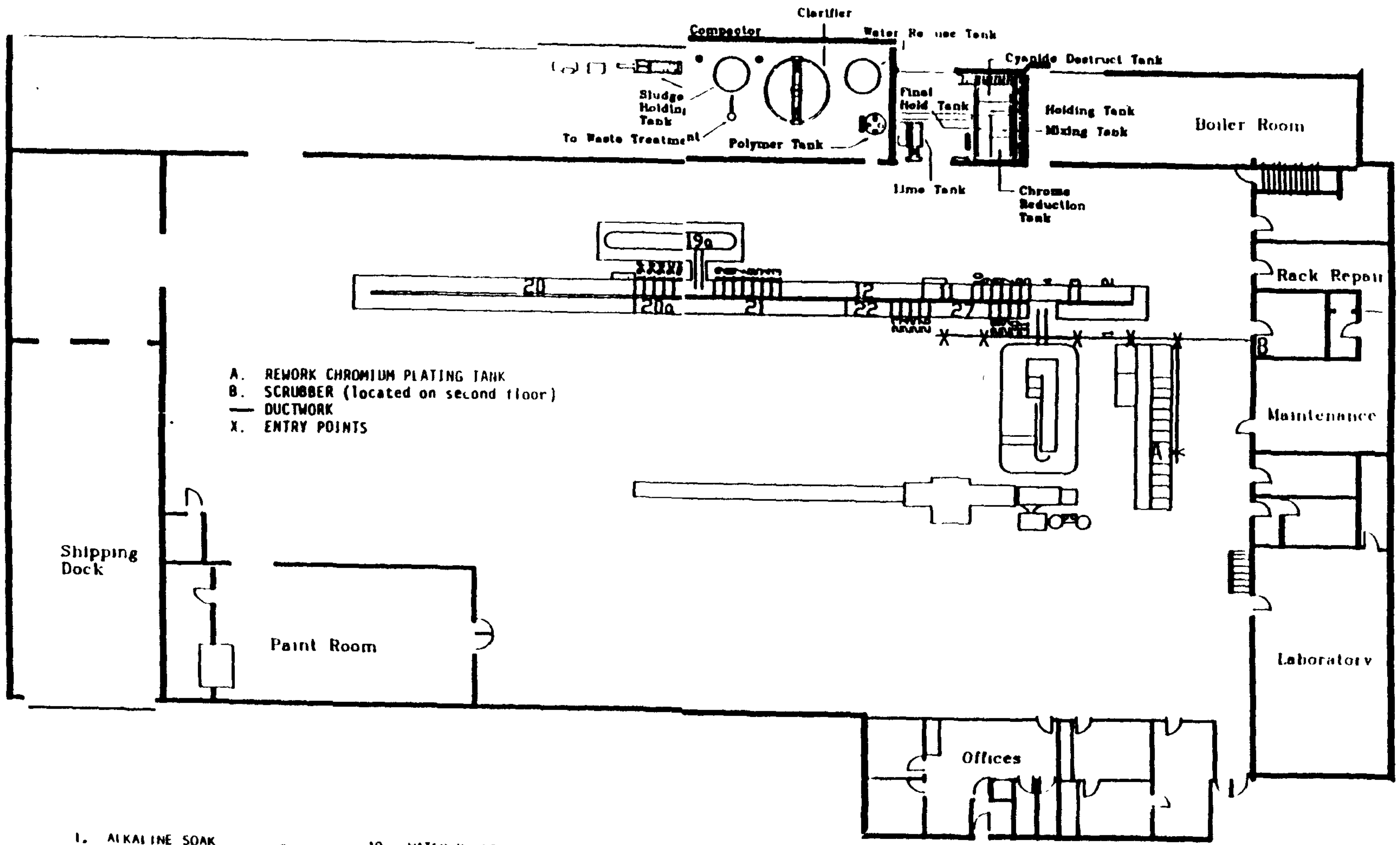


Figure C-18. Schematic of decorative chromium plating tank tested at Line 4 at Delco Products Division, General Motors Corporation, Livonia, Michigan.



1. ALKALINE SOAK
2. MILD ALKALINE POWER SPRAY
3. SPRAY RINSE
4. ALKALINE SOAK-SECONDARY
5. WATER RINSE
6. ELECTROCLEAN
7. WATER RINSE
8. SULFURIC ACID DIP
9. WATER RINSE
10. WATER RINSE
11. COPPER STRIKE
12. COPPER CYANIDE
13. COPPER SAVER
14. WATER RINSE
15. WATER RINSE
16. ELECTROCLEAN
17. WATER RINSE
18. WATER RINSE
19. WATER RINSE
19a. ACID COPPER
19b. WATER RINSE
19c. WATER RINSE
19d. SULFURIC ACID DIP
19e. WATER RINSE
19f. WATER RINSE
20. SEMI-BRIGHT NICKEL
20a. HIGH-SULFUR NICKEL
21. BRIGHT NICKEL
22. MICROPOROUS NICKEL
23. WATER RINSE
24. WATER RINSE
25. WATER RINSE
26. CHROMIUM DIP
27. CHROMIUM PLATING TANK
28. CHROMIUM SAVER
29. BISULFITE RINSE
30. BISULFITE RINSE
31. BISULFITE RINSE

Figure C-19. Plan view of the decorative chromium plating shop at Automatic Die Casting Specialties, Inc., St. Clair Shores, Michigan.

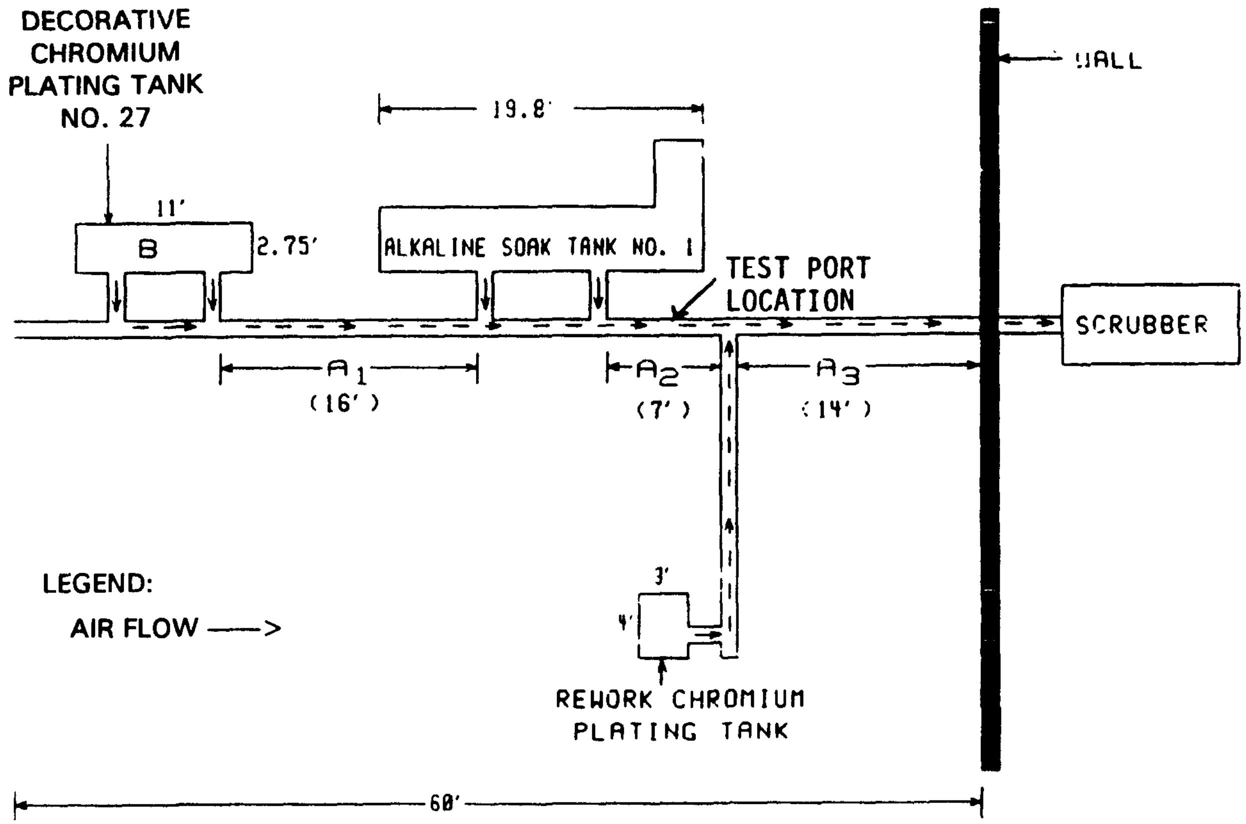
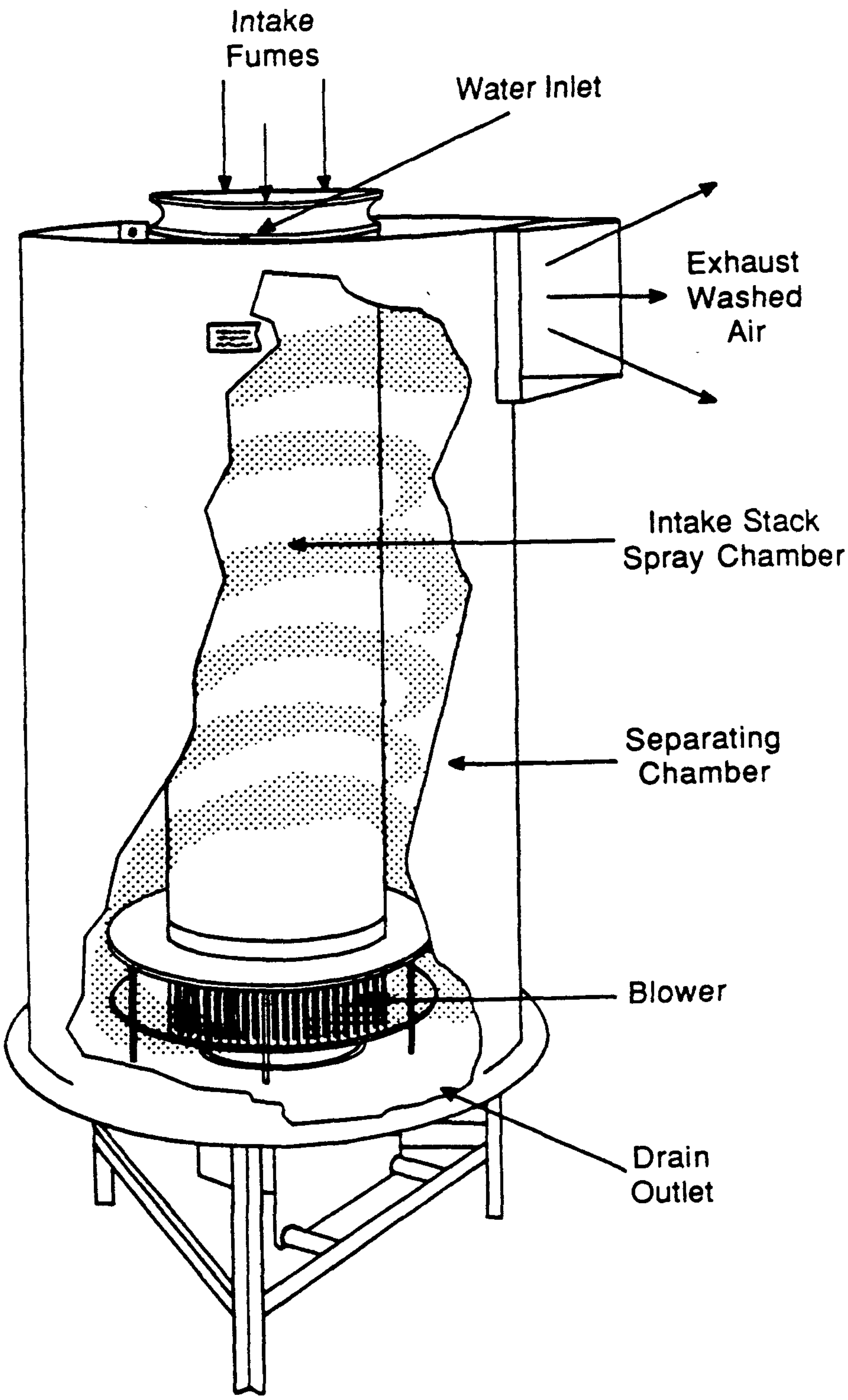


Figure C-20. Diagram of ventilation and control system for chromium plating Tank 27 at Automatic Die Casting Specialties, Inc., St. Clair Shores, Michigan.



Figures C-21. Diagram of centrifugal-flow scrubber at Reliable Plating and Polishing Company, Bridgeport, Connecticut.

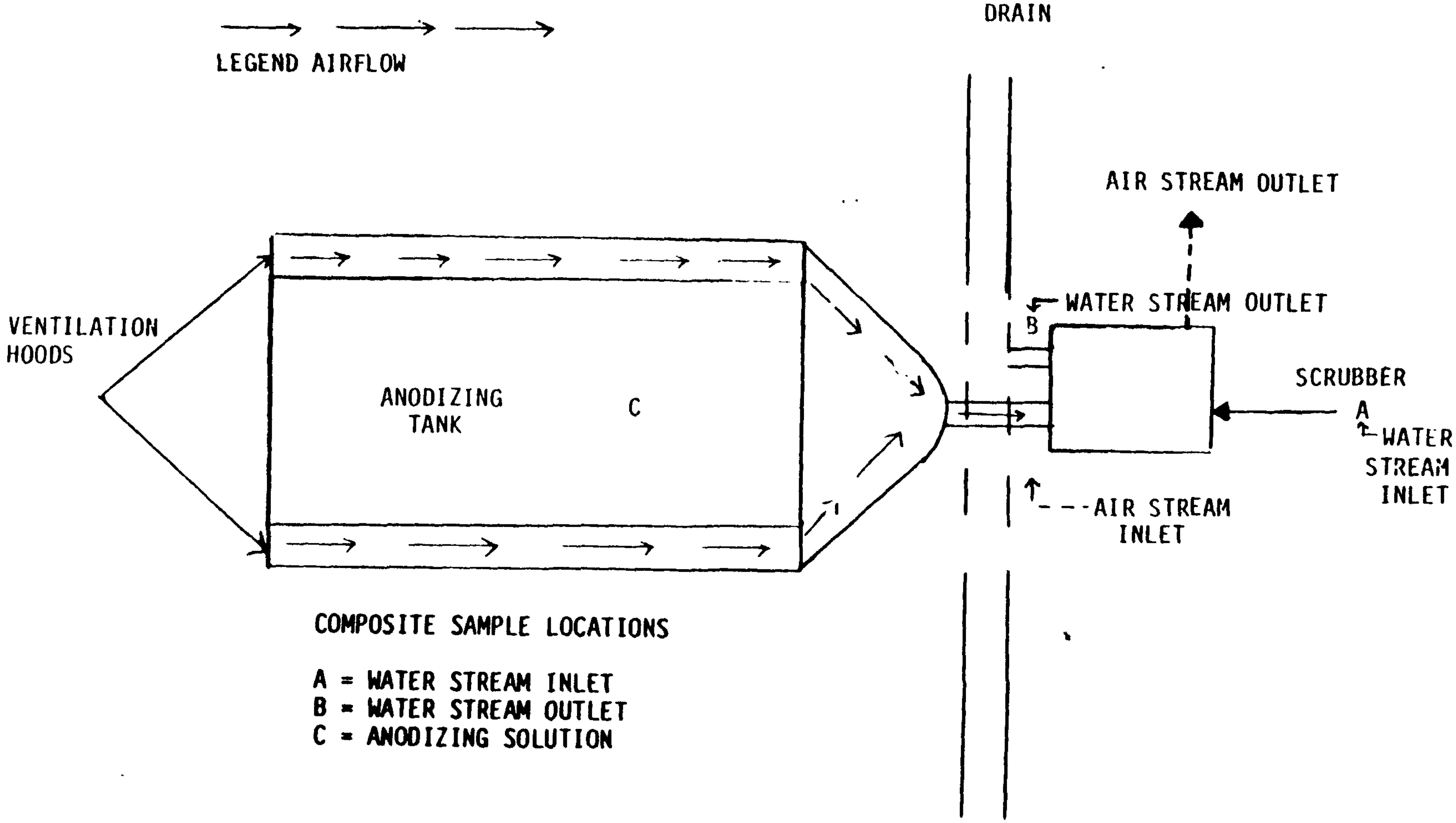


Figure C-22. Schematic of chromic acid anodizing tank and Niehaus fume scrubber at Reliable Plating Company in Bridgeport, Connecticut.

TABLE C-1. AVERAGE OPERATING PARAMETERS RECORDED DURING MASS EMISSIONS TESTS ON TANK 6 AT GREENSBORO INDUSTRIAL PLATERS, GREENSBORO, NORTH CAROLINA

Test run No.	Operating voltage, volts	Operating current, amperes	Temp. of plating solution, °C (°F)
1	9.3	5,960	49 (120)
2	8.1	5,560	46 (114)
3	10.0	7,930	50 (122)
4	8.7	5,440	62 (143)

TABLE C-2. TOTAL CURRENT SUPPLIED TO TANK 6 DURING MASS EMISSIONS TESTS AT GREENSBORO INDUSTRIAL PLATERS, GREENSBORO, NORTH CAROLINA

	Total current, ampere-hours	
Test run No.	Inlet test	Outlet test
1	11,800	13,200
2	10,400	11,000
3	15,900	16,900
4	10,600	11,200

TABLE C-3. CHROMIC ACID CONCENTRATIONS OF PLATING BATH AND MIST ELIMINATOR WASHDOWN SAMPLES AT GREENSBORO INDUSTRIAL PLATERS, GREENSBORO, NORTH CAROLINA

Grab sample	CrO_3 concentration, g/L (oz/gal)
<u>Test Run No. 1</u>	
Plating solution	261 (34.8)
Mist eliminator washdown water	148 (19.8)
<u>Test Run No. 2</u>	
Plating solution	258 (34.5)
Mist eliminator washdown water	77.1 (10.3)
<u>Test Run No. 3</u>	
Plating solution	247 (33.0)
Mist eliminator washdown water	120 (16.0)
<u>Test Run No. 4</u>	
Plating solution	251 (33.5)
Mist eliminator washdown water	42.7 (5.7)

TABLE C-4. AVERAGE OPERATING CONDITIONS RECORDED DURING MASS EMISSIONS TESTS AT CONSOLIDATED ENGRAVERS CORPORATION, CHARLOTTE, NORTH CAROLINA

Test run No. Inlet/Outlet	Tank No.	Work-station No.	Operating voltage, volts	Operating current, amperes	Temp. of plating solution, °C (°F)
I-1/0-1	1	1	15.5	1,600	68 (155)
	1	2	13.0	1,250	68 (155)
	2	1 and 2	10.0	2,050	55 (132)
I-2/0-2	1	1	15.5	1,460	62 (144)
	1	2	13.0	1,270	62 (144)
	2	1 and 2	9.8	2,210	58 (136)
I-3/0-3	1	1	112.6	1,265	67 (152)
	1	2	11.4	1,250	67 (152)
	2	1 and 2	9.8	2,170	55 (132)

TABLE C-5. TOTAL CURRENT SUPPLIED TO THE PLATING TANKS DURING EACH EMISSIONS TEST RUN AT CONSOLIDATED ENGRAVERS CORPORATION, CHARLOTTE, NORTH CAROLINA

Test run No. Inlet/outlet	Tank No.	Work-station No.	Total current, ampere-hours	
			Inlet	Outlet
I-1/0-1	1	1	4,830	4,840
	1	2	3,720	3,730
	2	1 and 2	6,470	6,510
			15,000	15,100
I-2/0-2	1	1	3,950	4,020
	1	2	3,550	3,560
	2	1 and 2	6,580	6,580
			14,100	14,200
I-3/0-3	1	1	3,790	3,780
	1	2	3,730	3,720
	2	1 and 2	6,590	6,590
			14,100	14,100

TABLE C-6. CHROMIC ACID CONCENTRATIONS OF PLATING BATH AND MIST ELIMINATOR WASHDOWN SAMPLES AT CONSOLIDATED ENGRAVERS CORPORATION, CHARLOTTE, NORTH CAROLINA

Run No./Sample	CrO_3 concentration, g/L (oz/gal)
Run No. 1	
Plating Tank 1	227 (30.4)
Plating Tank 2	246 (33.0)
Washdown water	207 (27.7)
Run No. 2	
Plating Tank 1	246 (33.0)
Plating Tank 2	259 (34.7)
Washdown water	112 (15.0)
Run No. 3	
Plating Tank 1	234 (31.4)
Plating Tank 2	238 (31.9)
Washdown water	105 (14.1)

TABLE C-7. AVERAGE OPERATING PARAMETERS FOR MASS EMISSIONS TESTS AT ABLE MACHINE COMPANY, TAYLORS, SOUTH CAROLINA

Test run No.	Operating voltage, volts	Operating current, amperes	Temp. of plating solution, °C (°F)
1	7.5	8,580	52 (125)
2	7.1	9,530	52 (125)
3	7.5	7,050	52 (126)

TABLE C-8. TOTAL CURRENT SUPPLIED TO THE TANK DURING MASS EMISSIONS TESTS AT ABLE MACHINE COMPANY, TAYLORS, SOUTH CAROLINA

	Total current, ampere-hours	
Test run No.	Inlet test	Outlet test
1	25,800	25,500
2	18,800	19,400
3	14,200	14,800

TABLE C-10. AVERAGE OPERATING PARAMETERS DURING EACH MASS EMISSIONS TEST RUN AT ROLL TECHNOLOGY, GREENVILLE, SOUTH CAROLINA

Run No.	Operating current, amperes	Operating voltage, volts	Temperature of plating solution, °C (°F)
1	4,500	6.8	54 (130)
2	5,200	7.0	54 (130)
3	5,200	7.3	54 (130)

TABLE C-11. TOTAL CURRENT SUPPLIED TO TANK 6 DURING EACH MASS EMISSIONS TEST RUN AT ROLL TECHNOLOGY, GREENVILLE, SOUTH CAROLINA

Run No.	Test time, hours	Total current, ampere-hours
1	3.2	15,400
2	2.0	10,400
3	2.0	10,400

TABLE C-12. CHROMIC ACID CONCENTRATIONS OF PLATING SOLUTION AND WASHDOWN SAMPLES AT ROLL TECHNOLOGY, GREENVILLE, SOUTH CAROLINA

	CrO_3 concentration	
Grab sample	g/L	oz/gal
Plating solution		
Run IA-1	280	37.4
Run IA-2	222	29.6
Run IA-3	229	30.6
Moisture extractor washdown water		
8/10/88	5.84	0.78
8/11/88	12.6	1.68
Mist eliminator washdown water		
8/10/88	0.90	0.12
8/11/88	1.20	0.16

TABLE C-9. CHROMIC ACID CONCENTRATIONS OF PLATING SOLUTION AND MIST ELIMINATOR WASHDOWN SAMPLES AT ABLE MACHINE COMPANY, TAYLORS, SOUTH CAROLINA

Grab sample	CrO_3 concentration, g/L (oz/gal)
Test Run No. 1	
Plating solution	152 (20.3)
Mist eliminator washdown water	5.3 (0.71)
Test Run No. 2	
Plating solution	156 (20.8)
Mist eliminator washdown water[a]	
Test Run No. 3	
Plating solution	159 (21.2)
Mist eliminator washdown water	6.6 (0.88)

[a]Mist eliminator was not washed down after test run No. 2.

TABLE C-13. AVERAGE OPERATING PARAMETERS DURING MASS EMISSIONS TESTS AT PRECISION MACHINE AND HYDRAULIC, WORTHINGTON, WEST VIRGINIA

Run No.	Rectifier No.	Operating voltage, volts	Operating current, amperes	Operating temperature, °C (°F)	Surface area plated, m^2 (ft^2)
1	1	4.6	2,800	56 (133)	1.4 (15.2)
	2	5.4	3,700		
2	1	4.7	2,000	56 (133)	1.3 (13.9)
	2	4.9	3,000		
3	1	4.7	1,500	56 (133)	1.3 (13.4)
	2	4.9	3,700		
4	1	4.7	1,200	55 (131)	1.1 (12.3)
	2	5.0	3,600		
5	1	4.9	1,300	56 (133)	1.1 (11.7)
	2	4.7	3,600		

TABLE C-14. TOTAL CURRENT SUPPLIED TO PLATING TANK DURING MASS EMISSIONS TEST AT PRECISION MACHINE AND HYDRAULIC, WORTHINGTON, WEST VIRGINIA

Run No.	Rectifier No.	Total current ampere-hours	
		Inlet	Outlet
1	1	9,240	9,240
	2	11,830	11,830
Total[a]		21,100	21,100
2	1	3,900	3,900
	2	6,100	6,100
Total[a]		10,000	10,000
3	1	3,000	3,000
	2	7,400	7,400
Total[a]		10,400	10,400
4	1	2,490	2,490
	2	7,130	7,130
Total[a]		9,600	9,600
5	1	2,600	2,600
	2	7,090	7,090
Total[a]		9,700	9,700

[a]Numbers are rounded to nearest 100.

TABLE C-15. CHROMIC ACID CONCENTRATIONS OF PLATING SOLUTION SAMPLES AT PRECISION MACHINE AND HYDRAULIC, WORTHINGTON, WEST VIRGINIA

Run No.	CrO_3 concentration	
	g/L	oz/gal
I-1	187	24.9
I-2	195	26.1
I-3	197	26.3
I-4	201	26.9
I-5	196	26.2

TABLE C-16. AVERAGE OPERATING PARAMETERS DURING EACH MASS EMISSIONS TEST RUN AT HARD CHROME SPECIALISTS, YORK, PENNSYLVANIA

Run No.	Operating current, amperes	Operating voltage, volts	Temperature of plating solution, °C (°F)
1	3,000	4.6	54 (130)
2	3,000	4.7	55 (131)
3	5,400	5.0	55 (131)
4	3,000	5.0	56 (132)
5	3,000	5.0	56 (132)

TABLE C-17. TOTAL CURRENT SUPPLIED TO PLATING TANK DURING EACH MASS EMISSIONS TEST RUN AT HARD CHROME SPECIALISTS, YORK, PENNSYLVANIA

Run No.	Test time, hours	Total current, ampere-hours
1	3.2	9,600
2	2.0	6,000
3	2.0	10,800
4	3.2	9,600
5	2.0	6,000

TABLE C-18. CHROMIC ACID CONCENTRATIONS OF PLATING BATH AND MIST ELIMINATOR WASHDOWN WATER GRAB SAMPLES AT HARD CHROME SPECIALISTS, INC., YORK, PENNSYLVANIA

	CrO_3 concentration	
Run No./Sample date	g/L	oz/gal
Plating solution		
I-1	205	27.4
I-2	215	28.7
I-3	215	28.7
I-4	208	27.8
I-5	205	27.4
Mist eliminator washdown water		
01/30/89	93.0	12.4
01/31/89	60.1	8.0
02/01/89	29.8	4.0

TABLE C-19. DIMENSIONS AND OPERATING PARAMETERS OF HARD CHROMIUM PLATING TANKS AT PIEDMONT INDUSTRIAL PLATING, STATESVILLE, NORTH CAROLINA

Tank	Tank dimensions (l, w, d), m (ft)	Tank capacity, L (gal)	Tank surface area, m^2 (ft^2)	Voltage, volts[a]	Current, amperes[a,b]
23-foot	7.0, 0.9, 1.2 (23.0, 3.0, 4.0)	6,850 (1,810)	6.3 (69)	12	9,000
10-foot	3.0, 0.9, 1.2 (10.0, 3.0, 4.0)	2,990 (790)	2.7 (30)	12	5,000

[a]Maximum operating values.

[b]A total of four work stations can be used in the 23-foot tank. One of the work stations is charged with a 6,000-A rectifier and three of the work stations each are charged with a 1,000-A rectifier. A total of five work stations are used in the 10-foot tank. Each work station is charged with separate 1,000-A rectifiers.

TABLE C-21. AVERAGE OPERATING PARAMETERS RECORDED DURING MASS EMISSIONS TESTS AT PIEDMONT INDUSTRIAL PLATING, STATESVILLE, NORTH CAROLINA

Test run No.	Tank	Operating voltage, volts	Operating current, amperes	Temperature of plating solution, °C (°F)	Pressure drop of scrubber, kPa (in. w.c.)
1	23-ft	9.2	1,560	57 (134)	0.55 (2.2)
	10-ft	6.6	700	60 (140)	0.55 (2.2)
2	23-ft	9.3	1,620	57 (134)	0.55 (2.2)
	10-ft	6.7	700	60 (140)	0.55 (2.2)
3	23-ft	9.3	1,630	58 (136)	0.55 (2.2)
	10-ft	7.1	720	60 (140)	0.55 (2.2)
4	23-ft	9.7	1,760	58 (137)	0.52 (2.1)
	10-ft	5.6	170	60 (140)	0.52 (2.1)
5	23-ft	9.7	1,800	59 (138)	0.52 (2.1)
	10-ft	5.8	240	60 (140)	0.52 (2.1)
6	23-ft	9.7	1,830	59 (138)	0.52 (2.1)
	10-ft	6.0	280	60 (140)	0.52 (2.1)
7	23-ft	9.0	2,000	57 (135)	0.52 (2.1)
	10-ft	6.0	430	60 (140)	0.52 (2.1)
8	23-ft	8.2	1,950	59 (138)	0.50 (2.0)
	10-ft	7.1	490	60 (140)	0.50 (2.0)
9	23-ft	8.0	2,000	59 (138)	0.50 (2.0)
	10-ft	6.9	380	60 (140)	0.50 (2.0)
10	23-ft	8.0	2,000	58 (136)	0.50 (2.0)
	10-ft	6.9	370	60 (140)	0.50 (2.0)
11	23-ft	8.5	2,000	58 (136)	0.52 (2.1)
	10-ft	6.5	400	60 (140)	0.52 (2.1)
12	23-ft	8.5	2,000	58 (136)	0.50 (2.0)
	10-ft	6.6	420	60 (140)	0.50 (2.0)

TABLE C-20. AVERAGE SCRUBBER WATER CHROMIC ACID CONCENTRATIONS DURING MASS EMISSIONS TESTS AT PIEDMONT INDUSTRIAL PLATING, STATESVILLE, NORTH CAROLINA

Test run No.	Target concentration, g/L (oz/gal)	Actual concentration, g/L (oz/gal)
1	0.0	1.38 (0.185)
2	0.0	1.73 (0.231)
3	0.0	1.75 (0.234)
4	30.0 (4.0)	25.24 (3.37)
5	30.0 (4.0)	25.54 (3.41)
6	30.0 (4.0)	24.64 (3.29)
7	60.0 (8.0)	50.56 (6.75)
8	60.0 (8.0)	45.24 (6.04)
9	60.0 (8.0)	41.94 (5.60)
10	120.0 (16.0)	78.94 (10.54)[a]
11	120.0 (16.0)	115.19 (15.38)
12	120.0 (16.0)	105.68 (14.11)

[a]About 5 minutes before the end of this test run, plating personnel inadvertently drained the scrubber water into the 23-foot plating tank to replace plating solution evaporation losses.

TABLE C-22. TOTAL CURRENT SUPPLIED TO THE TANKS DURING MASS EMISSIONS TESTS AT PIEDMONT INDUSTRIAL PLATING, STATESVILLE, NORTH CAROLINA

Test run No.	Tank	Ampere-hours	
		Inlet test	Outlet test
1	23-ft	6,210	6,210
	10-ft	6,010	6,010
	Total	12,200	12,200
2	23-ft	6,490	6,490
	10-ft	6,730	6,730
	Total	13,200	13,200
3	23-ft	6,520	6,550
	10-ft	6,480	6,500
	Total	13,000	13,100
4	23-ft	7,040	7,120
	10-ft	1,470	1,490
	Total	8,510	8,610
5	23-ft	7,150	7,260
	10-ft	2,250	2,310
	Total	9,400	9,570
6	23-ft	7,310	7,370
	10-ft	1,130	1,120
	Total	8,440	8,490
7	23-ft	4,000	4,000
	10-ft	2,470	2,490
	Total	6,470	6,490
8	23-ft	3,330	3,330
	10-ft	3,110	3,040
	Total	6,440	6,370
9	23-ft	4,000	4,030
	10-ft	1,470	1,450
	Total	5,470	5,480
10	23-ft	3,900	3,860
	10-ft	2,440	2,440
	Total	6,340	6,300
11	23-ft	4,000	4,030
	10-ft	2,230	2,250
	Total	6,230	6,280
12	23-ft	3,830	3,830
	10-ft	2,830	2,850
	Total	6,660	6,680

TABLE C-23. CHROMIC ACID CONCENTRATIONS OF PLATING SOLUTION DURING MASS EMISSIONS TESTS AT PIEDMONT INDUSTRIAL PLATING, STATESVILLE, NORTH CAROLINA

		Chromic acid concentration of solution, g/L (oz/gal)	
Test run No.	Date (1986)	10-ft tank	23-ft tank
1	08/19	227 (30.3)	226 (30.2)
2	08/19	225 (30.1)	229 (30.5)
3	08/19	224 (29.9)	232 (30.9)
4	08/20	229 (30.6)	227 (30.3)
5	08/20	231 (30.9)	231 (30.9)
6	08/20	238 (31.8)	228 (30.5)
7	08/21	230 (30.7)	229 (30.5)
8	08/21	224 (29.9)	227 (30.4)
9	08/21	201 (26.8)	226 (30.2)
10[a]	08/22	220 (29.3)	212 (28.3)
11	08/22	229 (30.6)	214 (28.5)
12	08/22	229 (30.6)	216 (28.8)

[a]About 5 minutes before the end of this test run, plating personnel inadvertently drained the scrubber water into the 23-foot plating tank to replace plating solution evaporation losses.

TABLE C-24. DIMENSIONS AND OPERATING PARAMETERS OF HARD CHROMIUM PLATING TANKS 1, 2, AND 4 AT STEEL HEDDLE COMPANY, GREENVILLE, SOUTH CAROLINA

Tank No.	Tank dimensions (l, w, d), m (ft)	Tank capacity, L (gal)	Tank surface area, m^2 (ft^2)	Voltage, volts[a]	Current, amperes[a]
1	3.8, 0.9, 0.9 (12.5, 3.0, 3.0)	2,650 (700)	3.4 (37)	15	10,000
2	3.0, 0.5, 0.9 (10.0, 1.8, 3.0)	1,290 (340)	1.5 (16)	15	6,000
4	2.1, 0.8, 0.9 (6.8, 2.5, 3.0)	1,210 (320)	1.7 (18)	30	5,000

[a]Maximum operating values.

TABLE C-25. AVERAGE OPERATING PARAMETERS RECORDED DURING MASS EMISSIONS TESTS AT STEEL HEDDLE COMPANY, GREENVILLE, SOUTH CAROLINA

Test run No.	Tank No.	Operating voltage, volts	Operating current, amperes	Temperature of plating solution, °C (°F)
1	1	5.7	2,230	52 (125)
	2	6.0	1,360	52 (125)
	4	6.3	860	43 (110)
2	1	5.3	400	52 (125)
	2	5.8	1,200	52 (125)
	4	6.8	610	43 (110)
3	1	6.0	1,520	52 (125)
	2	6.2	1,500	52 (125)
	4	7.0	650	43 (110)

TABLE C-26. TOTAL CURRENT SUPPLIED TO TANKS 1, 2, AND 4 DURING MASS EMISSIONS TESTS AT STEEL HEDDLE COMPANY, GREENVILLE, SOUTH CAROLINA

Test run No.	Tank No.	Total current, ampere-hours	
		Inlet test	Outlet test
1	1	5,410	5,400
	2	3,410	3,390
	4	2,580	2,580
	TOTAL	11,400	11,400
2	1	1,010	980
	2	3,440	3,430
	4	1,820	1,820
	TOTAL	6,270	6,230
3	1	3,200	3,160
	2	3,550	3,490
	4	1,960	1,960
	TOTAL	8,710	8,610

TABLE C-27. CHROMIC ACID CONCENTRATIONS OF PLATING SOLUTION AND SCRUBBER WATER DURING MASS EMISSIONS TESTS AT STEEL HEDDLE COMPANY, GREENVILLE, SOUTH CAROLINA

Test run No.	Date (1986)	Sample location	Fraction	CrO_3 concentration, g/L (oz/gal)
1	6/24	Tank 1	Liquid	187 (25.0)
	6/24	Tank 2	Liquid	184 (24.6)
	6/24	Tank 4	Liquid	159 (21.2)
	6/24	Scrubber	Liquid	0.013 (0.002)
2	6/25	Tank 1	Liquid	171 (22.8)
	6/25	Tank 2	Liquid	187 (25.0)
	6/25	Tank 4	Liquid	151 (20.2)
	6/25	Scrubber	Liquid	0.010 (0.001)
3	6/25	Tank 1	Liquid	174 (23.2)
	6/25	Tank 2	Liquid	191 (25.5)
	6/25	Tank 4	Liquid	157 (21.0)
	6/25	Scrubber	Liquid	0.014 (0.002)

TABLE C-28. AVERAGE SCRUBBER OPERATING PARAMETERS MONITORED DURING EACH MASS EMISSIONS TEST RUN AT FUSION, INC., HOUSTON, TEXAS

Test run No.	Frequency of water replacement, No. of times per run	Amount of makeup water added, L (gal)	Pressure drop, kPa (in. w.c.)
No washdown			
1	6	a	0.45 (1.8)
2	4	a	0.45 (1.8)
3	4	a	0.45 (1.8)
Periodic washdown			
4	4	260 (70)[b]	0.55 (2.2)
5	5	380 (100)[b]	0.55 (2.2)
6	4	260 (70)[b]	0.55 (2.2)
Continuous washdown			
7	c	1,590 (420)[d]	0.55 (2.2)
8	c	980 (260)[d]	0.55 (2.2)

[a]Makeup water was supplied by a garden hose and, therefore, the amount of water added was not measured.

[b]Makeup water was added through a flow meter. The quantities of water provided are based on the amount of time required to fill the sump and the flow rate measured through the flow meter.

[c]Fresh water was added continuously at a rate of 2 gal/min.

[d]Based on the total amount of time to collect a complete emission sample and a continuous fresh water flow rate of 2 gal/min.

TABLE C-29. CHROMIC ACID CONCENTRATIONS OF PLATING SOLUTION AND SCRUBBER WATER SAMPLES AT FUSION, INC., HOUSTON, TEXAS

Run No.	CrO_3 concentration in plating solution samples, g/L (oz/gal)	CrO_3 concentration in scrubber water samples, g/L (oz/gal)
1	221.0 (29.5)	0.028 (0.004)
2	223.0 (29.8)	0.027 (0.004)
3	226.1 (30.2)	0.177 (0.024)
4	223.0 (29.8)	3.837 (0.512)
5	223.6 (29.9)	5.210 (0.696)
6	221.8 (29.6)	0.056 (0.008)
7	220.0 (29.4)	0.230 (0.031)
8	219.4 (29.3)	0.124 (0.017)
AVG	222.2 (29.7)	1.211 (0.162)

TABLE C-30. AVERAGE OPERATING PARAMETERS MONITORED DURING EACH MASS EMISSIONS TEST RUN AT FUSION, INC., HOUSTON, TEXAS

Run No.	Operating voltage, volts	Operating current, amperes[a]	Operating bath temperature, °C (°F)
1	5.5	2,600	53 (127)
2	5.8	3,000	53 (127)
3	6.0	2,300	53 (127)
4	5.6	3,600	53 (127)
5	5.6	3,600	53 (127)
6	5.6	3,700	53 (128)
7	6.6	3,100	52 (126)
8	6.2	2,800	53 (127)

[a]Rounded to nearest 100.

TABLE C-31. TOTAL CURRENT SUPPLIED TO PLATING TANK DURING EACH MASS EMISSIONS TEST RUN AT FUSION, INC., HOUSTON, TEXAS

Test run No.	Test time, hours	Total current, ampere-hours[a]	
		Inlet	Outlet
1	2	5,500	5,400
2	2	6,000	6,000
3	2	4,600	4,600
4	2	7,200	7,100
5	2	7,200	7,200
6	2	7,400	7,400
7	3.2	10,000	10,000
8	2	5,600	5,600

[a]Numbers were rounded to the nearest 100.

TABLE C-32. AVERAGE OPERATING CONDITIONS RECORDED DURING EACH EMISSIONS TEST RUN AT DELCO PRODUCTS DIVISION, GENERAL MOTORS CORPORATION, LIVONIA, MICHIGAN

Test run No.	Bath temperature, °C (°F)	No. of cycles	Voltage, volts	Current, amperes	No. of bumpers
1	54 (130)	138	22.3	20,510	1,043
2	54 (130)	139	22.0	21,700	1,143
3	55 (131)	120	22.8	21,750	984

TABLE C-33. CHROMIC ACID CONCENTRATIONS OF PLATING BATH SAMPLES AT DELCO PRODUCTS DIVISION, GENERAL MOTORS CORPORATION LIVONIA, MICHIGAN

Run No./Sample	CrO_3 concentration, g/L (oz/gal)
Run No. 1	
Plating tank samples	
Cell No. 1	288 (38.6)
Cell No. 2	307 (41.1)
Cell No. 3	294 (39.4)
Average	296 (39.7)
Run No. 2	
Plating tank samples	
Cell No. 1	292 (39.1)
Cell No. 2	296 (39.7)
Cell No. 3	307 (41.1)
Average	298 (40.0)
Run No. 3	
Plating tank samples	
Cell No. 1	303 (40.6)
Cell No. 2	303 (40.6)
Cell No. 3	307 (41.1)
Average	304 (40.8)

TABLE C-34. TOTAL CURRENT CONSUMED DURING EACH EMISSIONS TEST RUN AT DELCO PRODUCTS DIVISION, GENERAL MOTORS CORPORATION, LIVONIA, MICHIGAN

Test run No.	Total current, ampere-hr
1	97,400
2	104,000
3	89,600

TABLE C-35. AVERAGE OPERATING PARAMETERS FOR EACH TEST RUN AT AUTOMATIC DIE CASTING SPECIALTIES, INC., ST. CLAIR SHORES, MICHIGAN

Run No.	Bath temperature, °C (°F)	Operating voltage, volts	Operating current, amperes
1	48 (118)	5.2	2,680
2	48 (118)	4.9	2,390
3	48 (118)	5.0	2,770
Average	48 (118)	5.0	2,610
4	48 (118)	5.2	2,730
5	48 (118)	5.1	2,660
6	48 (118)	5.1	2,600
Average	48 (118)	5.1	2,660
7	48 (119)	5.1	2,820
8	49 (120)	5.1	2,880
9	49 (120)	5.1	2,800
Average	49 (120)	5.1	2,830

TABLE C-36. CHROMIC ACID CONCENTRATIONS OF PLATING BATH SAMPLES AT AUTOMATIC DIE CASTING SPECIALTIES, INC., ST. CLAIR SHORES, MICHIGAN

Run No.	CrO_3 concentration, g/L (oz/gal)
1	267 (35.6)
2	273 (36.6)
3	275 (36.9)
4	250 (33.5)
6	257 (34.4)
7	286 (38.3)
8	273 (36.5)
9	286 (38.3)

TABLE C-37. AVERAGE PLATING SOLUTION AND FUME SUPPRESSANT PARAMETERS FOR EACH TEST RUN AT AUTOMATIC DIE CASTING SPECIALTIES, INC., ST. CLAIR SHORES, MICHIGAN

Run No.	Test condition	Surface tension dynes/cm	Fume suppressant additions	
			Makeup, g (lb)	Maintenance, g (lb)
1	Uncontrolled	66	0 (0)	0 (0)
2	Uncontrolled	72	0 (0)	0 (0)
3	Uncontrolled	74	0 (0)	0 (0)
4	Foam blanket[a]	67	910 (2.0)	0 (0)
5	Foam blanket[a]	71	0 (0)	140 (0.3)
6	Foam blanket[a]	72	0 (0)	450 (1.1)
7	Foam blanket/ wetting agent[b]	40	1,800 (4.0)	450 (1.0)
8	Foam blanket/ wetting agent[b]	38	0 (0)	590 (1.3)
9	Foam blanket/ wetting agent[b]	38	0 (0)	200 (0.5)

[a]Zero Mist™ HT
[b]Zero Mist™ HT-2

TABLE C-38. TOTAL CURRENT SUPPLIED DURING EACH EMISSIONS TEST RUN AT AUTOMATIC DIE CASTING SPECIALTIES, INC., ST. CLAIR SHORES, MICHIGAN

Run No.	Test time, hours	Total current, ampere-hours	Ampere-hours/hr[a]
1	3.20	8,700	2,700
2	2.15	5,200	2,400
3	2.02	5,600	2,800
4	3.03	8,400	2,800
5	2.00	5,300	2,700
6	4.18	11,900	2,900
7	4.00	11,300	2,800
8	4.00	11,700	2,900
9	3.00	8,500	2,800

[a]Time-weighted average.

TABLE C-39. SUMMARY OF EMISSIONS TEST DATA

Plant A: Greensboro Industrial Platers
Operation: Hard chromium electroplating
Emission Source: One hard chromium electroplating tank
Test Location: Mist eliminator inlet

Data	Run No. 1	Run No. 2	Run No. 3	Run No. 4	Average of test series
General					
Date	03/18/86	03/18/86	03/19/86	03/19/86	-
Sampling time, min	120	120	120	120	--
Isokinetic ratio, %	99.6	99.8	101	99.8	--
Process rate, ampere-hr/hr	5,900	5,200	7,950	5,300	6,090
Total current, ampere-hr	11,800	10,400	15,900	10,600	12,200
Gas stream data					
Temperature, °C (°F)	18 (65)	21 (70)	23 (74)	23 (74)	21 (71)
Moisture, %	1.0	1.3	2.1	2.3	1.7
Actual flow rate, m^3/min (ft^3/min)	230 (8,150)	222 (7,850)	228 (8,070)	222 (7,820)	226 (7,970)
Dry standard flow rate, dscm/min (dscf/min)	223 (7,890)	213 (7,510)	215 (7,600)	208 (7,340)	215 (7,580)
Chromium emissions					
Total chromium					
mg/dscm (gr/dscf) (10^{-3})	1,720 (0.751)	2,730 (1.19)	1,690 (0.737)	2,940 (1.28)	2,270 (0.990)
kg/hr (lb/hr) (10^{-3})	23.0 (50.8)	34.8 (76.7)	21.8 (48.0)	36.6 (80.7)	29.0 (64.0)
mg/ampere-hr (gr/ampere-hr)	3.90 (0.060)	6.69 (0.103)	2.74 (0.042)	6.91 (0.107)	5.06 (0.078)
Hexavalent chromium					
mg/dscm (gr/dscf) (10^{-3})	1,520 (0.663)	2,450 (1.07)	1,550 (0.676)	2,590 (1.13)	2,030 (0.885)
kg/hr (lb/hr) (10^{-3})	20.3 (44.8)	31.2 (68.8)	20.0 (44.0)	32.3 (71.2)	26.0 (57.2)
mg/ampere-hr (gr/ampere-hr)	3.44 (0.053)	6.00 (0.093)	2.52 (0.039)	6.09 (0.094)	4.51 (0.070)

TABLE C-40. SUMMARY OF EMISSIONS TEST DATA

Plant A: Greensboro Industrial Platers
Operation: Hard chromium electroplating
Emission source: One hard chromium electroplating tank
Test location: Mist eliminator outlet

Data	Run No. 1	Run No. 2	Run No. 3	Run No. 4	Average of test series
General					
Date	03/18/86	03/18/86	03/19/86	03/19/86	--
Sampling time, min	128	128	128	128	--
Isokinetic ratio, %	97.9	99.3	98.5	100	--
Process rate, ampere-hr/hr	6,190	5,160	7,920	5,250	6,130
Total current, ampere-hr	13,200	11,000	16,900	11,200	13,100
Gas stream data					
Temperature, °C (°F)	22 (71)	23 (74)	27 (80)	27 (80)	25 (76)
Moisture, %	1.1	1.6	1.5	1.8	1.5
Actual flow rate, m^3/min (ft^3/min)	190 (6,700)	193 (6,860)	192 (6,790)	192 (6,780)	192 (6,780)
Dry standard flow rate, dscm/min (dscf/min)	182 (6,410)	183 (6,480)	180 (6,350)	180 (6,330)	181 (6,390)
Chromium emissions					
Total chromium					
mg/dscm (gr/dscf) (10^{-3})	221 (0.097)	436 (0.190)	188 (0.082)	565 (0.247)	353 (0.154)
kg/hr (lb/hr) (10^{-3})	2.41 (5.31)	4.80 (10.6)	2.03 (4.47)	6.07 (13.4)	3.83 (8.44)
mg/ampere-hr (gr/ampere-hr)	0.389 (0.006)	0.930 (0.014)	0.256 (0.004)	1.16 (0.018)	0.684 (0.011)
Hexavalent chromium					
mg/dscm (gr/dscf) (10^{-3})	168 (0.074)	377 (0.165)	173 (0.076)	507 (0.221)	306 (0.134)
kg/hr (lb/hr) (10^{-3})	1.83 (4.05)	4.15 (9.15)	1.87 (4.13)	5.45 (12.0)	3.32 (7.34)
mg/ampere-hr (gr/ampere-hr)	0.296 (0.005)	0.804 (0.012)	0.236 (0.004)	1.04 (0.016)	0.594 (0.009)

TABLE C-41. SUMMARY OF EMISSIONS TEST DATA

Plant B: Consolidated Engravers Corporation
Operation: Hard chromium electroplating
Emission source: Two hard chromium electroplating tanks
Test location: Mist eliminator inlet

Data	Run No. 1	Run No. 2	Run No. 3	Average of test series
General				
Date	5/12/87	5/13/87	5/14/87	--
Sampling time, min	180	180	180	--
Isokinetic ratio, %	102	94.4	100	--
Process rate, ampere-hr/hr	5,000	4,700	4,700	4,800
Total current, ampere-hr	15,000	14,100	14,100	14,400
Gas stream data				
Temperature, °C (°F)	27 (81)	27 (80)	23 (73)	25 (78)
Moisture, %	2.3	2.3	2.0	2.2
Actual flow rate m^3/min (ft^3/min)	153 (5,420)	152 (5,380)	152 (5,370)	152 (5,390)
Dry standard flow rate, dscm/min (dscf/min)	143 (5,040)	142 (5,030)	144 (5,100)	143 (5,060)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	1,450 (0.633)	939 (0.410)	416 (0.182)	935 (0.409)
kg/hr (lb/hr) (10^{-3})	12.4 (27.3)	8.03 (17.7)	3.62 (7.97)	8.02 (17.7)
mg/ampere-hr (gr/ampere-hr)	2.48 (0.038)	1.71 (0.026)	0.77 (0.012)	1.65 (0.025)
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	1,810 (0.791)	1,740 (0.760)	1,740 (0.762)	1,760 (0.771)
kg/hr (lb/hr) (10^{-3})	15.5 (34.2)	14.8 (32.6)	15.2 (33.4)	15.2 (33.4)
mg/ampere-hr (gr/ampere-hr)	3.10 (0.048)	3.15 (0.048)	3.23 (0.050)	3.16 (0.049)

TABLE C-42. SUMMARY OF EMISSIONS TEST DATA

Plant B: Consolidated Engravers Corporation
Operation: Hard chromium electroplating
Emission source: Two hard chromium electroplating tanks
Test location: Mist eliminator outlet

Data	Run No. 1	Run No. 2	Run No. 3	Average of test series
General				
Date	5/12/87	5/13/87	5/14/87	--
Sampling time, min	180	180	180	--
Isokinetic ratio, %	103	101	103	--
Process rate, ampere-hr/hr	5,030	4,730	4,700	4,820
Total current, ampere-hr	15,100	14,200	14,100	14,400
Gas stream data				
Temperature, °C (°F)	29 (84)	27 (80)	24 (76)	27 (81)
Moisture, %	2.3	2.1	1.9	2.1
Actual flow rate, m^3/min (ft^3/min)	153 (5,400)	154 (5,440)	156 (5,520)	154 (5,450)
Dry standard flow rate, dscm/min (dscf/min)	142 (5,030)	144 (5,090)	150 (5,280)	145 (5,130)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	91 (0.040)	144 (0.063)	119 (0.052)	118 (0.052)
kg/hr (lb/hr) (10^{-3})	0.779 (1.72)	1.25 (2.76)	1.07 (2.36)	1.03 (2.28)
mg/ampere-hr (gr/ampere-hr)	0.15 (0.002)	0.26 (0.004)	0.23 (0.004)	0.21 (0.003)
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	89 (0.039)	224 (0.098)	135 (0.059)	149 (0.065)
kg/hr (lb/hr) (10^{-3})	0.757 (1.67)	1.94 (4.26)	1.21 (2.66)	1.30 (2.86)
mg/ampere-hr (gr/ampere-hr)	0.150 (0.002)	0.410 (0.006)	0.257 (0.004)	0.272 (0.004)

TABLE C-43. SUMMARY OF EMISSIONS TEST DATA

Plant D: Able Machine Company
Operation: Hard chromium electroplating
Emission source: One hard chromium electroplating tank
Test location: Mist eliminator inlet

Data	Run No. 1	Run No. 2	Run No. 3	Average of test series
General				
Date	06/30/86	07/01/86	07/01/86	--
Sampling time, min	180	120	120	--
Isokinetic ratio, %	98.3	97.8	98.3	--
Process rate, ampere-hr/hr	8,600	9,400	7,100	8,370
Total current, ampere-hr	25,800	18,800	14,200	19,600
Gas stream data				
Temperature, °C (°F)	34 (94)	30 (86)	36 (97)	33 (92)
Moisture, %	2.9	2.7	2.7	2.8
Actual flow rate, m^3/min (ft^3/min)	173 (6,120)	182 (6,420)	177 (6,240)	177 (6,260)
Dry standard flow rate, dscm/min (dscf/min)	156 (5,520)	166 (5,860)	159 (5,620)	160 (5,670)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	9,980 (4.36)	6,760 (2.95)	6,890 (3.01)	7,880 (3.44)
kg/hr (lb/hr) (10^{-3})	93.6 (206)	67.2 (148)	65.8 (145)	75.5 (167)
mg/ampere-hr (gr/ampere-hr)	10.9 (0.168)	7.15 (0.110)	9.27 (0.143)	9.11 (0.141)
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	10,200 (4.44)	6,850 (2.99)	6,830 (2.98)	7,960 (3.47)
kg/hr (lb/hr) (10^{-3})	95.4 (210)	68.1 (150)	65.2 (144)	76.2 (168)
mg/ampere-hr (gr/ampere-hr)	11.1 (0.171)	7.24 (0.112)	9.18 (0.142)	9.17 (0.142)

TABLE C-44. SUMMARY OF EMISSIQNS TEST DATA

Plant D: Able Machine Company
Operation: Hard chromium electroplating
Emission source: One hard chromium electroplating tank
Test location: Mist eliminator outlet

Data	Run No. 1	Run No. 2	Run No. 3	Average of test series
General				
Date	06/30/86	07/01/86	07/01/86	--
Sampling time, min	178	120	120	--
Isokinetic ratio, %	98.8	100	93.4	--
Process rate, ampere-hr/hr	8,600	9,700	7,400	8,570
Total current, ampere-hr	25,500	19,400	14,800	19,900
Gas stream data				
Temperature, °C (°F)	37 (99)	35 (95)	39 (102)	37 (99)
Moisture, %	3.8	3.8	2.4	3.3
Actual flow rate, m^3/min (ft^3/min)	182 (6,410)	180 (6,360)	179 (6,340)	180 (6,380)
Dry standard flow rate, dscm/min (dscf/min)	162 (5,730)	162 (5,730)	162 (5,720)	162 (5,730)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	139 (0.061)	146 (0.064)	112 (0.049)	132 (0.058)
kg/hr (lb/hr) (10^{-3})	1.35 (2.99)	1.42 (3.14)	1.09 (2.40)	1.29 (2.85)
mg/ampere-hr (gr/ampere-hr)	0.157 (0.002)	0.146 (0.002)	0.147 (0.002)	0.150 (0.002)
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	130 (0.057)	140 (0.061)	102 (0.045)	124 (0.054)
kg/hr (lb/hr) (10^{-3})	1.26 (2.78)	1.36 (2.99)	0.99 (2.19)	1.20 (2.66)
mg/ampere-hr (gr/ampere-hr)	0.147 (0.002)	0.140 (0.002)	0.134 (0.002)	0.140 (0.002)

TABLE C-45. SUMMARY OF EMISSIONS TEST DATA

Plant E: Roll Technology, Inc.
Operation: Hard chromium electroplating
Emission source: One hard chromium electroplating tank
Test location: Moisture extractor inlet

Data	Run No. 1	Run No. 2	Run No. 3	Average of test series
General				
Date	8/9/88	8/10/88	8/10/88	--
Sampling time, min	192	120	120	--
Isokinetic ratio, %	96.2	98.3	96.2	--
Process rate, ampere-hr/hr	4,810	5,200	5,200	5,070
Total current, ampere-hr	15,400	10,400	10,400	12,100
Gas stream data				
Temperature, °C (°F)	34 (93)	32 (89)	35 (95)	34 (92)
Moisture, %	2.32	2.62	2.62	2.53
Actual flow rate, m^3/min (ft^3/min)	195 (6,880)	180 (6,440)	190 (6,680)	190 (6,670)
Dry standard flow rate, dscm/min (dscf/min)	180 (6,250)	170 (5,870)	170 (6,010)	170 (6,040)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	--	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--	--
kg/ampere-hr (gr/ampere-hr)	--	--	--	--
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	2,840 (1.24)	3,320 (1.45)	3,060 (1.34)	3,070 (1.34)
kg/hr (lb/hr) (10^{-3})	30 (66)	33 (73)	31 (69)	31.3 (69.3)
mg/ampere-hr (gr/ampere-hr)	6.24 (0.096)	6.35 (0.098)	5.96 (0.092)	6.18 (0.095)

TABLE C-46. SUMMARY OF EMISSIONS TEST DATA

Plant E: Roll Technology, Inc.
Operation: Hard chromium electroplating
Emission source: One hard chromium electroplating tank
Test location: Mist eliminator inlet

Data	Run No. 1	Run No. 2	Run No. 3	Average of test series
General				
Date	8/9/88	8/10/88	8/10/88	--
Sampling time, min	188	117	117	--
Isokinetic ratio, %	101.9	98.6	99.2	--
Process rate, ampere-hr/hr	4,910	5,330	5,330	5,190
Total current, ampere-hr	15,400	10,400	10,400	12,100
Gas stream data				
Temperature, °C (°F)	36 (97)	34 (93)	37 (99)	36 (96)
Moisture, %	2.50	2.80	2.59	2.63
Actual flow rate, m^3/min (ft^3/min)	187 (6,600)	196 (6,910)	189 (6,670)	191 (6,730)
Dry standard flow rate, dscm/min (dscf/min)	167 (5,910)	176 (6,210)	168 (5,920)	170 (6,010)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	--	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--	--
kg/ampere-hr (gr/ampere-hr)	--	--	--	--
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	347 (0.152)	529 (0.231)	431 (0.188)	436 (0.191)
kg/hr (lb/hr) (10^{-3})	3.5 (7.7)	5.6 (12)	4.3 (9.5)	4.5 (9.8)
mg/ampere-hr (gr/ampere-hr)	0.713 (0.011)	1.05 (0.016)	0.807 (0.012)	0.857 (0.013)

TABLE C-47. SUMMARY OF EMISSIONS TEST DATA

Plant E: Roll Technology, Inc.
Operation: Hard chromium electroplating
Emission source: One hard chromium electroplating tank
Test location: Mist eliminator outlet

Data	Run No. 1	Run No. 2	Run No. 3	Average of test series
General				
Date	8/9/88	8/10/88	8/10/88	--
Sampling time, min	192	120	120	--
Isokinetic ratio, %	96.7	97.1	94.4	--
Process rate, ampere-hr/hr	4,810	5,200	5,200	5,070
Total current, ampere-hr	15,400	10,400	10,400	12,100
Gas stream data				
Temperature, °C (°F)	37 (98)	36 (96)	37 (99)	37 (98)
Moisture, %	2.43	3.04	2.50	2.66
Actual flow rate, m^3/min (ft^3/min)	197 (6,970)	191 (6,730)	197 (6,950)	195 (6,880)
Dry standard flow rate, dscm/min (dscf/min)	178 (6,280)	171 (6,050)	176 (6,230)	175 (6,190)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	--	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--	--
kg/ampere-hr (gr/ampere-hr)	--	--	--	--
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	30 (0.01)	43 (0.02)	47 (0.02)	40 (0.02)
kg/hr (lb/hr) (10^{-3})	0.3 (0.7)	0.4 (1.0)	0.5 (1.1)	0.4 (0.93)
mg/ampere-hr (gr/ampere-hr)	0.062 (0.001)	0.077 (0.001)	0.096 (0.002)	0.078 (0.001)

TABLE C-48. SUMMARY OF EMISSIONS TEST DATA

Plant F: Precision Machine and Hydraulic
Operation: Hard chromium electroplating
Emission source: One hard chromium electroplating tank
Test location: Mist eliminator inlet

Data	Run No. 1	Run No. 2	Run No. 3	Run No. 4	Run No. 5	Average of test series
General						
Date	9/20/88	9/21/88	9/21/88	9/22/88	9/22/88	--
Sampling time, min	192	120	120	120	120	--
Isokinetic ratio, %	98.3	98.9	99.2	99.9	100.1	--
Process rate, ampere-hr/hr	6,590	5,000	5,200	4,800	4,850	5,290
Total current, ampere-hr	21,100	10,000	10,400	9,600	9,700	12,200
Gas stream data						
Temperature, °C (°F)	27 (81)	22 (72)	24 (75)	22 (71)	27 (80)	24 (76)
Moisture, %	1.54	1.59	1.24	1.69	1.92	1.60
Actual flow rate, m^3/min (ft^3/min)	127 (4,480)	132 (4,660)	125 (4,420)	129 (4,570)	129 (4,550)	128 (4,540)
Dry standard flow rate, dscm/min (dscf/min)	118 (4,160)	125 (4,430)	119 (4,190)	123 (4,340)	120 (4,240)	121 (4,270)
Chromium emissions						
Total chromium						
mg/dscfm (gr/dscf) (10^{-3})	--	--	--	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--	--	--	--
mg/ampere-hr (gr/ampere-hr)	--	--	--	--	--	--
Hexavalent chromium						
mg/dscm (gr/dscf) (10^{-3})	7,250 (3.17)	10,450 (4.57)	12,010 (5.25)	13,930 (6.09)	13,360 (5.84)	11,400 (4.98)
kg/hr (lb/hr) (10^{-3})	51.3 (113)	78.6 (173)	85.6 (189)	103 (227)	96.1 (212)	82.9 (183)
mg/ampere-hr (gr/ampere-hr)	7.78 (0.120)	15.7 (0.242)	16.5 (0.254)	21.5 (0.331)	19.8 (0.305)	16.3 (0.250)

TABLE C-49. SUMMARY OF EMISSIONS TEST DATA

Plant F: Precision Machine and Hydraulic
Operation: Hard chromium electroplating
Emission source: One hard chromium electroplating tank
Test location: Mist eliminator outlet

Data	Run No. 1	Run No. 2	Run No. 3	Run No. 4	Run No. 5	Average of test series
General						
Date	9/20/88	9/21/88	9/21/88	9/22/88	9/22/88	--
Sampling time, min	192	120	120	120	120	--
Isokinetic ratio, %	97.6	99.6	99.8	100.1	100.6	--
Process rate, ampere-hr/hr	6,590	5,000	5,200	4,800	4,850	5,290
Total current, ampere-hr	21,100	10,000	10,400	9,600	9,700	12,200
Gas stream data						
Temperature, °C (°F)	29 (85)	24 (75)	26 (78)	23 (74)	28 (83)	26 (79)
Moisture, %	1.59	1.67	1.70	1.75	1.85	1.71
Actual flow rate, m^3/min (ft^3/min)	126 (4,460)	125 (4,400)	124 (4,390)	126 (4,440)	127 (4,470)	126 (4,430)
Dry standard flow rate, dscm/min (dscf/min)	117 (4,140)	118 (4,180)	118 (4,150)	120 (4,220)	118 (4,170)	118 (4,170)
Chromium emissions						
Total chromium						
mg/dscm (gr/dscf) (10^{-3})	--	--	--	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--	--	--	--
mg/ampere-hr (gr/ampere-hr)	--	--	--	--	--	--
Hexavalent chromium						
mg/dscm (gr/dscf) (10^{-3})	58.9 (0.026)	32.0 (0.014)	34.0 (0.015)	27.6 (0.012)	10.6 (0.005)	32.6 (0.014)
kg/hr (lb/hr) (10^{-3})	0.41 (0.91)	0.23 (0.50)	0.24 (0.53)	0.20 (0.44)	0.07 (0.16)	0.23 (0.51)
mg/ampere-hr (gr/ampere-hr)	0.062 (0.001)	0.046 (0.001)	0.046 (0.001)	0.042 (0.001)	0.014 (0.0002)	0.042 (0.001)

TABLE C-50. SUMMARY OF EMISSIONS TEST DATA

Plant G:	Hard Chrome Specialists
Operation:	Hard chromium electroplating
Emission source:	One hard chromium electroplating tank
Test location:	Mist eliminator inlet, no polypropylene balls

Data	Run No. 1	Run No. 2	Run No. 3	Average of test series
General				
Date	01/30/89	01/31/89	01/31/89	--
Sampling time, min	192	120	120	--
Isokinetic ratio, %	98.2	94.7	93.4	--
Process rate, ampere-hr/hr	3,000	3,000	5,400	3,800
Total current, ampere-hr	9,600	6,000	10,800	8,800
Gas stream data				
Temperature, °C (°F)	23 (74)	23 (74)	24 (76)	23 (75)
Moisture, %	1.1	0.84	0.94	0.96
Actual flow rate, m^3/min (ft^3/min)	92 (3,240)	97 (3,440)	97 (3,410)	95 (3,360)
Dry standard flow rate, dscm/min (dscf/min)	87 (3,080)	94 (3,300)	92 (3,250)	91 (3,210)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	--	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--	--
mg/ampere-hr (gr/ampere-hr)	--	--	--	--
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	3,940 (1.72)	4,020 (1.76)	5,280 (2.31)	4,410 (1.93)
kg/hr (lb/hr) (10^{-3})	20.6 (45.4)	22.6 (49.8)	29.1 (64.2)	24.1 (53.1)
mg/ampere-hr (gr/ampere-hr)	6.87 (0.106)	7.53 (0.116)	5.39 (0.083)	6.60 (0.102)

TABLE C-51. SUMMARY OF EMISSIONS TEST DATA

Plant G: Hard Chrome Specialists
Operation: Hard chromium electroplating
Emission source: One hard chromium electroplating tank
Test location: Mist eliminator outlet, no polypropylene balls

Data	Run No. 1	Run No. 2	Run No. 3	Average of test series
General				
Date	01/30/89	01/31/89	01/31/89	--
Sampling time, min	192	120	120	--
Isokinetic ratio, %	95.5	98.5	98.1	--
Process rate, ampere-hr/hr	3,000	3,000	5,400	3,800
Total current, ampere-hr	9,600	6,000	10,800	8,800
Gas stream data				
Temperature, °C (°F)	21 (70)	21 (69)	22 (71)	21 (70)
Moisture, %	1.1	0.77	0.90	0.92
Actual flow rate, m^3/min (ft^3/min)	102 (3,600)	108 (3,800)	107 (3,770)	106 (3,720)
Dry standard flow rate, dscm/min (dscf/min)	98 (3,460)	105 (3,710)	103 (3,640)	102 (3,600)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	--	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--	--
mg/ampere-hr (gr/ampere-hr)	--	--	--	--
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	43.9 (0.019)	34.9 (0.015)	51.1 (0.022)	43.3 (0.019)
kg/hr (lb/hr) (10^{-3})	0.26 (0.57)	0.22 (0.49)	0.32 (0.70)	0.27 (0.59)
mg/ampere-hr (gr/ampere-hr)	0.087 (0.001)	0.073 (0.001)	0.059 (0.001)	0.073 (0.001)

TABLE C-52. SUMMARY OF EMISSIONS TEST DATA

Plant G:	Hard Chrome Specialists
Operation:	Hard chromium electroplating
Emission source:	One hard chromium electroplating tank
Test location:	Mist eliminator inlet, with polypropylene balls

Data	Run No. 4	Run No. 5	Average of test series
General			
Date	02/01/89	02/01/89	--
Sampling time, min	192	120	--
Isokinetic ratio, %	97.4	97.9	--
Process rate, ampere-hr/hr	3,000	3,000	3,000
Total current, ampere-hr	9,600	6,000	7,800
Gas stream data			
Temperature, °C (°F)	23 (73)	23 (74)	23 (74)
Moisture, %	0.79	1.0	0.90
Actual flow rate, m^3/min (ft^3/min)	98 (3,460)	97 (3,410)	98 (3,440)
Dry standard flow rate, dscm/min (dscf/min)	94 (3,320)	93 (3,270)	94 (3,300)
Chromium emissions			
Total chromium			
mg/dscm (gr/dscf) (10^{-3})	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--
mg/ampere-hr (gr/ampere-hr)	--	--	--
Hexavalent chromium			
mg/dscm (gr/dscf) (10^{-3})	1,170 (0.511)	740 (0.323)	960 (0.417)
kg/hr (lb/hr) (10^{-3})	6.6 (14.6)	4.1 (9.04)	5.4 (11.8)
mg/ampere-hr (gr/ampere-hr)	2.20 (0.034)	1.37 (0.021)	1.79 (0.028)

TABLE C-53. SUMMARY OF EMISSIONS TEST DATA

Plant G: Hard Chrome Specialists
Operation: Hard chromium electroplating
Emission source: One hard chromium electroplating tank
Test location: Mist eliminator outlet, with polypropylene balls

Data	Run No. 4	Run No. 5	Average of test series
General			
Date	02/01/89	02/01/89	--
Sampling time, min	192	120	--
Isokinetic ratio, %	107	108	--
Process rate, ampere-hr/hr	3,000	3,000	3,000
Total current, ampere-hr	9,600	6,000	7,800
Gas stream data			
Temperature, °C (°F)	19 (67)	20 (68)	20 (68)
Moisture, %	0.43	0.59	0.51
Actual flow rate, m^3/min (ft^3/min)	106 (3,760)	107 (3,770)	107 (3,770)
Dry standard flow rate, dscm/min (dscf/min)	104 (3,680)	104 (3,680)	104 (3,680)
Chromium emissions			
Total chromium			
mg/dscm (gr/dscf) (10^{-3})	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--
mg/ampere-hr (gr/ampere-hr)	--	--	--
Hexavalent chromium			
mg/dscm (gr/dscf) (10^{-3})	31.7 (0.014)	28.3 (0.012)	30.0 (0.013)
kg/hr (lb/hr) (10^{-3})	0.20 (0.44)	0.18 (0.39)	0.19 (0.42)
mg/ampere-hr (gr/ampere-hr)	0.067 (0.001)	0.060 (0.001)	0.064 (0.001)

TABLE C-54. SUMMARY OF EMISSIONS TEST DATA

Plant I: Piedmont Industrial Plating
Operation: Hard chromium electroplating
Emission source: Two hard chromium electroplating tanks
Test location: Scrubber inlet

Data	Run No. 1	Run No. 2	Run No. 3	Average of runs Nos. 1, 2, and 3
General				
Date	08/19/86	08/19/86	08/19/86	--
Sampling time, min	120	120	120	--
Isokinetic ratio, %	98.7	99.0	99.5	--
Process rate, ampere-hr/hr	6,100	6,600	6,500	6,400
Total current, ampere-hr	12,200	13,200	13,000	12,800
Scrubber liquid chromic acid concentration g/L (oz/gal)	1.38 (0.185)	1.74 (0.231)	1.76 (0.234)	1.63 (0.218)
Gas stream data				
Temperature, °C (°F)	25 (77)	26 (79)	26 (79)	26 (78)
Moisture, %	2.5	3.0	3.4	3.0
Actual flow rate, m^3/min (ft^3/min)	294 (10,400)	297 (10,500)	300 (10,600)	297 (10,500)
Dry standard flow rate, dscm/min (dscf/min)	275 (9,710)	276 (9,740)	278 (9,820)	276 (9,760)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	5,160 (2.25)	7,980 (3.49)	8,060 (3.52)	7,070 (3.09)
kg/hr (lb/hr) (10^{-3})	85.1 (188)	132 (291)	134 (296)	117 (258)
mg/ampere-hr (gr/ampere-hr)	14.0 (0.215)	20.0 (0.308)	20.6 (0.317)	18.2 (0.280)
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	4,500 (1.97)	7,070 (3.09)	7,040 (3.07)	6,200 (2.71)
kg/hr (lb/hr) (10^{-3})	74.3 (164)	117 (258)	117 (259)	103 (227)
mg/ampere-hr (gr/ampere-hr)	12.2 (0.188)	17.7 (0.273)	18.0 (0.277)	16.0 (0.246)

TABLE C-54. (Continued)

Data	Run No. 4[a]	Run No. 5	Run No. 6	Average of run Nos. 5 and 6
General				
Date	08/20/86	08/20/86	08/20/86	
Sampling time, min	120	120	120	--
Isokinetic ratio, %	100	97.7	97.7	--
Process rate, ampere-hr/hr	4,250	4,700	4,220	4,460
Total current, ampere-hr	8,510	9,400	8,440	8,920
Scrubber liquid chromic acid concentration, g/L (oz/gal)	25.2 (3.37)	25.5 (3.41)	24.6 (3.29)	25.1 (3.35)
Gas stream data				
Temperature, °C (°F)	26 (78)	25 (77)	25 (77)	25 (77)
Moisture, %	2.9	2.9	3.0	2.9
Actual flow rate, m^3/min (ft^3/min)	286 (10,100)	283 (9,990)	286 (10,100)	284 (10,000)
Dry standard flow rate, dscm/min (dscf/min)	267 (9,430)	266 (9,390)	268 (9,450)	267 (9,420)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	18,000 (7.88)	5,990(2.62)	7,010 (3.06)	6,500 (2.84)
kg/hr (lb/hr) (10^{-3})	289 (637)	95.6 (211)	113 (248)	104 (230)
mg/ampere-hr (gr/ampere-hr)	67.9 (1.05)	20.3 (0.313)	26.8 (0.413)	23.6 (0.363)
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	15,900 (6.97)	5,480 (2.40)	6,420 (2.81)	5,950 (2.6)
kg/hr (lb/hr) (10^{-3})	255 (563)	87.4 (193)	103 (227)	95.2 (210)
mg/ampere-hr (gr/ampere-hr)	59.9 (0.923)	18.6 (0.286)	24.4 (0.376)	21.5 (0.331)

TABLE C-54. (Continued)

Data	Run No. 7	Run No. 8	Run No. 9	Average of run Nos. 7, 8, and 9
General				
Date	08/21/86	08/21/86	08/21/86	--
Sampling time, min	120	120	120	--
Isokinetic ratio, %	98.0	98.3	98.1	--
Process rate, ampere-hr/hr	3,240	3,220	2,740	3,070
Total current, ampere-hr	6,470	6,440	5,470	6,130
Scrubber liquid chromic acid concentration, g/L (oz/gal)	50.6 (6.75)	45.2 (6.04)	41.9 (5.60)	45.9 (6.13)
Gas stream data				
Temperature, °C (°F)	26 (78)	28 (82)	28 (83)	27 (81)
Moisture, %	2.6	2.5	2.5	2.5
Actual flow rate, m^3/min (ft^3/min)	286 (10,100)	294 (10,400)	292 (10,300)	291 (10,300)
Dry standard flow rate, dscm/min (dscf/min)	271 (9,560)	275 (9,700)	273 (9,640)	273 (9,630)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	5,620 (2.45)	5,000 (2.18)	4,800 (2.10)	5,140 (2.24)
kg/hr (lb/hr) (10^{-3})	91.2 (201)	82.4 (182)	78.6 (173)	84.1 (185)
mg/ampere-hr (gr/ampere-hr)	28.2 (0.434)	25.6 (0.395)	28.7 (0.443)	27.5 (0.424)
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	4,900 (2.14)	4,590 (2.00)	4,380 (1.91)	4,620 (2.02)
kg/hr (lb/hr) (10^{-3})	79.7 (176)	75.6 (167)	71.7 (158)	75.7 (167)
mg/ampere-hr (gr/ampere-hr)	24.6 (0.379)	23.5 (0.362)	26.2 (0.404)	24.8 (0.382)

TABLE C-54. (Continued)

Data	Run No. 10[b]	Run No. 11	Run No. 12	Average of Run Nos. 10, 11, and 12	Average of test series
General					
Date	08/22/86	08/22/86	08/22/86	--	--
Sampling time, min	120	120	120	--	--
Isokinetic radio, %	97.2	97.1	97.0	--	--
Process rate, ampere-hr/hr	3,170	3,120	3,330	3,120	4,270
Total current, ampere-hr/hr	6,340	6,230	6,660	6,410	8,530
Scrubber liquid chromic acid concentration, g/L (oz/gal)	110 (10.5)[b]	115 (15.4)	106 (14.1)	110 (13.3)	--
Gas stream data					
Temperature, °C (°F)	24 (75)	26 (78)	26 (79)	25 (77)	26 (79)
Moisture, %	2.1	2.5	2.5	2.4	2.7
Actual flow rate, m^3/min (ft^3/min)	289 (10,200)	286 (10,100)	286 (10,100)	287 (10,100)	290 (10,300)
Dry standard flow rate, dscm/min (dscf/min)	275 (9,720)	272 (9,570)	269 (9,490)	272 (9,590)	272 (9,620)
Chromium emissions					
Total chromium					
mg/dscm (gr/dscf) (10^{-3})	6,570 (2.87)	6,090 (2.66)	5,120 (2.24)	5,930 (2.59)	6,130 (2.68)
kg/hr (lb/hr) (10^{-3})	108 (239)	99.0 (218)	82.5 (182)	96.5 (213)	100 (221)
mg/ampere-hr (gr/ampere-hr)	34.1 (0.525)	31.7 (0.490)	24.8 (0.382)	30.2 (0.466)	25.0 (0.385)
Hexavalent chromium					
mg/dscm (gr/dscf) (10^{-3})	6,070 (2.65)	5,500 (2.40)	4,620 (2.02)	5,400 (2.36)	5,510 (2.41)
kg/hr (lb/hr) (10^{-3})	100 (221)	89.4 (197)	74.4 (164)	87.9 (194)	90.0 (199)
mg/ampere-hr (gr/ampere-hr)	31.5 (0.486)	28.7 (0.443)	22.3 (0.344)	27.5 (0.424)	22.5 (0.347)

[a]Results for this run not included in average; it is suspected that the nozzle may have contacted duct wall during testing.

[b]About 5 minutes before the end of this test run, plating personnel inadvertently drained the scrubber water into the 23-ft plating tank to make up for plating solution evaporation losses.

TABLE C-55. SUMMARY OF EMISSIONS TEST DATA

Plant I: Piedmont Industrial Plating
Operation: Hard chromium electroplating
Emission source: Two hard chromium electroplating tanks
Test location: Scrubber outlet

Data	Run No. 1	Run No. 2	Run No. 3[a]	Average of run Nos. 1 and 2
General				
Date	08/19/86	08/19/86	08/19/86	--
Sampling time, min	120	120	120	--
Isokinetic ratio, %	101	104	103	--
Process rate, ampere-hr/hr	6,100	6,600	6,600	6,400
Total current, ampere-hr	12,200	13,200	13,100	12,700
Scrubber liquid chromic acid concentration, g/L (oz/gal)	1.38 (0.185)	1.74 (0.231)	1.76 (0.234)	1.56 (0.21)
Gas stream data				
Temperature, °C (°F)	25 (77)	26 (78)	27 (80)	26 (78)
Moisture, %	2.5	2.0	2.8	2.3
Actual flow rate, m^3/min (ft^3/min)	312 (11,000)	314 (11,100)	312 (11,000)	313 (11,100)
Dry standard flow rate, dscm/min (dscf/min)	292 (10,300)	297 (10,500)	292 (10,300)	295 (10,400)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	37 (0.016)	36 (0.016)	158 (0.069)	36.5 (0.016)
kg/hr (lb/hr) (10^{-3})	0.644 (1.42)	0.648 (1.43)	2.77 (6.10)	0.646 (1.43)
mg/ampere-hr (gr/ampere-hr)	0.106 (0.002)	0.098 (0.002)	0.423 (0.007)	0.102 (0.002)
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	21.7 (0.010)	27.5 (0.012)	146 (0.064)	24.6 (0.011)
kg/hr (lb/hr) (10^{-3})	0.381 (0.840)	0.491 (1.08)	2.56 (5.64)	0.436 (0.961)
mg/ampere-hr (gr/ampere-hr)	0.062 (0.001)	0.074 (0.001)	0.391 (0.006)	0.068 (0.001)

TABLE C-55. (Continued)

Data	Run No. 4	Run No. 5	Run No. 6	Average of Nos. 4, 5, and 6
General				
Date	08/20/86	08/20/86	08/20/86	--
Sampling time, min	120	120	120	--
Isokinetic ratio, %	102	103	103	--
Process rate, ampere-hr/hr	4,300	4,790	4,250	4,450
Total current, ampere-hr	8,610	9,570	8,490	8,890
Scrubber liquid chromic acid concentrations g/L (oz/gal)	25.2 (3.37)	25.5 (3.41)	24.6 (3.29)	25.1 (3.36)
Gas stream data				
Temperature, °C (°F)	27 (80)	26 (78)	26 (79)	26 (79)
Moisture, %	2.0	2.2	2.1	2.1
Actual flow rate, m^3/min (ft^3/min)	300 (10,600)	309 (10,900)	300 (10,600)	303 (10,700)
Dry standard flow rate, dscm/min (dscf/min)	286 (10,100)	292 (10,300)	283 (10,000)	287 (10,100)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	39.5 (0.017)	47.3 (0.021)	45.5 (0.020)	44.1 (0.019)
kg/hr (lb/hr) (10^{-3})	0.678 (1.49)	0.829 (1.83)	0.774 (1.71)	0.760 (1.68)
mg/ampere-hr (gr/ampere-hr)	0.158 (0.002)	0.173 (0.003)	0.182 (0.003)	0.171 (0.003)
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	23.4 (0.010)	27.6 (0.012)	25.3 (0.011)	25.4 (0.011)
kg/hr (lb/hr) (10^{-3})	0.400 (0.883)	0.484 (1.07)	0.431 (0.950)	0.438 (0.968)
mg/ampere-hr (gr/ampere-hr)	0.093 (0.001)	0.101 (0.002)	0.102 (0.002)	0.099 (0.002)

TABLE C-55. (Continued)

Data	Run No. 7	Run No. 8	Run No. 9	Average of run Nos. 7, 8, and 9
General				
Date	08/21/86	08/21/86	08/21/86	--
Sampling time, min	120	120	120	--
Isokinetic ratio, %	100	101	102	--
Process rate, ampere-hr/hr	3,250	3,190	2,740	3,060
Total current, ampere-hr	6,490	6,370	5,480	6,110
Scrubber liquid chromic acid concentration, g/L (oz/gal)	50.5 (6.75)	45.2 (6.04)	41.9 (5.60)	45.9 (6.13)
Gas stream data				
Temperature, °C (°F)	26 (78)	27 (81)	27 (80)	27 (80)
Moisture, %	2.7	2.3	2.4	2.5
Actual flow rate, m^3/min (ft^3/min)	300 (10,600)	306 (10,800)	300 (10,600)	302 (10,700)
Dry standard flow rate, dscm/min (dscf/min)	286 (10,100)	289 (10,200)	286 (10,100)	287 (10,100)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	34.6 (0.015)	44.3 (0.019)	39.2 (0.017)	39.4 (0.017)
kg/hr (lb/hr) (10^{-3})	0.594 (1.31)	0.769 (1.70)	0.672 (1.48)	0.678 (1.50)
mg/ampere-hr (gr/ampere-hr)	0.183 (0.003)	0.241 (0.004)	0.246 (0.004)	0.223 (0.003)
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	30.1 (0.013)	39.2 (0.017)	33.8 (0.015)	34.4 (0.015)
kg/hr (lb/hr) (10^{-3})	0.517 (1.14)	0.680 (1.50)	0.578 (1.27)	0.592 (1.30)
mg/ampere-hr (gr/ampere-hr)	0.159 (0.002)	0.214 (0.003)	0.211 (0.003)	0.195 (0.003)

TABLE C-55. (Continued)

Data	Run No. 10	Run No. 11	Run No. 12	Average of run Nos. 10, 11, and 12	Average of test series
General					
Date	08/22/86	08/22/86	08/22/86	--	--
Sampling time, min	120	120	120	--	--
Isokinetic ratio, %	101	101	101	--	--
Process rate, ampere-hr/hr	3,150	3,140	3,340	3,210	4,080
Total current, ampere-hr	6,300	6,280	6,680	6,420	8,150
Scrubber liquid chromic acid concentration, g/L (oz/gal)	110 (10.5)	115 (15.4)	106 (14.1)	110 (13.3)	--
Gas stream data					
Temperature, °C (°F)	26 (78)	27 (80)	26 (79)	26 (79)	26 (79)
Moisture, %	2.2	2.7	1.5	2.1	2.2
Actual flow rate, m^3/min (ft^3/min)	300 (10,600)	300 (10,600)	297 (10,500)	300 (10,600)	303 (10,700)
Dry standard flow rate, dscm/min (dscf/min)	286 (10,100)	283 (10,100)	286 (10,100)	285 (10,100)	288 (10,200)
Chromium emissions					
Total chromium					
mg/dscm (gr/dscf) (10^{-3})	42.0 (0.018)	44.0 (0.019)	53.0 (0.023)	46.3 (0.020)	42.0 (0.018)
kg/hr (lb/hr) (10^{-3})	0.713 (1.57)	0.755 (1.66)	0.905 (2.00)	0.791 (1.74)	0.726 (1.60)
mg/ampere-hr (gr/ampere-hr)	0.226 (0.004)	0.240 (0.004)	0.271 (0.004)	0.246 (0.004)	0.193 (0.003)
Hexavalent chromium					
mg/dscm (gr/dscf) (10^{-3})	31.9 (0.014)	32.1 (0.014)	39.5 (0.017)	34.5 (0.015)	30.2 (0.013)
kg/hr (lb/hr) (10^{-3})	0.549 (1.21)	0.548 (1.21)	0.676 (1.49)	0.591 (1.30)	0.521 (1.15)
mg/ampere-hr (gr/ampere-hr)	0.174 (0.003)	0.175 (0.003)	0.202 (0.003)	0.184 (0.003)	0.143 (0.002)

[a]Results for this test run were not included in average; heavy rain entered the stack during testing and may have biased the results.

TABLE C-56. SUMMARY OF EMISSIONS TEST DATA

Plant K: Steel Heddle Company
Operation: Hard chromium electroplating
Emission source: Three hard chromium electroplating tanks
Test location: Scrubber inlet

Data	Run No. 1	Run No. 2	Run No. 3	Average of test series
General				
Date	06/24/86	06/25/86	06/25/86	--
Sampling time, min	180	180	180	--
Isokinetic ratio, %	96.6	94.3	94.5	--
Process rate, ampere-hr/hr	3,800	2,090	2,900	2,930
Total current, ampere-hr	11,400	6,270	8,710	8,790
Gas stream data				
Temperature, °C (°F)	36 (96)	32 (90)	36 (97)	34 (94)
Moisture, %	2.6	2.2	2.2	2.3
Actual flow rate, m^3/min (ft^3/min)	512 (18,100)	510 (18,000)	513 (18,100)	512 (18,100)
Dry standard flow rate, dscm/min (dscf/min)	462 (16,300)	467 (16,500)	464 (16,400)	464 (16,400)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	2,560 (1.12)	1,110 (0.486)	1,090 (0.476)	1,590 (0.694)
kg/hr (lb/hr) (10^{-3})	70.8 (156)	31.3 (69.0)	30.4 (67.0)	44.2 (97.3)
mg/ampere-hr (gr/ampere-hr)	18.6 (0.287)	15.0 (0.231)	10.5 (0.161)	14.7 (0.227)
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	2,680 (1.17)	1,200 (0.523)	1,130 (0.494)	1,670 (0.729)
kg/hr (lb/hr) (10^{-3})	74.4 (164)	33.6 (74.0)	31.3 (69.0)	46.4 (102)
mg/ampere-hr (gr/ampere-hr)	19.6 (0.302)	16.1 (0.248)	10.8 (0.162)	15.5 (0.238)

TABLE C-57. SUMMARY OF EMISSIONS TEST DATA

Plant K: Steel Heddle Company
Operation: Hard chromium electroplating
Emission source: Three hard chromium electroplating tanks
Test location: Scrubber outlet

Data	Run No. 1	Run No. 2	Run No. 3	Average of test series
General				
Date	06/24/86	06/25/86	06/25/86	--
Sampling time, min	180	180	180	--
Isokinetic ratio; %	97.7	97.3	97.4	--
Process rate, ampere-hr	3,800	2,080	2,870	2,920
Total current, ampere-hr	11,400	6,230	8,610	8,750
Gas stream data				
Temperature, °C (°F)	27 (80)	24 (75)	23 (74)	25 (76)
Moisture, %	2.9	2.5	2.3	2.6
Actual flow rate, m^3/min (ft^3/min)	513 (18,100)	518 (18,300)	518 (18,300)	515 (18,200)
Dry standard flow rate, dscm/min (dscf/min)	476 (16,800)	490 (17,300)	490 (17,300)	484 (17,100)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	50.1 (0.022)	49.0 (0.021)	56.5 (0.025)	51.9 (0.023)
kg/hr (lb/hr) 10^{-3})	1.42 (3.14)	1.44 (3.18)	1.64 (3.61)	1.50 (3.31)
mg/ampere-hr (gr/ampere-hr)	0.374 (0.006)	0.692 (0.011)	0.571 (0.009)	0.546 (0.008)
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	51.0 (0.022)	51.5 (0.23)	54.5 (0.024)	52.3 (0.023)
kg/hr (lb/hr) 10^{-3})	1.45 (3.19)	1.51 (3.33)	1.61 (3.54)	1.52 (3.35)
mg/ampere-hr (gr/ampere-hr)	0.382 (0.006)	0.726 (0.011)	0.561 (0.009)	0.556 (0.009)

TABLE C-58. SUMMARY OF EMISSIONS TEST DATA

Plant L: Fusion, Inc.
Operation: Hard chromium electroplating
Emission source: One hard chromium electroplating tank
Test location: Scrubber inlet

Data	Run No. 1[a]	Run No. 2	Run No. 3	Average of run Nos. 2 and 3
General				
Date	05/19/89	05/19/89	05/20/89	--
Sampling time, min	120	120	120	--
Isokinetic ratio, %	109	108	107	--
Process rate, ampere-hr	2,750	3,000	2,300	2,650
Total current, ampere-hr	5,500	6,000	4,600	5,300
Gas stream data				
Temperature, °C (°F)	29 (85)	28 (83)	31 (88)	30 (86)
Moisture, %	2.4	2.4	2.7	2.6
Actual flow rate, m^3/min (ft^3/min)	578 (20,400)	566 (20,000)	572 (20,200)	569 (20,100)
Dry standard flow rate, dscm/min (dscf/min)	544 (19,200)	535 (18,900)	538 (19,000)	537 (19,000)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	--	--	--	--
kg/hr (lb/hr) 10^{-3})	--	--	--	--
mg/ampere-hr (gr/ampere-hr)	--	--	--	--
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	299 (0.131)	646 (0.282)	783 (0.342)	715 (0.312)
kg/hr (lb/hr) 10^{-3})	9.7 (21.5)	20.8 (45.9)	25.2 (55.7)	23.0 (50.7)
mg/ampere-hr (gr/ampere-hr)	3.53 (0.054)	6.93 (0.107)	11.0 (0.169)	8.97 (0.138)

TABLE C-58. (Continued)

Data	Run No. 4	Run No. 5	Run No. 6	Average of run Nos. 4, 5, and 6
General				
Date	5/21/89	5/21/89	5/21/89	--
Sampling time, min	120	120	120	--
Isokinetic ratio, %	105	104	105	--
Process rate, ampere-hr/hr	3,600	3,600	3,700	3,600
Total current, ampere-hr	7,200	7,200	7,400	7,300
Gas stream data				
Temperature, °C (°F)	31 (87)	34 (93)	31 (88)	32 (89)
Moisture, %	2.3	2.3	2.5	2.4
Actual flow rate, m^3/min (ft^3/min)	578 (20,400)	580 (20,500)	572 (20,200)	578 (20,400)
Dry standard flow rate, dscm/min (dscf/min)	547 (19,300)	544 (19,200)	535 (18,900)	541 (19,100)
Chromium emissions				
Total chromium				
mg/dscm (gr/dsft^3/min) (10^{-3})	--	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--	--
mg/ampere-hr (gr/ampere-hr)	--	--	--	--
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	850 (0.371)	576 (0.252)	579 (0.253)	668 (0.292)
kg/hr (lb/hr) (10^{-3})	27.8 (61.4)	18.7 (41.3)	18.6 (41.0)	21.7 (47.8)
mg/ampere-hr (gr/ampere-hr)	7.72 (0.119)	5.19 (0.080)	5.03 (0.078)	5.98 (0.092)

TABLE C-58. (Continued)

Data	Run No. 7	Run No. 8	Average of run Nos. 7 and 8	Average of test series[a]
General				
Date	5/23/89	5/23/89	--	--
Sampling time, min	192	120	--	--
Isokinetic ratio, %	105	105	--	--
Process rate, ampere-hr/hr	3,130	2,800	2,970	3,160
Total current, ampere-hr	10,000	5,600	7,800	6,900
Gas stream data				
Temperature, °C (°F)	31 (88)	33 (92)	32 (90)	31 (88)
Moisture, %	2.3	2.3	2.3	2.4
Actual flow rate, m^3/min (ft^3/min)	583 (20,600)	578 (20,400)	580 (20,500)	575 (20,300)
Dry standard flow rate, dscm/min (dscf/min)	547 (19,300)	541 (19,100)	544 (19,200)	541 (19,100)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	--	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--	--
mg/ampere-hr (gr/ampere-hr)	--	--	--	--
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	752 (0.329)	693 (0.303)	723 (0.316)	697 (0.305)
kg/hr (lb/hr) (10^{-3})	24.7 (54.5)	22.5 (49.4)	23.6 (52.0)	22.6 (49.9)
mg/ampere-hr (gr/ampere-hr)	7.89 (0.122)	8.04 (0.124)	7.97 (0.123)	7.40 (0.114)

[a]Run No. 1 was not included in the average due to possible sample contamination.

TABLE C-59. SUMMARY OF EMISSIONS TEST DATA

Plant L: Fusion, Inc.
Operation: Hard chromium electroplating
Emission source: One hard chromium electroplating tank
Test location: Scrubber outlet

Data	Run No. 1	Run No. 2	Run No. 3	Average of run Nos. 1, 2, and 3
General				
Date	5/19/89	5/19/89	5/20/89	--
Sampling time, min	120	120	120	--
Isokinetic ratio, %	104	102	102	--
Process rate, ampere-hr/hr	2,700	3,000	2,300	2,670
Total current, ampere-hr	5,400	6,000	4,600	5,300
Gas stream data				
Temperature, °C (°F)	28 (83)	28 (82)	29 (84)	28 (83)
Moisture, %	2.7	3.0	2.9	2.9
Actual flow rate, m^3/min (ft^3/min)	527 (18,600)	532 (18,800)	530 (18,700)	530 (18,700)
Dry standard flow rate, dscm/min (dscf/min)	501 (17,700)	507 (17,900)	504 (17,800)	504 (17,800)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	--	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--	--
mg/ampere-hr (gr/ampere-hr)	--	--	--	--
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	37.5 (0.016)	39.0 (0.017)	41.2 (0.018)	39.2 (0.017)
kg/hr (lb/hr) (10^{-3})	1.13 (2.48)	1.19 (2.61)	1.24 (2.74)	1.19 (2.63)
mg/ampere-hr (gr/ampere-hr)	0.419 (0.006)	0.397 (0.006)	0.539 (0.008)	0.452 (0.007)

TABLE C-59. (Continued)

Data	Run No. 4	Run No. 5	Run No. 6	Average of run Nos. 4, 5, and 6
General				
Date	5/21/89	5/21/89	5/21/89	--
Sampling time, min	120	120	120	--
Isokinetic ratio, %	102	102	103	--
Process rate, ampere-hr/hr	3,550	3,600	3,700	3,620
Total current, ampere-hr	7,100	7,200	7,400	7,200
Gas stream data				
Temperature, °C (°F)	27 (81)	29 (84)	28 (82)	28 (82)
Moisture, %	2.5	2.9	3.1	2.8
Actual flow rate, m^3/min (ft^3/min)	530 (18,700)	524 (18,500)	524 (18,500)	527 (18,600)
Dry standard flow rate, dscm/min (dscf/min)	510 (18,000)	498 (17,600)	498 (17,600)	501 (17,700)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	--	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--	--
mg/ampere-hr (gr/ampere-hr)	--	--	--	--
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	25.7 (0.011)	21.6 (0.009)	22.9 (0.010)	23.4 (0.010)
kg/hr (lb/hr) (10^{-3})	0.786 (1.73)	0.646 (1.42)	0.684 (1.51)	0.705 (1.55)
mg/ampere-hr (gr/ampere-hr)	0.221 (0.003)	0.179 (0.003)	0.185 (0.003)	0.195 (0.003)

TABLE C-59. (Continued)

Data	Run No. 7	Run No. 8	Average of run No. 7 and 8	Average of test series
General				
Date	5/23/89	5/23/89	--	--
Sampling time, min	192	120	--	--
Isokinetic ratio, %	98	97	--	--
Process rate, ampere-hr/hr	3,130	2,800	2,970	3,100
Total current, ampere-hr	10,000	5,600	7,800	6,700
Gas stream data				
Temperature, °C (°F)	28 (82)	28 (82)	28 (82)	28 (83)
Moisture, %	2.9	2.9	2.9	2.9
Actual flow rate, m^3/min (ft^3/min)	527 (18,600)	532 (18,800)	530 (18,700)	530 (18,700)
Dry standard flow rate, dscm/min (dscf/min)	504 (17,800)	507 (17,900)	506 (17,900)	504 (17,800)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	--	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--	--
mg/ampere-hr (gr/ampere-hr)	--	--	--	--
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	22.7 (0.010)	20.1 (0.009)	21.4 (0.009)	NA[a]
kg/hr (lb/hr) (10^{-3})	0.686 (1.51)	0.613 (1.35)	0.650 (1.43)	NA[a]
mg/ampere-hr (gr/ampere-hr)	0.219 (0.003)	0.219 (0.003)	0.219 (0.003)	NA[a]

[a]NA = Not Applicable. Emissions averages for the test series are not presented because each group of test runs was performed under different control device operating conditions.

TABLE C-60. SUMMARY OF EMISSIONS TEST DATA

Plant M: Delco Products Division-General Motors Corp.
Operation: Decorative chromium electroplating
Emission source: One decorative chromium electroplating tank
Test location: Inlet to control system

Data	Run No. 1	Run No. 2	Run No. 3	Average of test series
General				
Date	3/18/87	3/18/87	3/19/87	--
Sampling time, min	180	180	180	--
Isokinetic ratio, %	98.0	98.5	98.3	--
Process rate, ampere-hr/hr	32,500	34,700	29,900	32,400
Total current, ampere-hr	97,400	104,000	89,600	97,000
Gas stream data				
Temperature, °C (°F)	24 (76)	23 (74)	24 (75)	24 (75)
Moisture, %	0.92	1.0	0.82	0.91
Actual flow rate, m^3/min (ft^3/min)	671 (23,700)	688 (24,300)	688 (24,300)	683 (24,100)
Dry standard flow rate, dscm/min (dscf/min)	640 (22,600)	657 (23,200)	654 (23,200)	650 (23,000)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	1,660 (0.724)	1,210 (0.526)	1,450 (0.634)	1,440 (0.629)
kg/hr (lb/hr) (10^{-3})	63.7 (140)	47.5 (105)	57.1 (126)	56.1 (124)
mg/ampere-hr (gr/ampere-hr)	1.96 (0.030)	1.37 (0.021)	1.91 (0.029)	1.75 (0.027)
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	1,950 (0.853)	1,300 (0.564)	1,540 (0.673)	1,600 (0.699)
kg/hr (lb/hr) (10^{-3})	75.0 (165)	61.9 (112)	60.6 (134)	65.8 (145)
mg/ampere-hr (gr/ampere-hr)	2.31 (0.036)	1.78 (0.027)	2.03 (0.031)	2.04 (0.031)

TABLE C-61. SUMMARY OF EMISSIONS TEST DATA

Plant N: Automatic Die Casting Specialties, Inc.
Operation: Decorative chromium electroplating
Emission source: One decorative chromium electroplating tank
Test location: Inlet (uncontrolled)

Data	Run No. 1	Run No. 2	Run No. 3	Average of test series
General				
Date	4/18/88	4/19/88	4/19/88	--
Sampling time, min	192	120	120	--
Isokinetic ratio, %	100	99.1	103	--
Process rate, ampere-hr/hr	2,700	2,400	2,800	2,600
Total current, ampere-hr	8,700	5,200	5,600	6,500
Gas stream data				
Temperature, °C (°F)	23 (73)	20 (68)	21 (70)	21 (70)
Moisture, %	1.6	1.3	1.4	1.4
Actual flow rate, m^3/min (ft^3/min)	70.5 (2,490)	70.2 (2,480)	69.4 (2,450)	70.0 (2,470)
Dry standard flow rate, dscm/min (dscf/min)	66.8 (2,360)	67.7 (2,390)	66.3 (2,340)	66.8 (2,360)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	--	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--	--
mg/ampere-hr (gr/ampere-hr)	--	--	--	--
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	846 (0.370)	923 (0.400)	993 (0.430)	921 (0.402)
kg/hr (lb/hr) (10^{-3})	3.3 (7.3)	3.6 (7.9)	3.9 (8.6)	3.6 (7.9)
mg/ampere-hr (gr/ampere-hr)	1.22 (0.019)	1.50 (0.023)	1.39 (0.021)	1.37 (0.021)

TABLE C-62. SUMMARY OF EMISSIONS TEST DATA

Plant N: Automatic Die Casting Specialties, Inc.
Operation: Decorative chromium electroplating
Emission source: One decorative chromium electroplating tank
Test location: Inlet (with foam blanket)

Data	Run No. 4	Run No. 5	Run No. 6	Average of test series
General				
Date	4/20/88	4/20/88	4/21/88	--
Sampling time, min	192	120	240	--
Isokinetic ratio, %	102	103	102	--
Process rate, ampere-hr/hr	2,800	2,700	2,900	2,800
Total current, ampere-hr	8,400	5,300	11,900	8,500
Gas stream data				
Temperature, °C (°F)	20 (68)	18 (65)	21 (70)	20 (68)
Moisture, %	1.0	1.0	1.2	1.1
Actual flow rate, m^3/min (ft^3/min)	69.1 (2,440)	69.7 (2,460)	69.1 (2,440)	69.4 (2,450)
Dry standard flow rate, dscm/min (dscf/min)	66.8 (2,360)	67.4 (2,380)	66.3 (2,340)	66.8 (2,360)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	--	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--	--
mg/ampere-hr (gr/ampere-hr)	--	--	--	--
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	3.39 (0.001)	6.81 (0.003)	3.81 (0.002)	4.67 (0.002)
kg/hr (lb/hr) (10^{-3})	0.013 (0.029)	0.027 (0.059)	0.015 (0.033)	0.018 (0.040)
mg/ampere-hr (gr/ampere-hr)	0.005 ($7.7x10^{-5}$)	0.010 ($1.5x10^{-4}$)	0.005 ($7.8x10^{-5}$)	0.007 ($1.0x10^{-4}$)

TABLE C-63. SUMMARY OF EMISSIONS TEST DATA

Plant N: Automatic Die Casting Specialties, Inc.
Operation: Decorative chromium electroplating
Emission source: One decorative chromium electroplating tank
Test location: Inlet (with combination fume suppressant)

Data	Run No. 7	Run No. 8	Run No. 9	Average of test series
General				
Date	4/25/88	4/26/88	4/26/88	--
Sampling time, min	240	240	180	--
Isokinetic ratio, %	99.3	98.8	98.5	--
Process rate, ampere-hr/hr	2,800	2,900	2,800	2,800
Total current, ampere-hr	11,300	11,700	8,500	10,500
Gas stream data				
Temperature, °C (°F)	22 (72)	24 (75)	24 (75)	23 (74)
Moisture, %	1.2	1.6	1.5	1.4
Actual flow rate, m^3/min (ft^3/min)	68.5 (2,420)	68.3 (2,410)	66.6 (2,350)	67.7 (2,390)
Dry standard flow rate, dscm/min (dscf/min)	66.3 (2,340)	64.3 (2,270)	63.4 (2,240)	64.6 (2,280)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	--	--	--	--
kg/hr (lb/hr) (10^{-3})	--	--	--	--
mg/ampere-hr (gr/ampere-hr)	--	--	--	--
Hexavalent chromium				
mg/dscm (gr/dscf)	1.9×10^{-3} (7.8×10^{-7})	1.2×10^{-3} (5.1×10^{-7})	3.4×10^{-3} (1.5×10^{-6})	2.2×10^{-3} (9.5×10^{-7})
kg/hr (lg/hr)	7.4×10^{-6} (1.6×10^{-5})	4.5×10^{-6} (9.9×10^{-6})	1.3×10^{-5} (2.9×10^{-5})	8.3×10^{-6} (1.8×10^{-5})
mg/ampere-hr (gr/ampere-hr)	0.003 (4.0×10^{-5})	0.002 (2.4×10^{-5})	0.005 (7.1×10^{-5})	0.003 (4.6×10^{-5})

TABLE C-64. PROCESS OPERATING PARAMETERS MONITORED DURING SAMPLING AT RELIABLE PLATING AND POLISHING COMPANY, BRIDGEPORT, CONNECTICUT

Run No.	Anodizing bath temperature, °C (°F)	Current, amperes	Voltage, volts	Outlet water flow rate, L/min (gal/min)
1	35 (95)	80-100	35	7.5 (2.0)
2	35 (95)	20-40	36	7.2 (1.9)
3	35 (95)	20	37	7.2 (1.9)
4	35 (95)	100	36	7.5 (2.0)
Average	35 (95)	20-100	36	7.5 (2.0)

TABLE C-65. ANALYTICAL RESULTS OF COMPOSITE SAMPLES TAKEN DURING EACH TEST RUN AT RELIABLE PLATING AND POLISHING COMPANY, BRIDGEPORT, CONNECTICUT

Sample description	Run No.	Sample concentration, μg/mL (oz/gal)	
		Hexavalent chromium	Total chromium
Outlet scrubber water	1	3.9 (5.2 x 10^{-4})	3.9 (5.2 x 10^{-4})
	2	0.8 (1.1 x 10^{-4})	0.8 (1.1 x 10^{-4})
	3	0.3 (4.0 x 10^{-5})	0.3 (4.0 x 10^{-5})
	4	5.1 (6.8 x 10^{-4})	5.1 (6.8 x 10^{-4})
	Average	2.5 (3.3 x 10^{-4})	2.5 (3.3 x 10^{-4})
Inlet scrubber water[a]	1	<0.1 (0)	<0.1 (0)
	2	<0.1 (0)	<0.1 (0)
	3	<0.1 (0)	<0.1 (0)
	4	≤0.1 (0)	≤0.1 (0)
	Average	<0.1 (0)	<0.1 (0)
Anodizing bath	1	50,300 (6.72)	52,000 (6.94)
	2	50,500 (6.74)	51,900 (6.93)
	3	50,700 (6.77)	51,100 (6.82)
	4	50,300 (6.72)	50,300 (6.72)
	Average	50,450 (6.74)	51,325 (6.85)

[a]The amount of chromium in the inlet water stream was below the detectable limit of the analytical procedure (0.1 μg/mL) and was assumed to be equal to zero.

TABLE C-66. ESTIMATED UNCONTROLLED CHROMIUM MASS EMISSION RATES BASED ON HEXAVALENT AND TOTAL CHROMIUM CONCENTRATIONS OF OUTLET SCRUBBER WATER AT RELIABLE PLATING AND POLISHING COMPANY IN BRIDGEPORT, CONNECTICUT

Run No.	Uncontrolled chromium emission rate at scrubber efficiency of 90 percent, kg/hr (lb/hr)[a]	No. of parts or racks anodized	Type of part anodized
1	0.0019 (0.0042)	14 racks	Small aircraft and electronic parts
2	0.00039 (0.00086)	22 parts	Aircraft parts
3	0.00015 (0.00033)	16 parts	Aircraft parts
4	0.0025 (0.0055)	17 racks	Small aircraft and electronic parts
Average	0.0012 (0.0026)		

[a]Total and hexavalent chromium concentrations in scrubber water were equal.

C.4 REFERENCES FOR APPENDIX C

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3. Chromium Electroplaters Test Report: Able Machine Company, Taylors, South Carolina. PEI Associates, Inc., Cincinnati, Ohio. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 86-CEP-3. June 1986.

4. Emission Test Report: Roll Technology Corporation, Greenville, South Carolina. Peer Consultants, Inc., Dayton, Ohio. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 88-CEP-13. August 1988.

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APPENDIX D.

EMISSION MEASUREMENT AND CONTINUOUS MONITORING

APPENDIX D - EMISSION MEASUREMENT AND CONTINUOUS MONITORING

D.1 EMISSION MEASUREMENT METHODS

During the standard support study for hexavalent chromium emissions from hard and decorative chromium electroplating facilities, the Emission Measurement Branch conducted emission tests at twelve facilities. Tests were performed on inlet and outlet locations of packed bed scrubbers and chevron blade or mesh pad demisters. One test determined the efficiency of a fume suppressant.

The sampling collection method uses a modified EPA Method 5 train which is also referred to in test reports as a Modified Method 13-B train. Developmental work on this train showed that more accurate results could be obtained by eliminating the filter from the train since recovery of the filter increased the difficulty of sample recovery and chromic acid could also be trapped in the filter frit and not recovered at all. Water in the impingers was replaced with 0.1 normal sodium hydroxide to stabilize the hexavalent chromium content of the samples.

Samples to be analyzed for hexavalent and total chromium were obtained as much as possible in accordance with EPA Method 5 (40 CFR Part 60 - Appendix A) with the modifications made to the sampling collection method mentioned above. Method 5, which also requires the use of Methods 1 through 4, provides detailed procedures, equipment criteria, and other considerations necessary to obtain accurate and representative emission samples.

After collection, the samples were analyzed for hexavalent and total chromium (total chromium is the sum of hexavalent chromium plus other chromium). Concentrations of hexavalent chromium were determined using spectrophotometric analysis while total chromium was determined using Inductively Coupled Argon Plasmography (ICAP). All samples were analyzed for hexavalent chromium; however, not all samples were analyzed for total chromium since it was necessary to reduce source testing expenses.

At the present time, sample analysis has been performed in accordance with the tentative method "Determination of Hexavalent Chromium from Decorative and hard Chrome Electroplating (December 13, 1989)," and a draft method: "EPA protocol for Emission Sampling for both Hexavalent and Total Chromium (February 22, 1985)."

One problem that has occurred in most of the facilities tested is the inlet sampling location. Only rarely did the inlet meet the criteria for port location set forth in Method 1. Control devices are usually located as close to the plating tank as possible meaning that there is an insufficient length of straight duct work for sampling as specified in Reference Method 1. In such cases, the choice made is whether to sample at an improper location, or not to sample at all. In this test series, all inlets were sampled although few inlet locations were acceptable relative to Method 1. Efficiencies calculated from these sampling locations may not truly reflect the efficiency of the control device. Visual observations through ports located close to the plating tank revealed large globules of chromic acid entrained in the stack gas. These globules, directly striking the nozzle opening will bias inlet emissions high. In one instance, a control device was sampled with the inlet location close to the plating tank, and the efficiency was calculated. An identical control unit was sampled with the inlet location properly located and the efficiency of the control device dropped one percent. One scrubber that showed an extremely high efficiency also had an improperly located inlet and many large droplets of chromic acid in the gas stream.

Particle size samples were obtained on four tests and all size distribution tests were performed in accordance with procedures detailed in the equipment manufacturer's manual, and through consultation with the manufacturer. All but one of the tests used button hook nozzles on the impactors. While button hook nozzles are effective on dry particulate sources, when used on liquid sources there is a tendency for the larger particles to adhere to the curved walls of the nozzle and never reach the impactor stages. The observed distribution of the particles will appear to be smaller than the true distribution. A straight nozzle should be used and the impactor stages should be at right angles to the flow of the duct when the sample is taken. This will allow all particles to enter the impactor.

When analyzing an impactor catch, a gravimetric analysis will be biased by the evaporation of water from the chromic acid; thus, a chemical analysis must be made to ensure the greatest degree of accuracy. The Consolidated Engravers Corporation report (EMB 87-CEP-9) is the only report containing particle size data where a straight nozzle was used on the impactor, and both gravimetric and chemical analyses were made.

There are two test reports of electroplating facilities that do not provide accurate data on chromium emissions. They are the C. S. Ohm Report (85-CHM-10) and the Carolina Platers Report (85-CHM-11). Data from the C. S. Ohm report are suspect since some of the test runs gave higher numbers at the outlet than at the inlet. Emissions at the facility were controlled with a fume suppressant and a scrubber that was located on the roof of the building. In the winter, the scrubber water was cut off to prevent freezing, leaving the fume suppressant as the only means of emission control. The reason for higher outlet emissions may never be known. At the Carolina Platers facility, cyclonic flow existed at the outlet and the sampling method used at this location was incorrect. At the inlet, a single horizontal traverse was used in lieu of both a horizontal and a vertical traverse. While this technique seemed suitable at the time, sampling of other plating facilities revealed that chromic acid mist at inlet sources is not uniformly distributed across the duct. For these reasons, data from the Carolina Platers test do not reflect the true emissions from the source.

Although the emission rates from the Carolina Platers report are indeterminate, it is interesting to note that the percent of total chromium in samples collected was noticeably higher at this location than at other facilities tested. At the time of this test, the plating tank hooding used to collect chromic acid mist was made of steel. The hooding was later replaced with plastic. A possible explanation for the high total chromium values is that there is a reaction between the steel hooding and the chromic acid, and conversion from hexavalent chromium to trivalent chromium occurs. This possibility is also indicated in an experiment performed by the Source Methods Standardization Branch of the Atmospheric Research and Exposure Assessment Laboratory. In this experiment, a weak solution of chromium acid was prepared and the concentration determined. The solution was then split and placed into two containers. A Swagelock fitting was placed into one of the containers. As time passed, subsequent analyses showed a decrease in hexavalent chromium in the container with the fitting while the other container showed no decrease at all.

During the early part of the chromium project, it was determined that the minute quantities of chromium found in the stainless steel nozzles would not create a high bias in the test data, but a reaction between the stainless nozzle and chromic acid was not considered. If metals such as steel or stainless steel cause hexavalent chromium to convert to trivalent chromium, then it is possible that samples collected with stainless nozzles may be biased low. This may also be the reason that the constant sampling rate train (occasionally called the screening train) had slightly higher emission rate and concentrations than the isokinetic train. The constant sampling rate train used a glass nozzle while the isokinetic train used a stainless nozzle.

D.2 MONITORING SYSTEMS AND DEVICES

Currently, there are no continuous monitoring systems available for the determination of chromium emissions from plating operations. The fine mist emitted from the process is not visible to the naked eye at outlet locations, and prohibits the use of continuous monitors or visible emission observers as a means of determining compliance.

At the beginning of the chromium study, the Emission Measurement Branch worked on a screening technique that would use inexpensive and readily available components to determine hexavalent chromium emission to within plus or minus 50 percent accuracy. If successful, this method was to be used as an inexpensive way to determine if conventional isokinetic testing would be required.

Some of the techniques tried were detector tubes, midget impingers, short pieces of teflon tubing, short pieces of tubing followed by cassette filters, and traversing the duct with the cassette filter/tubing combination while sampling with uniform sample times. These devices were only partially successful, always producing concentration and mass emission rates lower than those of the isokinetic train. Not one was adequate as a screening technique.

Successive test work showed that a screening technique would be difficult to develop due to the inconsistent distribution of chromic acid mist particles in the stack gas. The two primary areas of chromic acid mist generation in the plating tank are the anode and cathode. In a horizontal plating tank, the length of hooding used to capture these emissions extends along the entire length of the plating tank. ambient air pulled into the hooding will have the highest concentration of chromic acid mist where it enters the hooding at the point closest to the anode or cathode. With only the natural mixing effect of the ductwork, the exhaust gases are not uniform in concentration of chromic acid mist, and overall emission rates determined from single point sampling are inaccurate.

Although early efforts in the program did not produce a successful screening technique, they did lead to an alternate sampling method that is presently being considered as one of two ways to determine hexavalent chromium emissions from decorative and hard chromium electroplaters. The method uses proportional sampling, inexpensive components, and is simple enough that it can be fabricated and used by plant personnel. The method is described in Section D.3.

D.3 COMPLIANCE TEST METHODS

Consistent with the data base upon which standards have been established, the recommended test method for chromium emissions has been a modified Method 5 sampling train (also referred to as a modified 13-B train or simply a 13-B train). The train is modified by eliminating the filter in the train and charging the impingers with 0.1 normal sodium hydroxide rather than water. Method 5 is described in Appendix A, Title 40, Part 60 in the Code of Federal Regulations. In order to sample for chromium emissions, Methods 1, 2, and 4 must also be used.

Sampling costs for performing a test consisting of three modified Method 5 runs (an uncontrolled plating operation for example) with analysis for hexavalent chromium are approximately $4,200 plus travel expenses for two people. Inlet and outlet tests for a control device cost $8,400 plus travel for four people.

The Emission Measurement Branch has developed a simplified and low cost alternate sampling train that can be used to determine chromium emissions from electroplating and anodizing facilities. The train can be built and operated by plant personnel and obtaining a sample requires only half the personnel of a standard isokinetic train. The cost of building the apparatus is slightly over $500.00 which is one tenth the cost of a standard train, and using plant personnel to collect the samples would cost only $350.00 as compared to $3,500 to $5,000 for samples collected by a consultant using a conventional train. While the standard isokinetic train (Modified Method 5) samples by varying the sample rate at each point, the simplified train samples at a constant rate and the sample time is varied in order to obtain a proportional sample. Errors resulting from frequent adjustment of the sample rate are eliminated. Since the simplified train is smaller, less reagent is required for sample recovery, and the possibility of not recovering all of the sample is greatly reduced. The more concentrated sample is also easier to analyze.

A cost comparison of the alternate sampling method and the modified Method 5 follows:

	ALTERNATE METHOD	MODIFIED METHOD 5
Costs to build the train (parts and labor)	$800	
Plant personnel, 3 runs (1 person, $10/hr)	150	
Cost of analysis, 3 runs	150	
Total	$1,100	$4,200*
	Inlet and Outlet Tests	
Cost to build equipment (parts and labor)	$1,300	
Plant personnel, 3 runs (2 people, $10/hr ea.)	300	
Cost of analysis, 3 runs	300	
Total costs	$1,900	$8,400

*plus travel

ATTACHMENT 1.

METHOD __ - DETERMINATION OF HEXAVALENT CHROMIUM EMISSIONS FROM DECORATIVE AND HARD CHROMIUM ELECTROPLATING AND CHROMIC ACID ANODIZING OPERATIONS

Method __ - Determination of Hexavalent Chromium

Emissions from Decorative and Hard Chromium Electroplating and Chromic Acid Anodizing Operations

1. Applicability and Principle

1.1 Applicability. This method applies to the determination of hexavalent chromium (Cr^{+6}) in emissions from decorative and hard chromium electroplating and chromic acid anodizing operations.

1.2 Principle. Emissions are collected from the source by use of Method 5 (Appendix A, 40 CFR Part 60), with the filter omitted. The first and second impingers are charged with 0.1N sodium hydroxide. The collected samples remain in an alkaline solution until analysis, and are analyzed for CR^{+6}) by the diphenylcarbazide colorimetric method.

2. Range, Sensitivity, Precision, and Interferences

2.1 Range. A straight line response curve can be obtained in the range 5 Cr^{+6}/100 ml to 100 ug Cr^{+6}/100 ml. For a minimum analytical accuracy of ±10 percent, the lower limit of the range is 10 ug/100 ml. The upper limit can be extended by appropriate dilution.

2.2 Sensitivity. A minimum detection limit of 1 ug Cr^{+6}/100 ml has been observed.

2.3 Precision. To be determined.

2.4 Interference. Molybdenum, mercury and vanadium react with diphenylcarbazide to form a color; however, approximately 20 mg of these elements can be present in a sample without creating a problem. Iron produces a yellow color, but this effect is not measured photometrically at 540 nm.

APPARATUS

3.1 Sampling Train. Same as Method 5, Section 2.1, but omit filter.

3.2 Sample Recovery. Same as Method 5, Section 2.2, but use 0.1N NaOH in place of acetone.

3.3 Analysis. The following equipment is needed.

3.3.1 Beakers. Borosilicate, 250-ml, with watchglass covers.

3.3.2 Volumetric Flasks. 100-ml and other appropriate volumes.

3.3.3 Pipettes. Assorted sizes, as needed.

3.3.4 Spectrophotometer. To measure absorbance at 540 nm.

4. Reagents

Unless otherwise indicated, all reagents shall conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society. Where such specifications are not available, use the best available grade.

4.1 Sampling.

4.1.1 0.1N NaOH.

4.2 Sample Recovery.

4.2.2 0.1N NaOH.

4.3 Analysis. The following reagents are required.

4.3.1 Water. Deionized distilled, meeting American Society for Testing and Materials (ASTM) specifications for type 2 reagent - ASTM Test Method D 1193-77 (incorporated by reference - see s61.18).

4.3.2 Potassium Dichromate Stock Solution. Dissolve 141.4 mg of analytical reagent grade $K_2Cr_2O_7$ in water, and dilute to 1 liter (1 ml = 50 ug Cr^{+6}).

4.3.3 Potassium Dichromate Standard Solution. Dilute 10.00 ml $K_2Cr_2O_7$ stock solution to 100 ml (1 ml = 5 ug Cr^{+6}) with water.

4.3.4 Sulfuric Acid, 10 Percent (v/v). Dilute 10 ml H_2SO_4 to 100 ml in water.

4.3.5 Diphenylcarbazide Solution. Dissolve 250 mg of 1, 5-diphenylcarbizide in 50 ml acetone. Store in a brown bottle. Discard when the solution becomes discolored.

5. Procedure

5.1 Sampling. Same as Method 5, Section 4.1, except omit the filter and filter holder, and place 100 ml of 0.1N NaOH in each of the first two impingers.

5.2 Sample Recovery. Measure the volume and place all liquid in the first, second, and third impingers in a labelled sample container (Container Number 1). Use 200 ml of 0.1N NaOH to rinse the probe, three impingers, and connecting glassware. Place this wash in the same container. Place the silica gel from the fourth impinger in Container Number 3.

5.3 Preservation. Analyze all samples within ______ of collection.

5.4 Reagent Blank Preparation. Place 400 ml of 0.1N NaOH in a labelled sample container (Container Number 2).

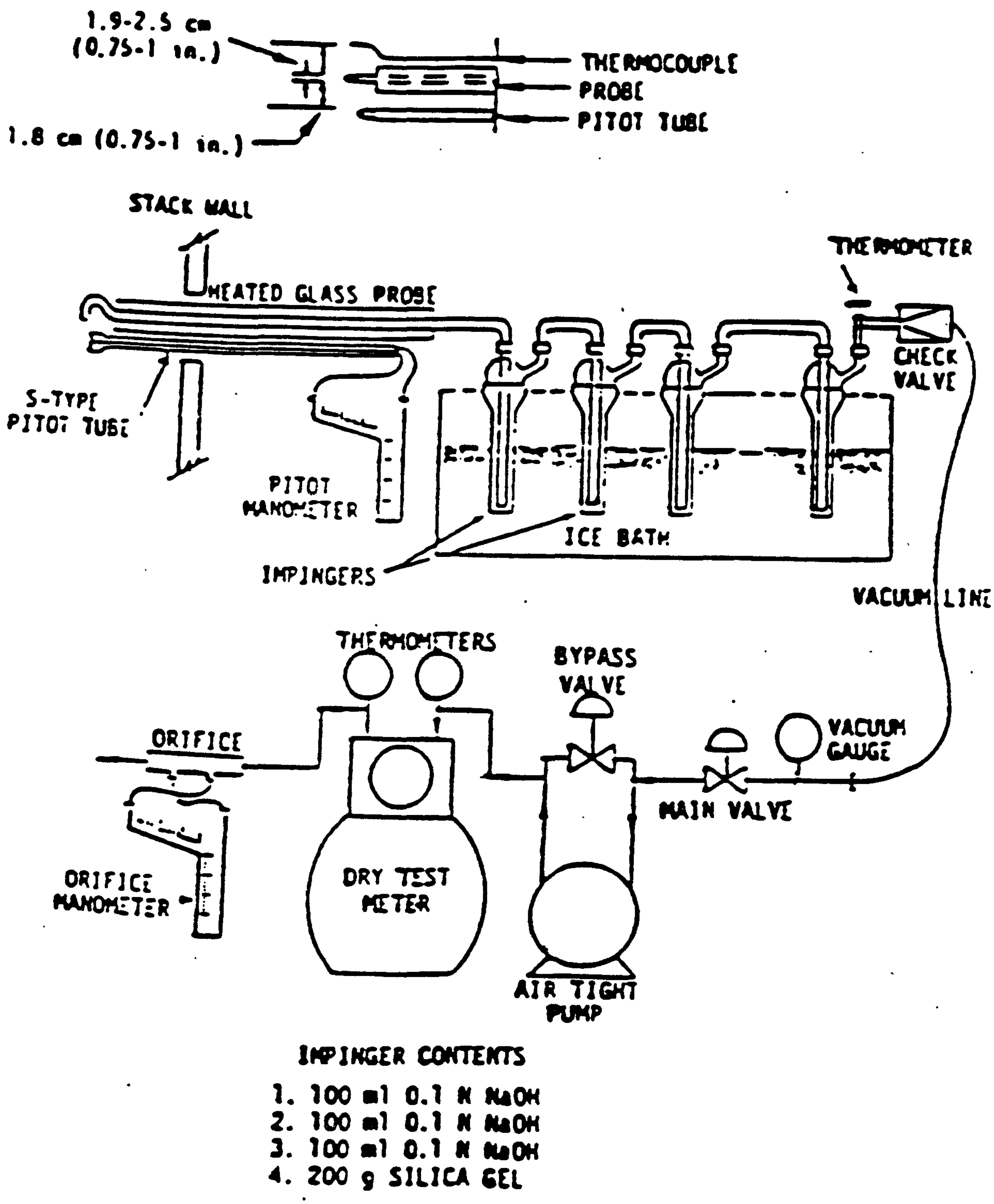

Figure D-1. Hexavalent/total Cr sampling train

5.5 Silica Gel Weighing. Weigh the spent silica gel (Container Number 3) or silica gel plus impinger to the nearest 0.5 g using a balance. This step may be conducted in the field.

5.6 Analysis.

5.6.1 Color Development and Measurement. After stirring the sample in Container Number 1, transfer a 50-ml or smaller measured aliquot to a 100 ml volumetric flask and add sufficient water to bring the volume to approximately 80 ml. Adjust the pH to 2 ± 0.5 with 10 percent H_2SO_4, add 2.0 ml of diphenylcarbazide solution, and dilute to volume with water. Allow the solution to stand about 10 minutes for color development. For each set of samples analyzed, treat an identical aliquot of reagent blank solution from Container Number 2 in the same way. Transfer a portion of the sample to a 1-cm absorption cell, and measure the absorbance at the optimum wavelength (Section 6.2.1). Measure and subtract the reagent blank absorbance reading, if any, to obtain a net reading. If the absorbance of the sample exceeds the absorbance of the 100 ug Cr^{+6} standard as determined in Section 6.2.2, dilute the sample and the reagent blank with equal volumes of water.

5.6.2 Check for Matrix Effects on the Cr^{+6} Results. Since the analysis for Cr^{+6} by colorimetry is sensitive to the chemical composition of the sample (matrix effects), the analyst shall check at least one sample from each source using the method of additions as follows:

Obtain two equal volume aliquots of the same sample solution. The aliquots should each contain between 30 and 50 ug of Cr^{+6}. Now treat both the spiked and unspiked sample aliquots as described in Section 5.6.1.

Next, calculate the Cr^{+6} mass C_s, in ug in the aliquot of the unspiked sample solution by using the following equation:

$$C_s = C_a \frac{A_s}{A_s}$$

where:

C_a = Cr^{+6} in the standard solution, ug.

A_s = Absorbance of the unspiked sample solution.

A_t = Absorbance of the spiked sample solution.

Volume corrections will not be required since the solutions as analyzed have been made to the same final volume. If the results of the method of additions procedure used on the single source sample do not agree to within 10 percent of the value obtained by the routine spectrophotometric analysis, then reanalyze all samples from the source using this method of additions procedure.

6. <u>Calibration</u>

6.1 Sampling Train. Perform all the calibrations described in Method 5, Section 5.

6.2 Spectrophotometer Calibration.

6.2.1 Optimum Wavelength Determination. Calibrate the wavelength scale of the spectrophotometer every 6 months. The calibration may be accomplished by using an energy source with an intense line emission such as a mercury lamp, or by using a series of glass filters spanning the measuring range of the spectrophotometer. Calibration materials are available commercially and from the National Bureau of Standards. Specific details on the use of such materials are normally supplied by the vendor; general information about calibration techniques can be obtained from general reference books on analytical chemistry. The wavelength scale of the spectrophotometer shall read correctly with ± 5 nm at all calibration points; otherwise, repair and recalibrate the spectrophotometer. Once the wavelength scale of the spectrophotometer is in proper calibration, use 540 nm as the optimum wavelength for the measurement of the absorbance of the standards and samples.

Alternatively, a scanning procedure may be employed to determine the proper measuring wavelength. If the instrument is a double-beam spectrophotometer, scan the spectrum between 530 and 550 nm using the 50 ug CR^{+6} standard solution (Section 4.3.4) in the sample cell and a blank solution in the reference cell. If a peak does not occur, the spectrophotometer is malfunctioning. When a peak is obtained within the 530 to 550 nm range, record and use the wavelength at which this peak occurs as the optimum wavelength for the measurement of absorbance of both the standards and the samples. For single-beam spectrophotometer, follow the scanning procedure described above, except scan the blank and standard solutions separately. For this instrument, the optimum wavelength is the wavelength at which the maximum difference in absorbance between the standard and the blank occurs.

6.2.2 Spectrophotometer Calibration. Alternative calibration procedures are allowed, provided acceptable accuracy and precision can be demonstrated. Add 0.0 ml, 1 ml, 2 ml, 5 ml, 10 ml, 15 ml, and 20 ml of the working standard solution (1 ml = 5 ug Cr^{+6}) to a series of seven 100-ml volumetric flasks. Dilute each to mark with water. Analyze these calibration standards as in Section 5.6.1. Repeat this calibration procedure on each day that samples are analyzed. Calculate the spectrophotometer calibration factor K_c as follows:

$$K_c = 5\,\frac{A_1 + 2A_2 + 5A_3 + 10A_4 + 15A_5 + 20A_6}{A_1^2 + A_2^2 + A_3^2 + A_4^2 + A_5^2 + A_6^2}$$

where:

K_c = Calibration factor.

A_1 = Absorbance of the 5 ug Cr^{+6}/100 ml standard.

A_2 = Absorbance of the 10 ug Cr^{+6}/100 ml standard.

A_3 = Absorbance of the 25 ug Cr^{+6}/100 ml standard.

A_4 = Absorbance of the 50 ug Cr^{+6}/100 ml standard.

A_5 = Absorbance of the 75 ug Cr^{+6}/100 ml standard.

A_6 = Absorbance of the 100 ug Cr^{+6}/100 ml standard.

6.2.2.1 Spectrophotometer Calibration Quality Control. Multiply the absorbance value obtained for each standard by the K_c factor (least squares slope) to determine the distance each calibration point lies from the theoretical calibration line. These calculated concentration values shall not differ from the actual concentrations (i.e., 5, 10, 25, 50, 75, and 100 ug Cr^{-6}/100 ml) by more than ___ percent (to be determined) for five of the six standards.

7. Emission Calculations

Carry out the calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculations.

7.1 Total Cr^{-6} in Sample. Calculate m, the total ug Cr^{-6} in each sample, as follows:

$$m = \frac{V_{ml} K_c A F}{V_a}$$

where:

V_{ml} = Volume in ml of total sample.

A = Absorbance of sample.

F = Dilution factor (required only if sample dilution was needed to reduce the absorbance into the range of calibration).

V_a = Volume in ml of aliquot analyzed.

7.2 Average Dry Gas Meter Temperature and Average Orifice Pressure Drop. Same as Method 5, Section 6.2.

7.3 Dry Gas Volume, Volume of Water Vapor, Moisture Content. Same as Method 5, Sections 6.3, 6.4, and 6.5, respectively.

7.4 Cr^{+6} Emission Concentration. Calculate c_s (g/dscm), the Cr^{+6} concentration in the stack gas, dry basis, corrected to standard conditions, as follows:

$$c_s = (10^{-6} g/ug)\ [m/V_m(std)]$$

7.5 Isokinetic Variation, Acceptable Results. Same as Method 5, Sections 6.11 and 6.12, respectively.

ATTACHMENT 2.

EMTIC CONDITIONAL TEST METHOD
DETERMINATION OF CHROMIUM EMISSIONS FROM CHROMIUM ELECTROPLATERS

Determination of Chromium Emissions from Chromium Electroplaters

1. APPLICABILITY AND PRINCIPLE

1.1 **Applicability.** This method is used to determine the concentration of chromium emissions from chromium electroplaters and anodizing operations using a chromic acid bath. If correctly applied, the results will be as accurate as those obtained by a modified Method 5 train.

1.1.1 **Method Requirements.** This method requires ambient moisture, air and temperature. Particle size must be less than 10 micrometers in diameter. The probe is not heated.

1.1.2 **Vacuum.** A minimum vacuum of 15 in. Hg or 0.47 atmosphere between the critical orifice and pump is required to maintain critical flow.

1.2 **Principle.** The chromium emissions are collected in a probe and impinger at a constant sampling rate determined by a critical orifice. The concentration is determined by wet chemistry and visible spectrophotometry.

2. APPARATUS

Note: Mention of trade names or specific products does not constitute endorsement by the Environmental Protection Agency.

2.1 **Sampling Train.** A schematic of the sampling train is shown in Figure 1. The components of the train are available commercially but some fabrication and assembly are required.

2.1.1 **Probe Nozzle/Liner and Sheath.** Approximately 1/4" ID glass or rigid plastic tubing with a short 90 degree bend to form the nozzle/liner assembly. Grind a slight taper on the nozzle end before making the bend. Select tubing of sufficient length to collect a sample from the stack. Use a piece of larger diameter rigid tubing (metal or plastic) to form a sheath that encases the nozzle/liner from the right angle bend of the nozzle/liner to the end of the nozzle/liner.

2.1.2 **S-Type Pitot.** Velocity probe as specified in Method 2.

2.1.3 **Sample Line.** Thick wall flexible "Tygon" tubing about 1/4" to 3/8" ID to connect the train components. A combination of rigid plastic tubing and thin wall flexible tubing may be used as long as neither tubing collapses when leak checking the train. Metal tubing cannot be used.

2.1.4 Impinger. One quart capacity "Mason" glass jar with vacuum seal lid. Install leak tight inlet and outlet tubes for assembly with train. The tubes may be made of approximately 1/4"ID glass or rigid plastic. Size the inlet tube so that the lower end is about 1/4" above the bottom of the jar when assembled. Seal the bottom end of the tube and provide 4 holes 1/8" in diameter in the side of the tubing as close to the bottom of the "Mason" jar as possible. Two impingers are required, one for the collecting reagent and one for the drying agent. Locate outlet tube end about 1/2 " beneath the bottom of the lid.

2.1.5 Manometer. Inclined, to read water column to 1/100 inch for the first inch and 1/10 inch thereafter. Range 0 - 6 inches.

2.1.6 Orifice Meter. Small diameter, approximately 1/8", brass tubing sealed inside larger diameter, approximately 3/8", brass tubing to serve as a critical orifice giving a constant sample flow of about 0.75 cfm.

2.1.7 Connecting Hardware. Standard pipe and fittings, 1/4" or 1/8", to install vacuum pump and dry gas meter in train.

2.1.8 Pump Oiler. Glass oil reservoir with wick mounted at pump inlet to lubricate pump vanes.

2.1.9 Vacuum Pump. "Gast" sliding vane mechanical pump suitable to deliver a minimum of 26 in. Hg vacuum and 2.0 cfm.

2.1.10 Dry Gas Meter. Residential 175 cubic feet per hour (CFH) capacity dry gas meter with thermometer installed to monitor meter temperature.

2.2 Sample Recovery.

2.2.1 Wash Bottles. Glass or inert plastic, 1000 ml, with spray tube.

2.2.3 Sample Container. The first "Mason" jar is the sample container.

2.3 Analysis.

2.3.1 Beakers. Glass, 250 ml, with watchglass covers.

2.3.2 Volumetric Flasks. Glass, 25, 100, and 1000 ml.

2.3.3 Hot Plate - Stirrer. 120° to 400°C, with inert stir bar.

2.3.4 Pipettes. Glass, volumetric type, assorted sizes as needed.

2.3.5 Spectrophotometer. To measure visible absorbance at 540 nanometers, with sample and reference cuvettes.

3. REAGENTS

3.1 Sampling and Sample Recovery.

3.1.1 Water. Deionized distilled.

3.1.2 Sodium Hydroxide Solution. 0.1 N. Dissolve 4.00 g of sodium hydroxide (NaOH) in reagent water and dilute to 1 liter.

3.1.3 Sulfuric Acid. 0.5 N. Add 14.0 ml of concentrated sulfuric acid (H_2SO_4) to reagent water in a 1 liter flask, dilute to mark.

3.1.4 Sulfuric Acid. 6 N. Add 167.0 ml of concentrated sulfuric acid (H_2SO_4) to reagent water in a 1 liter flask, dilute to mark.

3.1.5 Potassium Dichromate Stock Solution. Dissolve 141.4 mg of analytical reagent grade $K_2Cr_2O_7$ in reagent water and dilute to 1 liter (50 μg CR^{+6}/ml).

3.1.6 Potassium Chromate Standard Solution. Dilute stock K_2CRO_4 solution 1:10 with reagent water (5μg Cr^{+6}/ml).

3.1.7 Diphenylcarbazide Solution. Dissolve 250 mg 1,5-diphenylcarbazide in 50 ml of reagent acetone. Store in amber bottle; discard when solution becomes discolored.

4. PROCEDURE

4.1 Sampling.

4.1.1 Pretest Preparation.

4.1.1.1 Port Location. Locate ports as specified in Section 2 of Method 1. Use a total of 24 sampling points for round ducts and 24 or 25 points for rectangular ducts. Mark the pitot and sampling probe with thin strips of tape to permit velocity and sample traversing.

4.1.1.2 Velocity Traverse. Perform a velocity traverse before obtaining samples. If testing occurs over several days, perform the traverse at the beginning of each each day. At the end of the test effort, perform a final traverse. Perform traverses as specified in Section 3 of Method 2, but record the Δp (velocity head) values only. Check the stack temperature before and after recording the Δp values and use the average of the two temperatures for the stack temperature. Enter the Δp values for each point. Check for cyclonic flow during the first traverse to verify that cyclonic flow does not exist, or if cyclonic flow does exist, make sure that the absolute average angle of misalignment does not exceed 20 degrees. If the average angle of misalignment exceeds 20 degrees at an outlet location, install straightening vanes to eliminate the cyclonic flow. If it is necessary to test the inlet location and cyclonic flow does exist, it may not be possible to install straightening vanes.

In this case, a variation of the alignment method must be used. This must be approved by the Administrator.

4.1.1.3 Point Sampling Times. Since the sampling rate of the train is constant, it is necessary to calculate specific sampling times for each point in order to obtain a proportional sample. If all sampling can be completed in a single day, it is necessary to calculate the point times only once. If sampling occurs over several days, calculate the point sample times for each day using velocity traverse data obtained earlier in the day.

Determine the average of the Δp values obtained during the velocity traverse. Calculate the sampling times for each point using the equation:

$$Minutes\ at\ point = \sqrt{\frac{Point\ \Delta p}{Average\ \Delta p}} \times 5\ minutes \qquad \text{Eq. 1}$$

Convert decimal parts of minutes to seconds.

4.1.1.4 Gas Molecular Weight. It is not necessary to determine the stack gas molecular weight by Method 3. Use 28.95 for the dry molecular weight of air.

4.1.1.5 Gas Moisture Content. Use the approximation method specified in Section 3 of Method 4 to determine moisture content. Use a wet bulb-dry bulb psychrometer, a relative humidity indicator, or call the local weather bureau.

4.1.1.6 Preparation of Sampling Train. Assemble the sampling train as shown in Figure 1. Secure the nozzle-liner assembly to the sheath to prevent slipping when sampling. Put 250 ml of 0.1 N sodium hydroxide solution into the first impinger. Put silica gel into the second impinger until the impinger is half full. Place both impingers into an ice bath and check to ensure that the lids are tight.

4.1.1.7 Train Leak Check Procedure. Before the run, wait until the ice has cooled the impingers. Next, seal the nozzle and turn on the pump. Observe any leak rate on the dry gas meter. The leak rate should not exceed 0.02 cfm.

4.1.2 Sampling Train Operation.

4.1.2.1 Record all pertinent process and sampling data on the data sheet (see Figure 3). Ensure that the process operation is suitable for sample collection.

4.1.2.2 Place the probe/nozzle into the duct at point 1 and turn on the pump. Sample for the number of minutes and seconds previously determined

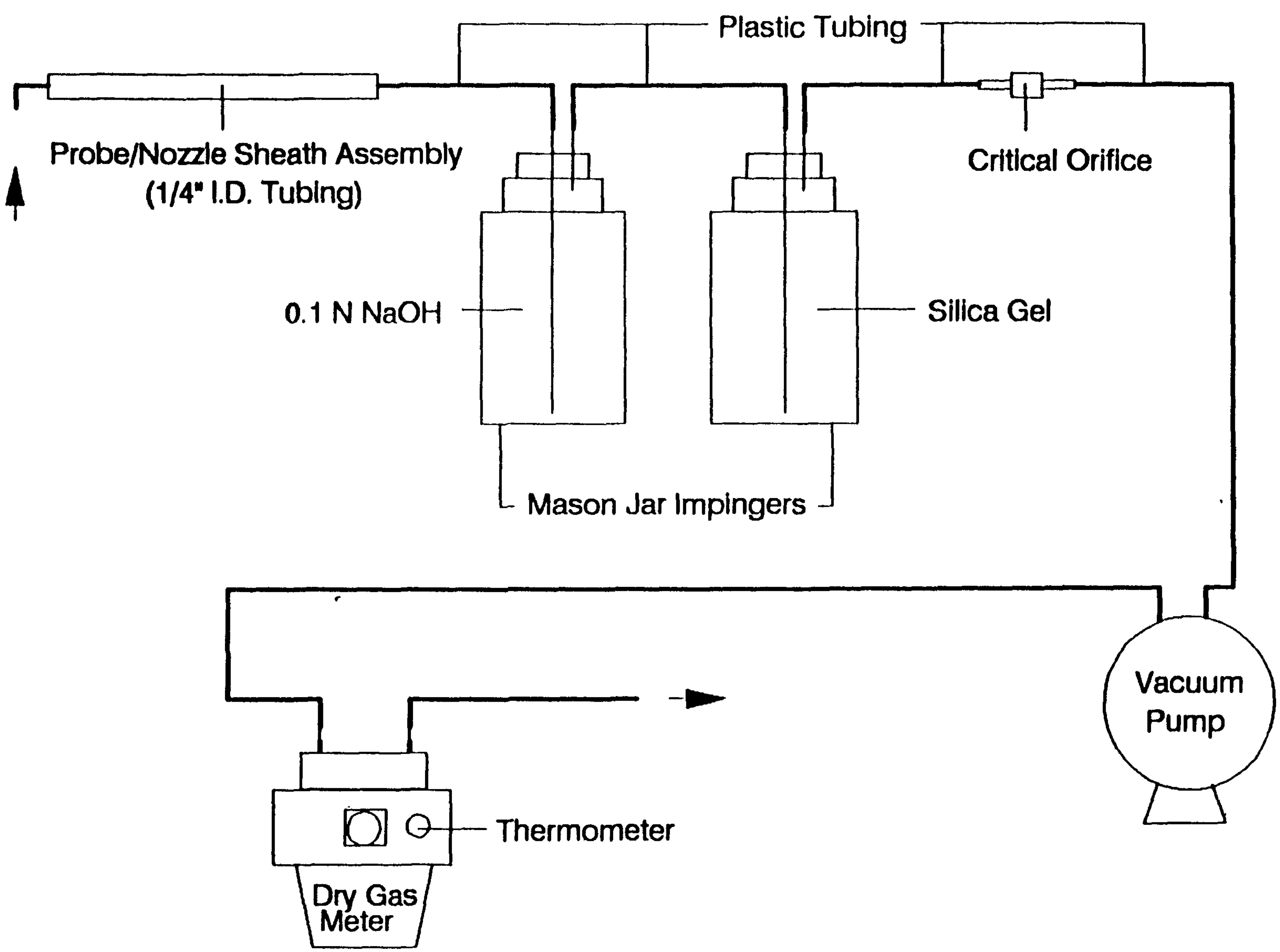

Figure D-2. Sampling train schematic.

Plant ____________________

Date ____________ Time ____________

Location ____________________

Stack ID __________

Operator(s) ____________________

SCHEMATIC OF POINTS

Barometric Pressure (in. Hg) __________ Static Pressure (in. H2O) ________

% Moisture ____________________ or % Relative Humidity __________

RUN: BEFORE RUN 1 ____ RUN 2 ____ RUN 3 ____ AFTER RUN 3 ____

TRAVERSE POINT NUMBER	* POINT LOCATION	* CYCLONIC ANGLE DEGREES	STACK TEMP. (F)	VELOCITY HEAD (Δp IN H2O)	SAMPLE TIME (MIN/SEC)

AVERAGES:				

(OPTIONAL) STACK ACTUAL CFM ______________ * FIRST TRAVERSE ONLY

Figure D-3. Chromium velocity traverse data.

Plant ______________________ Date ________ Run Number __________

Sampling Site ______________________ Operator ______________________

Total micrograms catch (mCr) __________ Stack radius (r) ______________________

Avg dry gas meter temp F (Tm) __________ Avg delta p (Δp avg) __________

Meter correction factor (Ym) __________ Stack temp F (Ts) __________

Meter volume - actual cu ft (Vm) __________ Leak rate before run __________

Barometric pressure in. Hg (Pbar) __________ Leak rate after run __________

Start clock time ______________________ Stop meter volume __________

Stop clock time ______________________ Start meter volume __________

REMARKS: ____

POINT NO.	SAMPLE (MIN/SEC)	GAS METER TEMP (F)

POINT NO.	SAMPLE (MIN/SEC)	GAS METER TEMP (F)

$$Cs = \frac{m\,Cr\,(Tm + 460)}{499.8\,(Ym)\,(Vm)\,(Pbar)}$$

$$Kg/Hr = (Cs)\,0.0001597\,r^2 \sqrt{\frac{\Delta p\ avg\,(Ts + 460)}{Pbar\,(28.73)}}$$

Mg/Cubic Meter (Cs) ______________ (Optional) Kg/Hr ______________

Figure D-4. Chromium constant sampling rate field data.

for that point. Sample all points on the traverse in this manner. Keep ice around the impingers during the run. Complete the traverse and turn off the pump. Move to the next sampling port and repeat. Record the final dry gas meter reading.

4.1.2.3 Post Test Leak Check. Remove the probe assembly and flexible tubing from the first impinger. Do not cover the nozzle. Take the probe assembly and flexible tubing to the sample recovery area. Seal the inlet tube of the first impinger and turn on the pump. Observe any leak rate on the dry gas meter. If the leak rate exceeds 0.02 cfm, reject the run. If the run is acceptable, take the remainder of the train to the sample recovery area.

4.2 Sample Recovery.

4.2.1 After the train has been moved to the sample recovery area, disconnect the tubing that joins the first impinger with the second.

4.2.2 The first impinger jar is also used for the sample collection jar. Unscrew the lid from the impinger jar. Lift the assembly almost out of the jar, and using the wash bottle, rinse the outside of the impinger tip that was immersed in the impinger jar. Rinse the inside of the tip as well.

4.2.3 Hold the probe and connecting plastic tubing in a vertical position so that the tubing forms a "U". Using the wash bottle, partially fill the tubing with 0.1 N NaOH. (Keep a minimum of 100 ml of the 0.1 N NaOH for a blank analysis). Raise and lower the end of the plastic tubing several times to cause the NaOH solution to thoroughly contact the major portion of the internal parts of the assembly. Do not raise the solution level too high or part of the sample will be lost. Place the nozzle end of the assembly over the mouth of the "Mason" jar and elevate the plastic tubing so that the solution flows rapidly out of the nozzle. *Perform this procedure three times.*

4.2.4 Remove the plastic tubing from the probe. Hold both ends in a vertical position so that the tubing forms a "U". Partially fill the tubing with 0.1 N NaOH solution. "Rock" the tubing back and forth to move the solution through the tubing toward the ends, being careful not to overflow the solution. Place the end of the tubing that was connected to the first impinger over the opening of the Mason jar and elevate the other end of the tubing, causing the tubing contents to flow rapidly into the jar. Perform the entire procedure three times.

4.2.5 Place a piece of "Saran" wrap over the mouth of the impinger jar. Use a standard lid and band assembly to seal the jar. Label the jar with the sample number and mark the liquid level to gauge any losses during handling.

4.3 Analysis.

4.3.1 Color Development and Measurement. After checking the sample for any losses transfer a 50 ml or smaller measured aliquot to a 100 ml volumetric flask and add water to make about 80 ml. Adjust the pH to 2 ± 0.5 with 6 N H_2SO_4. Add 2.0 ml diphenylcarbazide solution to the volumetric flask with the sample and the sample blank. Dilute to the mark to obtain 100 ml with 0.5 N H_2SO_4. Shake to mix and let stand approximately 10 minutes to allow color development.

Set the wavelength on the spectrophotometer to 540 nm (see Section 6.2.1). Zero using an aliquot of the 0.0 µg Cr^{+6} ml standard (see Section 6.2.2) in a cuvette. Transfer a portion of the sample and the sample blank to another cuvette and measure the absorbances. Record on an appropriate data sheet (see Figure 4). The sample blank absorbance is subtracted from the sample reading in calculating the mass of Cr^{+6} in the sample. If the absorbance of the sample exceeds the absorbance of the 100 µg Cr^{+6} standard as determined in Section 6.2.2, dilute the sample and the sample blank using equal volumes of a 1:1 mixture of 0.5 N H_2SO_4 and 0.1 N NaOH.

4.3.2 **Matrix Effects Check.** Since the analysis for Cr^{+6} by colorimetry is sensitive to certain chemical compounds in the sample matrix, the analyst shall check at least one sample from any source suspected of having nickel in the emissions using the method of additions as follows:

Obtain two equal volume aliquots of the same sample solution. The aliquots should each contain between 30 and 50 µg of Cr^{+6}, but may contain less if this is not possible. Spike one of the aliquots with the same volume aliquot of standard solution that contains between 30 and 50 µg of CR^{+6}. Prepare and analyze both the spiked and the unspiked sample aliquots as described in Section 4.3.1.

Calculate the CR^{+6} mass C_s, in µg in the aliquot of the unspiked sample solution with the following equation:

$$C_s = C_a \frac{A_s}{A_t - A_s} \qquad \text{Eq. 2}$$

Where:

C_a = Cr^{+6} in the standard solution, µg.

A_s = Absorbance of the unspiked sample solution.

A_t = Absorbance of the spiked sample solution.

Volume corrections will not be required since the solutions as analyzed have been made to the same final volume. If the results of the method of additions procedure used on the single source sample do not agree to within 10 percent of the value obtained by the routine spectrophotometric analysis, then reanalyze all samples from the source using this method of additions.

5. CALIBRATION

5.1 **Dry Gas Meter.** Calibrated by manufacturer or as specified in Method 5.

5.2 **Spectrophotometer.**

5.2.1 **Optimum Wavelength Determination.** Calibrate the wavelength scale of the spectrophotometer every 6 months. A scanning procedure may be employed to determine the proper wavelength. If the instrument is a double-beam spectrophotometer, scan the spectrum between 530 and 550 nm using a 50 μg CR^{+6} standard solution in the sample cell and the H_2SO_4 sample blank solution in the reference cell. If a peak does not occur, the spectrophotometer is malfunctioning and should be repaired. When a peak is obtained within the 530 to 550 nm range, the wavelength at which this peak occurs shall be the optimum wavelength for the measurement of absorbance of both the standards and the samples. For a single-beam spectrophotometer, follow the scanning procedure described above, except that the blank and standard solutions shall be scanned separately. The optimum wavelength shall be the wavelength at which the maximum difference in absorbance between the standard and the blank occurs.

5.2.2 **Spectrophotometer Calibration.** Alternative calibration procedures are allowed provided acceptable accuracy and precision can be demonstrated. Pipet 0, 1, 2, 5, 10, 15, and 20 ml (1 ml = 5 μg Cr^{+6}) of the working standard solution into a series of seven 100-ml volumetric flasks. Add 2.0 ml diphenylcarbazide solution to each and a sufficient amount of a 1:1 mixture of 0.5 N H_2SO_4 and 0.1 N NaOH to bring the volume to 100 ml. These working standards contain 0 to 100 μg Cr^{+6}. Analyze these calibration standards as in Section 4.3.1. This calibration procedure must be repeated on each day that samples are analyzed. Prepare or calculate a linear regression plot to the standard masses in μg Cr^{+6} (x-axis) versus absorbance (y-axis). From this curve or equation, determine the reciprocal of the slope and denote as the calibration factor, K_c. The absolute value of the correlation coefficient, r, for the regression line should be greater than 0.999.

6. CALCULATIONS

6.1 **Pollutant Concentration.** Calculate the concentration (C_s) of hexavalent chrome in milligrams per dry standard cubic meter (dscm) as follows:

$$C_s = \frac{m_{cr} \times (T_m + 460)}{499.8\ (Y_m)\ (V_m)\ (P_{bar})} \qquad \text{Eq. 3}$$

Where:

m_{cr} = Total micrograms of Cr^{+6} in sample.

T_m = Dry gas meter temperature in °F.

Y_m = Dry gas meter correction factor.

V_m = Dry gas meter volume in ft^3

P_{bar} = Barometric pressure in inches Hg.

Plant____________________ Date of Analysis ____________________

Location ________________ Sample Number ____________________

Spectrophotometer ________ Analyst ________________________

Wavelength for Analysis ______

Calibration Factor * Analysis

Std. Mass ug Cr +6	Absorbance A
0.0	
5.0	
10.0	
25.0	
50.0	
75.0	
100.0	

* Calibration Factor (Kc) = Reciprocal of calibration line slope

Kc = ________

Absolute value of correlation coefficient for the calibration line must be greater than 0.999

Sample Analysis

Sample Number	Absorbance S	Dilution Factor F	Blank Asb. B	Micrograms Cr +6 in Sample M[a]

[a]M = Kc (S - B) F

Figure D-5. Chromium analytical data.

6.1.1 (Optional) Approximate Mass Emission Rate. Calculate an approximate mass emission rate in kilograms per hour using the following equation:

$$Kg/hr = 0.0001597 \ r^2 \sqrt{\frac{\Delta p_{ave} \ (T_s + 460)}{P_{bar} \ (28.73)}} x \ C_s \qquad \text{Eq. 4}$$

Where:

r = Radius of stack in inches.

Δp_{ave} = Average of Δp values.

T_s = Stack temperature in °F.

P_{bar} = Barometric pressure in inches Hg.

C_s = Concentration of hexavalent chromium in mg/dscm.

7. BIBLIOGRAPHY

1. F. R. Clay, Impinger Collection Efficiency - Mason Jars vs. Greenburg-Smith Impingers, Dec. 1989.

2. Robin Segal, Draft Screening Method for Emissions from Chromium Plating Operations, Entropy Environmentalists, Jan. 1988.

APPENDIX E.

MODEL PLANT PRODUCTION RATE CALCULATIONS

APPENDIX E.

MODEL PLANT PRODUCTION RATE CALCULATIONS

This appendix contains the calculations used to determine the electrochemical equivalent of chromium at a 10 percent cathode efficiency, and the subsequent model plant production rate calculations for hard and decorative chromium plating operations.

E.1 DETERMINATION OF ELECTROCHEMICAL EQUIVALENT

EQUATIONS FOR CALCULATING THE ELECTROCHEMICAL EQUIVALENT FOR CHROMIUM

Definition: The electrochemical equivalent is defined as the amount of current required to plate a part with a surface area of 1 square foot with a plate thickness of 1 mil at a cathode efficiency of 100 percent.

Equation 1: $\text{Plate thickness} = \dfrac{\text{(weight of chromium)}}{\text{(density of chromium)(surface area plated)}}$

Faraday's Law: During electrolysis 96,487 coulombs (ampere-seconds) of electricity reduce and oxidize, respectively, 1 gram-equivalent of the oxidizing and the reducing agent.

Equation 2: 96,487 ampere-seconds (A·s) are required to deposit the (metal's atomic weight)/(valence) in grams (use 96,500).

ASSUMPTIONS:

Plate thickness = 1 mil
Surface area of part = 1 square foot
Cathode efficiency = 100 percent

GIVEN:

Density of water = 62.43 lb/ft^3
Specific gravity of Cr = 7.1
Cr valence = +6
Atomic weight of Cr = 52

By rearranging equation 1,

Weight of chromium = (thickness)(density of Cr)(surface area plated)

Weight of chromium = (0.001 in./12 in./ft)(7.1)(62.43 lb/ft^3)(1 ft^2)

Weight of chromium = 0.0369 lb = 16.74 grams

Using equation 2,

$$\frac{96{,}500 \text{ A}\cdot\text{s}}{52 \text{ grams}/{+6}} = \frac{\text{X A}\cdot\text{s}}{16.74 \text{ grams}} \qquad x = 186{,}400 \text{ A}\cdot\text{s}$$

Converting ampere-seconds to ampere-hours,

$\dfrac{186{,}400 \text{ A}\cdot\text{s}}{3{,}600 \text{ sec/hr}} =$ 51.8 Ah is required to plate a part with a surface area of 1 square foot and a plate thickness of 1 mil at a cathode efficiency of 100 percent.

Correction for cathode efficiency of 10 percent for hexavalent chromium,

(51.8)(10.0) = 518 ampere-hours required to plate a part with a surface of 1 square foot and a plate thickness of 1 mil at a cathode efficiency of 10 percent.

E.2 HARD CHROMIUM PLATING PRODUCTION RATE CALCULATIONS

TABLE E-1. AVERAGE SURFACE AREA-TO-VOLUME RATIOS FOR HARD CHROMIUM PLATING OPERATIONS TESTED DURING THE EMISSION TEST PROGRAM

Plant	Tank No.	Capacity, ft^3	Average surface area plated, ft^2	Surface area-to-volume ratio, ft^2/ft^3
Steel Heddle	1	94	5.63	0.06
	2	45	4.08	0.09
	4	43	4.64	0.11
Roll Technology	1	161	7.14	0.04
	2	302	11.48	0.04
	3	486	13.81	0.03
	7	324	5.59	0.02
Greensboro Industrial Platers	1	347	18.29	0.05
Able Machine Company	1	532	34.74	0.07
Average				0.06

HARD CHROMIUM PLATING MODEL TANKS

Tank No.	Dimensions, l, w, d (ft)	Capacity, ft^3 (gal)
1	12, 3.5, 6.0	231 (1,728)
2	12, 4.0, 6.0	264 (1,975)
3	25, 3.0, 6.0	413 (3,089)
4	4.0, 4.0, 10.0	152 (1,137)

Surface area plated in each tank calculated by using factor of 0.06 ft^2/ft^3 from Table E-1:

Tank No.	Capacity, ft^3	Volume factor, ft^2/ft^3	Surface area plated, ft^2
1	231	0.06	14.0
2	264	0.06	16.0
3	413	0.06	25.0
4	152	0.06	9.0

Process parameter assumptions:
  Plating thickness = 1 mil
  Plating time = 2 hours

Electrochemical equivalent = $\frac{518\ \text{Ah}}{\text{mil}\cdot\text{ft}^2}$ at 10 percent cathode efficiency

Ampere-hour requirement for each tank to plate the surface area values stated above:

Tank No.	Plating thickness, mils	Electrochemical equivalent, $Ah/mil \cdot ft^2$	Surface area, ft^2	Ah
1	1	518	14.0	7,250
2	1	518	16.0	8,290
3	1	518	25.0	12,950
4	1	518	9.0	4,660

Current settings for each model tank:

Tank No.	Ampere-hour requirements, Ah	Plating time, hr	Current, A
1	7,250	2.0	3,625
2	8,290	2.0	4,145
3	12,950	2.0	6,475
4	4,660	2.0	2,330

Model plant production rates

Small model plant

No. of tanks = 1
Size of tank, (l,w,d), ft = 12, 3.5, 6.0 (Tank 1)
Current setting of tank = 3,625 A
Operating time = 2,000 hr/yr
Percent time electrodes are energized = 70 percent

Ampere-hours/year = (3,625 A)(2,000 hr/yr)(0.70) = 5.0×10^6 Ah/yr

Medium model plant

No. of tanks = 4
Size of tanks (l,w,d), ft = 1 at (4.0, 4.0, 10.0) (Tank 4)
2 at (12.0, 4.0, 6.0) (Tank 2)
1 at (25.0, 3.0, 6.0) (Tank 3)

Current settings = 1 at 2,330 A
2 at 4,145 A
1 at 6,475 A

Operating time = 3,500 hr/yr

Percent time electrodes are energized = 70 percent

Ampere-hours/year = [(2,330 A) + (2)(4,145 A) + (6,475 A)] (3,500 hr/yr)(0.70) = 42.0×10^6 Ah/yr

Large model plant

No. of tanks = 8
Size of tanks (l,w,d), ft = 2 at (4.0, 4.0, 10.0) (Tank 4)
4 at (12.0, 4.0, 6.0) (Tank 2)
2 at (25.0, 3.0, 6.0) (Tank 3)

Current settings = 2 at 2,330 A
4 at 4,145 A
2 at 6,475 A

Operating time = 6,000 hr/yr

Percent time electrodes are energized = 80 percent

Ampere-hours/year = [2(2,330 A) +(4)(4,145 A) + 2(6,475 A)](6,000 hr/yr)(0.80) = 164×10^6 Ah/yr

E.3 DECORATIVE CHROMIUM PLATING PRODUCTION RATE CALCULATIONS

SURFACE AREA-TO-VOLUME RATIO FOR DECORATIVE CHROMIUM PLATING OPERATIONS

GMC-Delco Test Data

No. of tanks =	1
Size of tank (l,w,d,), ft =	(20.0, 12.0, 9.0)
Capacity =	2,040 ft^3 (15,260 gallons)
Tank holds =	Three racks of bumpers
Rack contains =	8 bumpers
Square footage in tank =	(3 racks) (8 bumpers/rack) (8 ft^2/1 bumper) = 192 ft^2

$$\frac{192\ ft^2\ \text{parts}}{2{,}040\ ft^3\ \text{plating solution}} = 0.09\ ft^2/ft^3$$

DECORATIVE CHROMIUM PLATING MODEL TANKS

Tank No.	Dimensions (l, w, d), ft	Capacity, ft^3 (gal)
1	12.0, 3.5, 6.0	231 (1,728)
2	12.0, 6.0, 9.0	612 (4,578)

Surface area plated in each tank calculated by using factor of 0.09 ft^2/ft^3 from above:

Tank No.	Capacity, ft^3	Volume factor, ft^2/ft^3	Surface area plated, ft^2
1	231	0.09	21
2	612	0.09	55

Process parameter assumptions:
  Plate thickness = 0.012 mil
  Plating time = 3.0 minutes = 0.05 hours

Electrochemical equivalent = $\frac{518\ \text{Ah}}{\text{mil}\cdot ft^2}$ at 10 percent cathode efficiency

Ampere-hour requirement for each tank to plate the surface area values stated above:

Tank No.	Plate thickness, mils	Electrochemical equivalent, Ah/mil·ft^2	Surface area, ft^2	Ah
1	0.012	518	21	130
2	0.012	518	55	340

Current settings for each model tank:

Tank No.	Ampere-hour requirement	Plating time, hr	Current, A
1	130	0.05	2,600
2	340	0.05	6,800

Model plant production rates

Small model plant

No. of tanks =	1
Size of tanks (l,w,d,), ft =	(12.0, 3.5, 6.0) (Tank 1)
Current setting of tank =	2,600 A
Operating time =	2,000 hr/yr
Percent time electrodes are energized =	60 percent

Ampere-hours/year = (2,600 A)(2,000 hr/yr)(0.60) = 3.0×10^6 Ah/yr

Medium model plant

No. of tanks =	2
Size of tanks (l,w,d), ft =	2 at (12.0, 3.5, 6.0) (Tank 1)
Current settings =	2 at 2,600 A
Operating time =	4,000 hr/yr

Percent time electrodes are energized = 60 percent

Ampere-hours/year = (2)(2,600 A)(4,000 hr/yr)(0.60) = 12.0×10^6 Ah/yr

Large model plant

No. of tanks =	5
Size of tanks (l,w,d), ft =	5 at (12.0, 6.0, 9.0) (Tank 2)
Current settings =	5 at 6,800 A
Operating time =	6,000 hr/yr

Percent time electrodes are energized = 60 percent

Ampere-hours/year = (5)(6,800 A)(6,000 hr/yr)(0.60) = 122×10^6 Ah/yr

APPENDIX F. DEVELOPMENT OF MODEL PLANT COSTS

APPENDIX F. DEVELOPMENT OF MODEL PLANT COSTS

F.1 CHEVRON-BLADE MIST ELIMINATORS AND PACKED-BED SCRUBBERS

This section presents the capital and annualized costs of chevron-blade mist eliminators and packed-bed scrubbers used to control chromium emissions from the hard and decorative chromium electroplating and chromic acid anodizing model plants. Each model plant is composed of various sized model tanks. The model tanks are arranged into five control device configurations. Schematics of these configurations are shown in Chapter 5 of this document. Table F-1 presents the model plant parameters on which the installed capital and annualized costs are based.

Capital cost estimates for each of five different sizes of mist eliminators and scrubbers specified in the model plants were obtained from three control device vendors (designated as Vendors A, B, and C).[1-3] The vendors also provided operating parameters for mist eliminators and scrubbers (e.g., fan and recirculation pump motor horsepower [hp] requirements, water consumption rates, maintenance hours, and the life expectancy of control devices and scrubber packing material) that were used to calculate annualized costs. The cost estimates presented here are based on Vendor A estimates only, which were the highest cost estimates obtained from the three vendors. Vendor B provided installed capital cost estimates for mist eliminators and scrubbers that ranged from $10,000 to $20,000 lower than those provided by Vendor A. Annualized cost estimates calculated from the control device operating parameters provided by Vendor B ranged from $1,000 to $10,000 lower than the annualized cost estimates calculated from the control device operating parameters provided by Vendor A. Capital cost estimates provided by

Vendor C were incomplete because Vendor C did not provide installation costs.

All cost data presented here are in November 1988 dollars. The capital costs originally received from Vendor A were in October 1986 dollars. These costs were updated to November 1988 dollars by multiplying the costs by the ratio of the Chemical Engineering (CE) plant indices for October 1986 (319.3) and November 1988 (347.8).[4] Data sources used to calculate capital and annualized costs of the pollution control techniques are presented in Table F-2. Cost factors used to calculate annualized costs are presented in Table F-3.

F.1.1 Unit Costs

This section presents the installed capital and annualized cost estimates for each of the five different sizes of mist eliminators and scrubbers specified in the model plants.

F.1.1.1 Capital Costs. Tables F-4 and F-5 present capital costs for chevron-blade mist eliminators with single and double sets of blades, respectively; and Tables F-6 and F-7 present capital costs for single and double packed-bed scrubbers, respectively. Each table presents cost data for each of five different sizes of control devices specified in the model plants.

The capital costs for mist eliminators and packed-bed scrubbers include the purchase cost of the control device and auxiliaries such as exhaust fans, motors, inlet and outlet transitions, and stack; direct installation costs for electrical panels and wiring, instrumentation and controls, and piping; indirect costs for erection, engineering services, contractor fees, and contingencies; and startup costs. Installation costs are based on the assumptions that the control device would be installed on the roof of the plating shop, the roof is 6.1 m (20 ft) high, and the roof would require no major structural modifications to support the weight of the control device. Erection costs include the cost of renting a crane to hoist the control device onto the roof of the shop. The purchased equipment cost also includes taxes and freight costs, which are assumed to be 3 and 5 percent of the base equipment cost, respectively.[5] The startup cost is assumed to be 1 percent of the purchased equipment cost.[5]

F.1.1.2 Annualized Costs. Tables F-8 and F-9 present annualized costs for chevron-blade mist eliminators with single and double sets of blades, respectively, and Tables F-10 and F-11 present annualized costs for single and double packed-bed scrubbers, respectively. The annualized costs include direct operating costs such as utilities; operator, supervisor, and maintenance labor and materials; indirect operating costs such as overhead, property taxes, insurance and administration; and capital recovery costs. The annualized costs of packed-bed scrubbers also includes the cost of scrubber packing replacement and disposal.

Utility costs include the costs of electricity and water required to operate mist eliminators and packed-bed scrubbers. The annual electrical cost attributable to pollution control results from the additional fan horsepower needed to overcome the pressure drop added to the ventilation system by the control device and the horsepower needed to operate the scrubber recirculation pumps. The incremental fan and recirculation pump electrical costs were calculated using the following equation:

$$\text{Electrical cost, \$/yr} = [(\frac{0.746\ \text{kW}}{\text{hp}})(\text{hp})(\text{t})][\text{C}]$$

where:

kW = kilowatt;

hp = horsepower of pump motor or incremental horsepower of fan motor;

t = operating time, hr/yr; and

C = electricity cost, \$0.0461 kWh.[6]

For example, the single packed-bed scrubber that is sized for an exhaust gas flow rate of 280 actual m^3/min (10,000 actual ft^3/min) (Column A in Table F-10) requires an additional 5 hp to operate the fan, and the scrubber operates 6,000 hr/yr.

Therefore, the incremental annual electrical cost to operate the fan is:

$$\left(\frac{0.746\ \text{kW}}{\text{hp}}\right)(5\ \text{hp})\left(\frac{6,000\ \text{hr}}{\text{yr}}\right)\left(\frac{\$0.0461}{\text{kWh}}\right) = \$1,030/\text{yr}.$$

In addition, the single packed-bed scrubber requires a 1-hp pump to recirculate the scrubber water. The annual electrical cost to operate the pump is:

$$\left(\frac{0.746\ \text{kW}}{\text{hp}}\right)(1\ \text{hp})\left(\frac{6,000\ \text{hr}}{\text{yr}}\right)\left(\frac{\$0.0461}{\text{kWh}}\right) = \$210/\text{yr}.$$

Therefore, the total annual electrical cost for the scrubber is $1,240/yr.

Water consumption costs are associated with the washdown of mist eliminators and the operation of scrubbers. For the purposes of this analysis, it was assumed that water for washdown of mist eliminators is recycled to the process, as is typically the case. Scrubber water also was assumed to be recirculated for 8 hours of operation, at which time the water in the recirculation basin is drained to the process and the basin is replenished with clean water. Water costs were calculated using the following equations:

(1) Mist eliminators

Water cost, $/yr = [(V)(N)(S)][C]

where:

V = volume of washdown water, L (gal);
N = number of washdowns per 8-hour shift;
S = number of 8-hour shifts per year; and
C = water cost, $0.20/1,000 L ($0.77/1,000 gal).[7]

(2) Scrubbers

Water cost, $/yr = [(V)(f)+(FR)(60 min/hr)(t)][C]

where:

V = recirculation tank volume, L (gal);
f = frequency of washdowns, number per year;
FR = makeup water flow rate, L/min (gal/min);
N = number of times per year water is replaced (t/8 hr);
t = operating time, hr/yr; and

C = water cost, \$0.20/1,000 L (\$0.77/1,000 gal).[7]

For example, for the single packed-bed scrubber used in the examples above, the recirculation tank volume is 450 L (120 gal); the makeup water flow rate is 5.7 L/min (1.5 gal/min); the scrubber is operated 6,000 hr/yr; and the scrubber water is drained to the process and replaced with clean water every 8 hours of operation, or 750 times per year. Therefore, the annual water cost for this unit is:

$$[(120\ \text{gal})(750) + (\frac{1.5\ \text{gal}}{\text{min}})(\frac{60\ \text{min}}{\text{hr}})(\frac{6,000\ \text{hr}}{\text{yr}})][\frac{\$0.77}{1,000\ \text{gal}}] = \$490/\text{yr}.$$

The total annual cost of utilities for the scrubber is equal to the sum of the annual electrical and water costs, which is \$1,730/yr.

Scrubber packing material replacement costs were included in annualized scrubber costs because the life of the packing material is less than the life of the control device. Vendor A estimates that most facilities will probably need to replace the packing material every 10 years. The packing material costs approximately \$600/m^3 (\$17/ft^3) of material.[8] Annualized packing material replacement costs include the replacement cost of the packing and the transportation and disposal costs associated with the used packing. The replacement costs of the packing material were calculated based on the following equation:

$$\text{Replacement cost, \$/yr} = [(v)(c)][CRF_p]$$

where:

v = volume of packing required for each control device, m^3 (ft^3);

c = cost of packing material, \$620/m^3 (\$17/ft^3)[8]; and

CRF_p = capital recovery factor of 0.1628, based on an interest rate of 10 percent and a depreciable life of 10 years for the packing.

The transportation and disposal costs for the packing material were calculated based on the following equation:

$$\text{Disposal and transportation cost, \$/yr} = [(N)(dc) + (N)(tc)][CRF_p]$$

where:

- N = number of 55-gal drums, V/V_d, rounded to the nearest whole number;
- V = volume of packing material disposed for each control device, m^3 (ft^3) (see Tables F-6 and F-7);
- V_d = volume of 55-gal drum, 0.21 m^3 (7.35 ft^3);
- dc = disposal cost, $50.00/drum[9];
- tc = transportation cost, $40.00/drum[9]; and
- CRF_p = capital recovery factor of 0.1628, based on an interest rate of 10 percent and a depreciable life of 10 years for the packing material.

The annual cost of operating labor is based on the amount of labor required to operate the control device plus supervision. The operator labor is based on vendor estimates for labor hours required per day of operation, and a labor rate of $8.37/hour.[10] It was assumed that 0.25 hour per day of operator labor is required for chevron-blade mist eliminators, and 0.5 hour per day of operator labor is required for packed-bed scrubbers. The operator labor is independent of the control device size and the number of operating hours per day. The supervisor labor cost is assumed to be 15 percent of the operator labor cost.[5]

The annual cost of maintenance labor for each control device is based on vendor estimates of the maintenance hours required per 2,000 hours of operation and a maintenance labor rate of $9.21/hr.[10,11] The annual cost of materials is assumed to be 100 percent of the maintenance labor cost.[5]

Indirect costs include overhead, property taxes, insurance, and administration. The overhead cost was calculated based on 60 percent of the operator, supervisor, and maintenance labor plus any material costs.[5] Property taxes, insurance, and administration were assumed to be 4 percent of the total capital cost.[5]

Capital recovery costs, which are the costs of capital spread over the depreciable life of the control device, were calculated using the following equation:[5]

$$CRC = [TCC][(i\{1 + i\}^n)/(\{1 + i\}^n - 1)]$$

where:

CRC = capital recovery cost, \$/yr;

TCC = total capital cost, \$;

i = annual interest rate, 10 percent; and

n = depreciable life, 20 years.

F.1.2 <u>Model Plant Costs</u>

This section presents the installed capital and annualized costs of chevron-blade mist eliminators and packed-bed scrubbers for the hard and decorative chromium plating and chromic acid anodizing model plants. The model plant costs are representative of control costs for new sources. The capital costs for ventilation hoods and ductwork were not included in the capital costs for control devices because plants must typically install ventilation hoods and ductwork to comply with occupational health standards that regulate employee exposure to chromium emissions in the workplace.

F.1.2.1 <u>Capital Costs</u>. Tables F-12 through F-14 present the purchased equipment, installation, startup, and total capital costs of chevron-blade mist eliminators and packed-bed scrubbers for the hard and decorative chromium plating and chromic acid anodizing model plants. The capital cost estimates were compiled from Tables F-4 through F-7 as described below.

<u>Hard Chromium Plating</u>

Small model plant = Column B costs

Medium model plant = Column D costs

Large model plant = 2(Column D) costs

Decorative Chromium Plating

Small model plant = Column B costs

Medium model plant = 2(Column B) costs

Large model plant = 2(Column C) + Column A costs

Chromic Acid Anodizing

Small model plant = Column B costs

Large model plant = Column E costs

F.1.2.2 Annualized Costs. The annualized costs for the model plants are presented in Tables F-15 through F-17. The annualized cost estimates, with the exception of the labor requirements and indirect costs, were compiled from Tables F-8 through F-11 as described below.

Hard Chromium Plating

Small model plant = Column B_1 costs

Medium model plant = Column D_1 costs

Large model plant = 2(Column D_2) costs

Decorative Chromium Plating

Small model plant = Column B_1 costs

Medium model plant = 2(Column B_2) costs

Large model plant = 2(Column C) + Column A costs

Chromic Acid Anodizing

Small model plant = Column B_1 costs

Large model plant = Column E costs

The operator, supervisor, and maintenance labor requirements for each model plant were calculated based on the assumption that the labor required to operate and maintain more than one control device increased the labor requirement by only 30 percent for each additional control device, instead of increasing the labor requirement by 100 percent. For example, for the large decorative chromium plating model plant with chevron-blade mist eliminators with a single set of blades (which requires a total of three control devices), the operator and maintenance labor requirement was calculated as follows:

Operator and maintenance labor, \$/yr = (\$1,290)(1.6) = \$2,100 instead of (\$1,290)(3) = \$3,870.

The material cost, which is based on 100 percent of the maintenance labor for each control device, was assumed to increase 100 percent for each additional control device for the model plants, and can be computed from Tables F-8 through F-11.

The indirect costs for each model plant include overhead, property taxes, insurance, and administration. The overhead cost is based on 60 percent of the sum of the operator and maintenance labor plus the material costs for each model plant. The property taxes, insurance, and administration are equal to 4 percent of the total capital cost for each model plant. For example, for the large decorative chromium plating model plant operating with chevron-blade mist eliminators with a single set of blades, the indirect costs were calculated as follows:

Indirect costs, \$/yr = 0.60[(1.6)(\$1,290) + 3(\$690)]
+ 0.04[2(27,100) + 20,600] = \$2,480 + \$2,990 = \$5,500.

The chromic acid recovery credits are calculated based on the estimated removal efficiency for chevron-blade mist eliminators and packed-bed scrubbers and 100 percent recovery of the chromic acid captured by the control device. The chromic acid recovery credit is calculated using the following equation:

Chromic acid recovery credit, \$/yr = [ER][Eff][1.923][C]

where:

ER = uncontrolled hexavalent chromium emission rate per plant, kg/yr (lb/yr);

Eff = efficiency of control device, decimal percent;

1.923 = ratio of chromic acid molecular weight (100) to hexavalent chromium molecular weight (52); and

C = cost of chromic acid (CrO_3), \$3.28/kg (\$1.49/lb).[12]

The critical variables influencing chevron-blade mist eliminator and packed-bed scrubber annualized costs are the labor and materials and indirect costs.

F.2 MESH-PAD MIST ELIMINATORS

This section presents the capital and annualized costs of mesh-pad mist eliminators used to control chromium emissions from the hard and decorative chromium electroplating and chromic acid anodizing model plants. Each model plant is composed of various sizes of model tanks. The model tanks are arranged in six control device configurations. Schematics of these configurations are presented in Chapter 5 of this document. Table F-18 presents the model plant parameters on which the installed capital and annualized costs are based.

For model tanks that require more than 340 m^3/min (12,000 ft^3/min) of ventilation air, two or more mesh-pad mist eliminators in parallel were used to control emissions from the plating tanks because mesh-pad mist eliminators are designed to handle maximum airflows of 340 m^3/min (12,000 ft^3/min).[13] However, the vendor of the control device, Vendor I, indicates there may be design problems with mesh-pad mist eliminators sized for flow rates above 230 m^3/min (8,000 ft^3/min). The construction of the frame holding the mesh pads on units designed to handle airflows in excess of 230 m^3/min (8,000 ft^3/min) will probably require structural modifications so that the pads will not be pulled out of the frame. Currently, there are no units in service that are designed for airflows over approximately 170 m^3/min (6,000 ft^3/min).

Vendor I provided capital cost estimates and operating parameters used to calculate annualized cost data for mesh-pad mist eliminators based on the model plant information presented above.[14-16] Capital cost estimates and operating parameters were obtained for four different sizes of mesh-pad mist eliminators specified in the model plants. Operating parameters provided by Vendor I include the fan and washdown water pump horsepower requirements, washdown frequency, water consumption rates, maintenance and operating hours, and the life expectancy of the units. All cost data are presented in November 1988 dollars. Data sources and cost factors used to calculate capital and annualized costs of mesh-pad mist eliminators are presented in Table F-19.

F.2.1 Unit Costs

F.2.1.1 Capital Costs. Table F-20 presents the capital costs for the four sizes of mesh-pad mist eliminators specified in the model plants. The capital costs include the purchase cost of the control device and auxiliaries such as inlet and outlet transition zones, exhaust fans and motors, washdown pumps and motors, and stack; direct installation costs for erection, electrical panels and wiring, instrumentation and controls, and piping; and startup costs. Installation costs are based on the assumptions that the control device would be installed on the roof of the plating shop, that the roof is 6.1 m (20 ft) high, and that the roof would require no major structural modifications to support the weight of the control device. The purchased equipment cost also includes taxes and freight costs, which are assumed to be 3 and 5 percent of the base equipment cost, respectively.[5] The startup cost is assumed to be 1 percent of the purchased equipment cost.[5]

F.2.1.2 Annualized Costs. Table F-21 presents annualized costs for the four sizes of mesh-pad mist eliminator units specified in the model plants. The annualized costs include direct operating costs such as utilities; operator, supervisor, and maintenance labor and materials; mesh pad replacement; indirect operating costs such as overhead, property taxes, insurance and administration; and capital recovery costs.

Utility costs include the costs of electricity and water required to operate the mesh-pad mist eliminators. The annual electrical cost results from both the additional horsepower requirement needed by the fan to overcome the pressure drop added to the ventilation system by the control device, and the horsepower needed to operate the washdown water pumps. The incremental fan electrical costs were calculated based on the following equation:

$$\text{Fan electrical cost, \$/yr} = [(0.746\ \text{kW/hp})(\text{hp})(\text{t})][\text{c}]$$

where:

kW = kilowatt;

hp = horsepower requirement;

t = operating time, hr/yr; and

c = electrical cost, \$0.0461 kWh.[6]

The washdown water pumps are operated for approximately 5 minutes per 8-hour shift to wash down the pads in the mist eliminator. The pump electrical costs were calculated based on the following equation:

$$\text{Pump electrical cost, \$/yr} = [(0.746\ \text{kW/hp})(\text{hp})(t_p)(t_{cd})][c]$$

where:

kW = kilowatt;

hp = horsepower requirement;

t_p = operating time of pump per hour of control device operation, 0.010 hr/hr;

t_{cd} = operating time of control device, hr/yr; and

c = electrical cost, \$0.0461 kWh.[6]

The total annual electrical cost of the mist eliminator is equal to the sum of the fan and washdown water pump electrical costs.

Water consumption costs are associated with the washdown of the mesh-pad mist eliminator. For the purposes of this analysis, it was assumed that the washdown water is recycled to the process, as is typically the case. The amount of washdown water required and the frequency of the washdown was provided by Vendor I for each size of mesh-pad unit. The water costs for mesh-pad mist eliminators were calculated using the following equation:

$$\text{Water cost, \$/yr} = [(v)(f)(s)][c]$$

where:

v = volume of water per washdown, L (gal);

f = frequency of washdown, No. of times/8-hr shift;

s = number of 8-hr shifts per year, No./yr; and

c = water cost, \$0.20/1,000 L (\$0.77/1,000 gal).[7]

Mesh pad replacement costs were included because the estimated life of the pads is less than the estimated life of the control device. Vendor I estimates that most facilities will need to replace the mesh pads every 4 years. The mesh pad material is estimated to cost approximately \$10,600/m^3 (\$300/ft^3) of material.[16] Mesh pad replacement costs include the replacement cost of the pads and the transportation and disposal costs associated with the used pads. The annualized replacement costs of the mesh pads were calculated using the following equation:

$$\text{Replacement cost, \$/yr} = [(v)(c)][CRF_p]$$

where:

v = volume of pad material required for each control device, m^3 (ft^3);

c = cost of pad material, \$10,600/m^3 (\$300/ft^3)[16]; and

CRF_p = capital recovery factor of 0.3154, based on an interest rate of 10 percent and a depreciable life of 4 years for the mesh pads.

The transportation and disposal costs for the mesh pad material were calculated based on the following equation:

$$\text{Disposal and transportation cost, \$/yr} = [(N)(dc) + (N)(tc)][CRF_p]$$

where:

N = number of 55-gal drums, V/V_d, rounded up to the nearest whole number;

V = volume of pad material disposed for each control device, m^3 (ft^3) (see Table F-21);

V_d = volume of 55-gal drum, 0.21 m^3 (7.35 ft^3);

dc = disposal cost, \$50.00/drum[9];

tc = transportation cost, \$40.00/drum[9]; and

CRF_p = capital recovery factor of 0.3154, based on an interest rate of 10 percent and a depreciable life of 4 years for the mesh pads.

The annual cost of operating labor is based on the amount of labor required to operate the control device plus supervision. The operator labor is based on vendor estimates for labor hours required per day of operation, and a labor rate of \$8.37/hr.[10] The operator labor is independent of both the control device size and the number of operating hours per day. The supervisor labor cost is assumed to be 15 percent of the operator labor cost.[5]

The annual cost of maintenance labor for each control device is based on vendor estimates of the maintenance hours required per 2,000 hours of operation, and a maintenance labor rate of \$9.21/hr.[10,11] The maintenance labor is independent of the control device size. The annual cost of maintenance materials is assumed to be 100 percent of the maintenance labor cost.[5]

Indirect costs include overhead, property taxes, insurance, and administration. The overhead cost was calculated based on 60 percent of the sum of the operator, supervisor, and maintenance labor plus any material costs.[5] Property taxes, insurance, and administration were collectively assumed to be 4 percent of the total capital cost.[5]

Capital recovery costs associated with the mesh-pad mist eliminator unit(s), which are the costs of capital spread over the depreciable life of the control device, were calculated using the following equation:[5]

$$CRC = [TCC][(i\{1 + i\}^n)/(\{1 + i\}^n - 1)]$$

where:

CRC = capital recovery cost, \$/yr;

TCC = total capital cost of control device(s), \$;

i = annual interest rate, 10 percent; and

n = depreciable life, 10 years.[16]

F.2.2 Model Plant Costs

This section presents the installed capital and annualized costs of mesh-pad mist eliminators for the hard and decorative chromium plating and chromic acid anodizing model plants. The model plant costs are representative of control costs for new sources. The capital costs for ventilation hoods and ductwork were not included in the capital costs for control devices because plants must typically install ventilation hoods and ductwork to comply with occupational health standards that regulate employee exposure to chromium emissions in the workplace. However, additional ductwork is required for mesh-pad mist eliminator systems, compared to typical ventilation systems. Typical ventilation systems have multiple tanks connected via short runs of ductwork that carry large airflows. The mesh-pad mist eliminator vendor indicated that for airflows greater than 340 m^3/min (12,000 ft^3/min), the exhaust stream should be split and directed to multiple, small mesh-pad units. This splitting of the exhaust stream requires additional ductwork. Therefore, the cost of additional ductwork is included in the model plant capital cost estimates for mesh-pad mist eliminator systems.

F.2.2.1 Capital Costs. Table F-22 presents the purchased equipment, additional ductwork, installation, startup, and total capital costs of mesh-pad mist eliminators for the hard and decorative chromium plating and chromic acid anodizing model plants. The capital cost estimates, with the exception of the additional ductwork costs and installation costs, were compiled from Table F-20 as described below.

Hard Chromium Plating

Small model plant = Column D costs

Medium model plant = Column A + B + 2(Column C) costs

Large model plant = 2[Column A + B + 2(Column C) costs]

Decorative Chromium Plating

Small model plant = Column D costs

Medium model plant = 2(Column D costs)

Large model plant = 5(Column C costs)

Chromic Acid Anodizing

Small model plant = Column D costs

Large model plant = 4(Column C costs)

The additional ductwork expense for each model plant was estimated by comparing the total ductwork expense associated with the ventilation systems specially designed to accommodate installation of the mesh-pad mist eliminators at each model plant with the ventilation systems designed based on typical plant practices. Schematics of these typical systems are shown in Chapter 5 of the Chromium Electroplating Background Information Document.

Installation costs for each model plant include the direct installation costs of each unit and an indirect cost of $7,000 that covers the cost of engineering services, contractors fees, and contingencies. The mesh-pad mist eliminator vendor provided the amount of the indirect costs on a per-model-plant basis. Therefore, model plant installation costs were assumed to be $7,000 plus the cost of the direct installation of the unit, calculated as described above for the other capital cost estimates.

F.2.2.2 Annualized Costs. The annualized costs for the model plants are presented in Table F-23. The annualized cost estimates, with the exception of the labor requirements, indirect costs and chromic acid recovery credits, were compiled from Table F-21 as described below.

Hard Chromium Plating

Small model plant = Column D_1 costs

Medium model plant = Column A_1 + B_1 + 2(Column C_1) costs

Large model plant = 2[Column A_2 + B_2 + 2(Column C_2) costs]

Decorative Chromium Plating

Small model plant = Column D_1 costs

Medium model plant = 2(Column D_2 costs)

Large model plant = 5(Column C_2 costs)

Chromic Acid Anodizing

Small model plant = Column D_1 costs

Large model plant = 4(Column C_2 costs)

The operator, supervisor, and maintenance labor requirements for each model plant were calculated based on the assumption that the labor required to operate and maintain more than one control device increased the labor requirement by only 30 percent for each additional control device, instead of increasing the labor requirement by 100 percent. For example, for the medium hard chromium plating model plant, which requires a total of four control devices, the operator and maintenance labor requirement was calculated as follows:

Operator and maintenance labor, \$/yr = 1,240 + 0.3(1,240) + 0.3(1,240) + 0.3(1,240) = (\$1,240)(1.9) = \$2,400; instead of (\$1,240)(4) = \$5,960.

The maintenance material cost, which is based on 100 percent of the maintenance labor for each control device, was assumed to increase 100 percent for each additional control device for the model plants and can be computed from Table F-21.

The indirect costs for each model plant include overhead, property taxes, insurance, and administration. The overhead cost is based on 60 percent of the sum of the operator, supervisor, and maintenance labor plus the material costs for each model plant. The property taxes, insurance, and administration are equal to 4 percent of the total capital cost for each model plant. For example, for the medium hard chromium plating model plant, the indirect costs were calculated as follows:

$$\text{Indirect costs, \$/yr} = \overbrace{0.60[(1.9)(\$1,240) + 4(\$640)]}^{\text{overhead}} + \overbrace{[0.04(\$66,000)]}^{\text{taxes, ins., adm.}}$$
$$= \$2,950 + \$2,640 = \$5,600.$$

The chromic acid recovery credits are calculated based on the estimated removal efficiency for mesh-pad mist eliminators and 100 percent recovery of the chromic acid captured by the control device. The chromic acid recovery credit is calculated using the following equation:

Chromic acid recovery credit, \$/yr = [ER][Eff][1.923][C]

where:

ER = uncontrolled hexavalent chromium emission rate per plant, kg/yr (lb/yr);

Eff = efficiency of control device, decimal percent;

1.923 = ratio of chromic acid molecular weight (100) to hexavalent chromium molecular weight (52); and

C = cost of chromic acid (CrO_3), \$3.28/kg (\$1.49/lb).[12]

The critical variables influencing mesh-pad mist eliminator annualized costs are the labor and materials, and indirect costs.

F.3 RETROFIT COSTS FOR CHEVRON-BLADE MIST ELIMINATORS, PACKED-BED SCRUBBERS, AND MESH-PAD MIST ELIMINATORS

This section presents the capital and annualized cost estimates for retrofitting chevron-blade mist eliminators (single and double), packed-bed scrubbers (single and double), and mesh-pad mist eliminators on each of the model plants for hard and decorative chromium electroplating and chromic acid anodizing. The retrofit costs for each model plant include costs for ductwork modifications and for the removal and disposal of existing air pollution control equipment. Actual retrofit costs will vary from plant to plant and will depend on the particular facility's layout and present control level. Based on site visit information on the plant layout and location of the existing control devices, the retrofit cost estimates presented are representative of expenditures that existing facilities would incur. Not included in the retrofit cost scenario is consideration for structural modifications because of possible space constraints that an existing facility might encounter, such as removal of a wall or equipment to make room for the control device.

F.3.1 Model Plant Retrofit Capital Cost Estimates

Three control device vendors were contacted to obtain estimates on the additional cost to retrofit new controls at an existing facility (including the removal of an existing control device) over the installed capital cost for control at a new facility.[17-19] Two control device vendors estimated that the cost to retrofit new controls at an existing facility would increase the total capital costs from 5 to 15 and 5 to 20 percent, respectively.[17,18] A third control device vendor estimated the increase in the total capital cost for new controls could be as much as 50 percent for smaller, less expensive control systems, but that the increase would be less for larger, more expensive control systems.[19] Based on these vendor estimates, an increase of 20 percent of the installed capital costs for new facilities was selected for calculating retrofit costs for the model plants. Transportation and disposal costs for existing control devices, which were not included in the vendor estimates, were assumed to be 5 percent of the installed capital costs of control at new facilities. This assumption was based on transportation and disposal costs for hexavalent chromium solid wastes and estimates of the amount of waste to be disposed. Bulk transportation and disposal costs were obtained from Chemical Waste Management in Anaheim, California.[9] The amount of waste to be disposed was based on the type and size of various control devices. Thus, the total increase in cost to retrofit new controls at existing facilities is 25 percent of the installed capital cost of control for new facilities (i.e., estimated retrofit capital costs are 125 percent of the installed capital cost for new facilities).

The total installed capital costs for chevron-blade mist eliminators, packed-bed scrubbers, and mesh-pad mist eliminators at new facilities were compiled from vendor estimates for each type of control device. These costs are presented in Sections F.1 and F.2 of this appendix. Table F-24 presents the estimated retrofit capital cost of these control devices for each model plant.

F.3.2 Model Plant Retrofit Annualized Cost Estimates

Total annualized retrofit costs of chevron-blade mist eliminators, packed-bed scrubbers, and mesh-pad mist eliminators for each hard and decorative chromium plating and chromic acid anodizing model plant are presented in Table F-25. The annualized retrofit costs are the same as the annualized costs of a new control device except for the capital recovery costs and indirect costs because these costs are both a function of the installed capital cost. Capital recovery costs for a retrofit situation are higher because the installed capital costs for retrofit control devices are 25 percent higher than those for new control devices. Indirect costs include overhead, taxes, insurance, and administration. Taxes, insurance, and administration are based on 4 percent of the capital costs; thus, these costs also are higher for retrofit than for new facilities. Table F-26 presents the net annualized retrofit costs (annualized cost minus the chromic acid recovery credit) for the model plants.

F.4 FUME SUPPRESSANTS

This section presents annual costs of permanent and temporary fume suppressants for the model decorative chromium plating plants and annual costs of permanent fume suppressants for the model chromic acid anodizing plants. The annual costs include the material cost of an initial makeup addition and maintenance additions of the fume suppressant in the plating or anodizing baths. The initial makeup addition is the fume suppressant that is added to a plating bath not previously containing a fume suppressant. Maintenance addition is the fume suppressant added periodically after startup to maintain the fume suppressant concentration in the bath at the recommended level. There is no capital investment in equipment associated with the use of fume suppressants as a control technique. The makeup addition of the fume suppressant is not considered a capital cost because it is an expendable material and would only last a few days without frequent maintenance additions. Permanent fume suppressants are wetting agents, foam blankets, or a combination of a wetting agent and foam blanket that are depleted primarily by drag-out. Temporary fume suppressants are mainly foam blankets, but can be wetting agents or a combination of a wetting agent and foam blanket that are depleted primarily from decomposition and drag-out.

All model tank annual costs are in 1986 dollars. The model plant costs have been updated from October 1986 dollars to November 1988 dollars using the Chemical Engineering (CE) plant index from the February 1989 issue of Chemical Engineering. The ratio of the CE plant indices for November 1988 (347.8) and October 1986 (319.3), equal to 1.09, was used to update costs.

F.4.1 Model Tank Annual Costs

Fume suppressant cost information was obtained from five manufacturers of fume suppressants for model tanks used in the decorative chromium and chromic acid anodizing model plants. Table F-27 presents the manufacturers and fume suppressant brands for which cost data were obtained.

The model plant and model tank parameters were revised in March 1988 based on data obtained from the Section 114 information requests. These revisions were made after the cost data for fume suppressants had been obtained based on the previous set of model tank parameters. Therefore, the fume suppressant costs are adjusted to reflect the revisions made to the model tank parameters. Only the maintenance addition costs and not the initial makeup costs were affected by these revisions. Tables F-28 and F-29 present the model tank parameters upon which the fume suppressant cost data were initially based along with the current model tank parameters for decorative chromium plating and chromic acid anodizing operations, respectively. The parameters that were changed for the decorative chromium model tanks include the operating current and voltage, the percent time electrodes are energized and the chromic acid-to-sulfuric acid ratio. The parameters that were changed for the chromic acid anodizing model tanks include the percent time electrodes are energized and the operating time of the large model plant. The parameters that affect costs are plant operating time and percent time electrodes are energized, which affects the operating time of individual tanks.

Permanent fume suppressants are depleted primarily by drag-out. Because drag-out is proportional to the number of parts plated (which is proportional to the length of time a plating line is operated), the cost data originally provided by the vendors was adjusted based on the revised model tank operating times.

Temporary fume suppressants are depleted by both drag-out and the chemical electrolysis that occurs in the plating bath. Information from fume suppressant vendors suggests that drag-out, which is dependent on operating time, appears to be a more dominant factor than chemical electrolysis, which is dependent on operating current. Therefore, like the permanent fume suppressants, the cost data for temporary fume suppressants was adjusted based on the revised model tank operating times.

F.4.1.1 Decorative Chromium Plating. Information on all of the fume suppressant brands listed in Table F-27 was used to develop annual costs with three exceptions. Cost data for Product 1 and Product 3 (manufactured by Vendor D) were not included in the development of annual costs because these fume suppressants are used only as supplements for Product 2 and are rarely used alone in a decorative chromium plating tank. In addition, cost data for Product 16 (manufactured by Vendor H) were not included in the analysis. Product 16 is a new fume suppressant, and the vendor requested that the preliminary information supplied by his company not be used in the cost analysis.

Fume suppressant cost information was obtained for two different sizes of model tanks (42 ft^2 of surface area and 72 ft^2 of surface area) that are used to develop model plants. Makeup and maintenance addition costs of permanent and temporary fume suppressants for the 42-ft^2 model tank are presented in Tables F-30 and F-31, respectively. Makeup and maintenance addition costs of permanent and temporary fume suppressants for the 72-ft^2 model tank are presented in Tables F-32 and F-33, respectively. Maintenance addition cost estimates for the fume suppressants were based on a tank operating time of 1,600 hr/yr for the 42-ft^2 tank and 4,800 hr/yr for the 72-ft^2 tank.

F.4.1.2 Chromic Acid Anodizing. Cost data were obtained for two brands of permanent fume suppressants--Product 3, manufactured by Vendor D, and Product 4, manufactured by Vendor E.[25,26] While Product 3 is used only as a supplement in decorative chromium plating tanks, it is used for both makeup and maintenance additions for chromic acid anodizing operations. The requests for cost information that was submitted to fume suppressant vendors listed specific brands for which information was desired. While both temporary- and permanent-type fume suppressants were included in this list, the vendors supplied cost data for only the permanent type. However, temporary fume suppressants are used in chromic acid anodizing baths. For this analysis, the cost of this type fume suppressant is assumed to be comparable to the cost of permanent fume suppressants based on the cost data provided for decorative chromium plating tanks.

Fume suppressant cost information was obtained for two different sizes of model tanks (42 ft^2 of surface area and 150 ft^2 of surface area). Makeup and maintenance addition costs of the permanent fume suppressants are presented in Table F-34. Maintenance addition cost estimates for the fume suppressants were based on a tank operating time of 500 hr/yr for the 42-ft^2 model tank, and 5,760 hr/yr for the 150-ft^2 model tank.

F.4.2 Model Plant Annual Costs

F.4.2.1 Decorative Chromium Plating. The average makeup and maintenance addition costs of both the permanent and temporary fume suppressants for each tank size were used to compute the annual costs for the decorative chromium plating model plants. These annual costs are presented in Tables F-35 and F-36, respectively.

The methodology used for the cost calculations is also shown in Tables F-35 and F-36. The annual cost was calculated by multiplying the number of tanks in each model plant by the average fume suppressant makeup and maintenance addition costs associated with that size tank. The maintenance addition cost for each model plant includes an operating time adjustment ratio. The operating time adjustment ratio corrects for the difference between the operating time of the model tanks upon which the cost data were originally based and the revised operating time for the model tanks. As shown in Table F-35, the average permanent fume suppressant maintenance addition cost supplied by vendors (and updated to November 1988 dollars) for the 42-ft^2 model tank is $1,060 based on a tank operating time of 1,600 hr/yr. The revised 42-ft^2 model tank in the small model plant operates 1,200 hr/yr. Therefore, the operating time adjustment ratio is 1,200/1,600, or 0.75, and the annual maintenance addition cost is $800 (0.75 times $1,060). Similar calculations were performed for the medium and large model plants. The revised model tanks in the medium and large model plant operate 2,400 hr/yr and 3,600 hr/yr, respectively.

F.4.2.2 Chromic Acid Anodizing. The makeup and maintenance addition costs of the permanent fume suppressants for each tank size were used to compute the annual costs for the small and large chromic acid anodizing model plants. The small model plant consists of one 42-ft^2 model tank, and the large model plant consists of two 150-ft^2 model tanks. The average annual cost of permanent fume suppressants for each tank size and model plant are presented in Table F-37. The methodology used to calculate the annual costs for anodizing operations is the same as that used for decorative chromium plating operations (Section F.4.2.1).

F.5 TRIVALENT CHROMIUM PLATING PROCESS

This section presents a model plant analysis of the capital costs for converting decorative chromium electroplating model plants from the hexavalent chromium process to the trivalent chromium process and incremental capital costs for installing a trivalent chromium process instead of a hexavalent chromium process at new plants. Also presented are the results of a preliminary analysis of the incremental annualized costs of trivalent chromium processes over the hexavalent chromium process. At present, the hexavalent process is the predominant process used in the industry, although interest in and use of the trivalent chromium process is increasing. The trivalent chromium process is reported to be technically superior and has minimal environmental impacts.[27-30] Information obtained from a vendor indicates that there are approximately 100 electroplating plants currently using the trivalent chromium process.[31]

Cost data for converting from a hexavalent chromium to a trivalent chromium process were obtained from four manufacturers of hexavalent and trivalent chromium plating baths.[27-30] Table F-38 presents the manufacturers and the trivalent chromium process products for which cost data were obtained.

There are two types of trivalent chromium processes (single-cell and double-cell) currently marketed. The main difference between the single- and double-cell processes is that the double-cell process requires a physical separation of the anode from the plating solution. In the double-cell process, the anodes are encased in anode boxes that are lined with a permeable membrane and contain a dilute solution of sulfuric acid which surrounds the anodes. In the single-cell process the anodes are placed in direct contact with the plating solution. The single-cell processes are sold by Vendor F and Vendor E. The double-cell processes are sold by Vendor H and Vendor D. The capital cost estimates developed for the model plants are representative of either process and are based on a compilation of cost data obtained from the four vendors. The individual cost data supplied by each vendor are presented in Tables F-39 and F-40 for the 42-ft^2 and 72-ft^2 model tanks, respectively. All costs are in October 1986 dollars. The vendor estimates for the process conversion of the 42-ft^2 model tank ranged from $22,800 to $31,700. The vendor estimates for the process conversion of the 72-ft^2 model tank ranged from $46,700 to $58,000.

F.5.1 Capital Costs for Existing Facilities

F.5.1.1 Model Tanks. Capital cost information was obtained for the two different sizes of model tanks (42 ft^2 and 72 ft^2 of surface area) that are used in the model plants. Table F-41 presents the model tank parameters upon which the capital cost estimates are based.

Table F-42 presents the capital cost associated with the process conversion for each tank size. These costs have been updated from October 1986 dollars to November 1988 dollars using the ratio presented in Section F.4. The capital cost includes the direct cost of new equipment, startup, and installation/modification costs, plus indirect costs, taxes, and freight charges. The new equipment purchases consist of an ampere-hour controller(s) used to determine the frequency of chemical additions and to provide automatic control of additions of required chemicals to the bath, a tank liner, replacement anodes and hangers, and anode boxes. The purchase costs of chillers and filters also are presented in Table F-42, but these items are considered to be optional equipment purchases. Chillers are required for some operations where parts are plated at high current densities and the production load is heavy or for operations where the temperature of the cooling water is too high to maintain the bath within its normal operating temperature range.[32-33] Filters are usually recommended to aid in the control of plating bath contaminants.

The startup (tank conversion) cost includes the initial makeup cost of the trivalent chromium plating solution, the initial makeup cost of the passivation solution, and the disposal cost (transportation and treatment) of the hexavalent solution as hazardous waste. The passivation solution is required for some double-cell trivalent chromium processes and improves the corrosion resistance of the part following plating. The capital cost of a passivation tank is not included in the equipment costs because an existing rinse tank can be converted to hold the passivation solution. The cost to dispose of the hexavalent plating solution was obtained from Chemical Waste Management, Inc., in Anaheim, California.[34]

Installation/modification costs are based on data obtained from actual operating plants and are estimated to be 20 percent of the purchased equipment cost.[35] Installation/modification costs include installation of new equipment, tank cleaning, and any modifications to the plating line, electrical supply, or cooling system. Indirect costs include costs associated with engineering and supervision (10 percent), process startup (1 percent), and contingencies (20 percent).[36] Taxes and freight charges were estimated at 3 and 5 percent of the base equipment cost, respectively.[36]

F.5.1.2 Model Plants. The capital cost information obtained for each tank size was used to calculate the capital costs for converting three model plants of varying size (small, medium, and large) from the hexavalent to the trivalent chromium process. The small and medium model plants consist of one and two 42-ft^2 model tanks, respectively. The large model plant consists of five 72-ft^2 model tanks. The capital cost of conversion for each model plant is presented in Table F-43.

F.5.2 Capital Costs for New Facilities

The incremental capital cost associated with installing the trivalent chromium process instead of the hexavalent chromium process at a new facility is presented in Table F-44 for each model plant. The capital cost includes the direct cost of new equipment, installation, and startup plus indirect costs, taxes, and freight charges.

The new equipment purchases consist of equipment that is unique to the trivalent chromium process: an ampere-hour controller(s) used to determine and automatically make chemical additions to the plating bath, anode boxes, a filter system, and chillers. The filter system and chillers are optional equipment purchases. The incremental cost of anodes and hangers for a trivalent chromium bath over a hexavalent chromium bath is insignificant and is not included in Table F-44. The cost of a tank liner is not included as an equipment cost because a tank liner also would be needed for a hexavalent chromium tank. The startup (plating tank[s]) cost includes the incremental cost of the initial makeup solution for trivalent chromium over hexavalent chromium and the initial makeup cost of the passivation solution. Installation costs are based on data obtained from plants and are estimated to be 15 percent of the purchased equipment cost.[35] Indirect costs were based on 31 percent of the purchased equipment cost and include costs associated with engineering and supervision, process startup, and contingencies.[36] Taxes and freight charges were 3 and 5 percent of the base equipment cost, respectively.[36]

A benefit of the trivalent chromium process is the elimination of the need for hexavalent chromium reduction units in the wastewater treatment system. The capital cost for the hexavalent chromium reduction system was obtained from an EPA document.[37] The capital cost of hexavalent chromium reduction units includes storage and feed systems for the treatment reagents, as well as the costs for hardware, piping, instrumentation, and utility connections. These cost estimates also are presented in Table F-44. The volume of process wastewater to be treated was estimated for each model plant based on information published in the effluent guidelines development document.[38] The small model plant was assumed to have a batch system because of its low volume of wastewater. The medium and large model plants were assumed to be equipped with a continuous wastewater treatment system. Treatment equipment and ancillary items required strictly for the reduction purposes were identified and their associated costs were determined. The cost of the reduction equipment was subtracted from the process capital cost to achieve the net capital cost for new facilities.

F.5.3 Case Studies

Case studies were produced for three decorative chromium plating facilities that had converted from a hexavalent chromium process to a trivalent chromium process. Table F-45 presents a description of the plating operation and the trivalent chromium process operated at each of the facilities.[35,39,40] Table F-46 presents the capital cost data provided by the three facilities for the conversion from a hexavalent chromium process to a trivalent chromium process.[35,39,40] This information was used to confirm or validate the estimating procedure for capital costs developed from the vendor quotations.

Based on information obtained from vendors and confirmed during site visits to the three trivalent chromium plating facilities, the capital cost of conversion is dependent upon the size of the operation, the amount and type of available equipment, and the configuration of the existing decorative chromium plating line. The capital cost data obtained from the facilities visited was used to determine whether the capital costs estimated for the model plants are representative of what existing plants have incurred to convert from a hexavalent chromium process to a trivalent chromium process.

Table F-47 presents a comparison of the actual capital cost data obtained from industry to the capital cost estimates developed for the model plants. Plants 1 and 2 would be classified as small operations, and Plant 3 would be considered a medium operation. The small model plant capital cost estimate is near the upper end of the range represented by the costs submitted by Plants 1 and 2. Plant 1 operates a double-cell trivalent chromium process, and Plant 2 operates a single-cell process. The double-cell process is more expensive to convert because of the need for anode boxes and the passivation solution. Also, Plant 1 incurred more modification costs than Plant 2. Because the model plant cost estimates are based on both process costs and the cost to modify the plating line, the cost for the small model plant would be expected to be comparable to the costs submitted by Plant 1. The capital cost data obtained from Plant 3 are comparable to the capital cost estimated for the medium model plant, even though the equipment required and modifications needed were not the same.

F.5.4 Annualized Costs

Based on the results of cost analyses and cost data provided by operators of trivalent chromium processes, it was concluded that the annual production cost difference between the hexavalent chromium process and the trivalent chromium process is negligible. The analysis of plating line costs for the trivalent chromium plating process versus the hexavalent chromium plating process is presented in Appendix G.

TABLE F-1. MODEL PLANT PARAMETERS FOR THE HARD AND DECORATIVE CHROMIUM PLATING AND CHROMIC ACID ANODIZING MODEL PLANTS -- CHEVRON-BLADE MIST ELIMINATORS AND PACKED-BED SCRUBBERS

Model operation	Plant size: Small	Medium	Large
Hard chromium plating			
Operating time, hr/yr	2,000	3,500	6,000
Percent time electrodes are energized	70	70	80
Total ampere-hours per year	5.0×10^6	42×10^6	160×10^6
No. of tanks	1	4	8
Dimensions of tanks (l,w,d), m (ft)	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	1.2, 1.2, 3.0 (4.0, 4.0, 10.0) 2 @ 3.6, 1.2, 1.8 (12.0, 4.0, 6.0) 7.6, 0.9, 1.8 (25.0, 3.0, 6.0)	2 @ 1.2, 1.2, 3.0 (4.0, 4.0, 10.0) 4 @ 3.6, 1.2, 1.8 (12.0, 4.0, 6.0) 2 @ 7.6, 0.9, 1.8 (25.0, 3.0, 6.0)
Ventilation rate per tank, m^3/min (ft^3/min)	297 (10,500)	57 (2,000) 2 @ 170 (6,000) 531 (18,750)	2 @ 57 (2,000) 4 @ 170 (6,000) 2 @ 531 (18,750)
No. of control devices	1	1	2
Size of each control device, m^3/min (ft^3/min)	340 (12,000)	990 (35,000)	2 @ 990 (35,000)
Uncontrolled hexavalent chromium emission rate, kg/yr (lb/yr)	50 (110)	420 (925)	1,600 (3,530)
Decorative chromium plating			
Operating time, hr/yr	2,000	4,000	6,000
Percent time electrodes are energized	60	60	60
Total ampere-hours	3.0×10^6	12×10^6	120×10^6
No. of tanks	1	2	5
Dimensions of tanks (l,w,d), m (ft)	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	2 @ 3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	5 @ 3.6, 1.8, 2.7 (12.0, 6.0, 9.0)
Ventilation rate per tank, m^3/min (ft^3/min)	297 (10,500)	2 @ 297 (10,500)	5 @ 255 (9,000)
No. of control devices	1	2	3
Size of each control device, m^3/min (ft^3/min)	340 (12,000)	340 (12,000)	280 (10,000) 2 @ 510 (18,000)
Uncontrolled hexavalent chromium emission rate, kg/yr (lb/yr)	6.0 (13.0)	24 (53)	240 (530)
Chromic acid anodizing			
Operating time, hr/yr	2,000		6,000
Percent time electrodes are energized	70		40
No. of tanks	1		2
Dimensions of tanks (l,w,d), m (ft)	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)		2 @ 9.1, 1.5, 2.7 (30.0, 5.0, 9.0)
Ventilation rate per tank, m^3/min (ft^3/min)	297 (10,500)		2 @ 531 (18,750)
No. of control devices	1		1
Size of each control device, m^3/min (ft^3/min)	340 (12,000)		1,130 (40,000)
Uncontrolled hexavalent chromium emission rate, kg/yr (lb/yr)	3.3 (7.2)		40 (88)

TABLE F-2. CAPITAL AND ANNUALIZED COST DATA SOURCES FOR CHEVRON-BLADE MIST ELIMINATORS AND PACKED-BED SCRUBBERS

Cost item	Source	Date	Ref.
A. Capital Costs			
1. Chevron-blade mist eliminators	Vendor A	October 1986 updated to November 1988[a]	1
2. Packed-bed scrubbers	Vendor A	October 1986 updated to November 1988[a]	1
B. Annualized Costs			
1. Electricity	Department of Energy	October 1988	6
2. Water	American Water Works Association	March 1989	7
3. Chromic acid	Ashland Chemical Company	June 1989[a]	12
4. Labor			
a. Operator	Bureau of Labor Statistics	August 1988, January 1989	10, 11
b. Supervisor and maintenance	EPA/OAQPS/EAB	August 1988, January 1989	5, 10, 11
5. Replacement packing material	Vendor A, EPA/OAQPS/EAB	March 1989, February 1987	8, 5
6. Transportation and disposal of old packing	Chemical Waste Management	April 1989	9
7. Overhead, property tax, insurance, administration	EPA/OAQPS/EAB	February 1987	5
8. Capital recovery	EPA/OAQPS/EAB	February 1987	5

[a]Costs were updated by multiplying base year costs by the ratio of the Chemical Engineering plant indices for November 1988 and the base year.

TABLE F-3. ANNUAL OPERATING COST FACTORS

Cost categories	Cost factors
Direct operating costs	
1. Operating labor	
a. Operator[10,11]	\$8.37/man-hr
b. Supervisor[5]	15 percent of 1a
2. Maintenance	
a. Labor [5,10,11]	\$9.21/hr
b. Materials[5]	100 percent of 3a
3. Replacement parts (packing material)[5,8]	16.3 percent of the total replacement cost at \$17.50/ft^3[a]
4. Transportation and disposal of used packing	\$50/drum disposal (plus 10 percent tax) \$40/drum transportation
5. Utilities	
a. Electricity[6]	\$0.0461/kWh
b. Water[7]	\$0.77/1,000 gal
Indirect operating costs	
6. Overhead[5]	60 percent of 1a + 1b + 3a + 3b
7. Property tax[5]	1 percent of capital cost
8. Insurance[5]	1 percent of capital cost
9. Administration[5]	2 percent of capital cost
10. Capital recovery[5]	11.7 percent of capital cost[b]
Credits	
Chromic acid recovery[12]	\$3.28/kg

[a]Based on an interest rate of 10 percent and a scrubber packing life of 10 years.
[b]Based on an interest rate of 10 percent and an equipment life of 20 years.

TABLE F-4. CAPITAL COSTS OF CHEVRON-BLADE MIST ELIMINATOR (SINGLE SET OF BLADES)

	Mist eliminator size[a]				
	A	B	C	D	E
Control device parameters					
Design gas flow rate, m^3/min (ft^3/min)[b]	280 (10,000)	340 (12,000)	510 (18,000)	990 (35,000)	1,130 (40,000)
Pressure drop, kPa (in. w.c.)	0.19 (0.75)	0.19 (0.75)	0.19 (0.75)	0.19 (0.75)	0.19 (0.75)
Fan static pressure, kPa (in. w.c)[c]	0.62 (2.5)	0.75 (3.0)	0.87 (3.5)	1.4 (5.5)	1.2 (5.0)
Fan motor size, hp (kW)[d]	7.5 (5.6)	10 (7.5)	20 (15)	50 (37)	50 (37)
Cost data[e]					
1. Basic mist eliminator	2,560	2,970	4,040	6,540	7,170
2. Inlet and outlet transition	640	660	840	1,800	1,980
3. Fan and motor	4,250	5,000	6,480	13,090	15,300
4. Stack	590	720	910	1,180	1,230
5. Base equipment[f]	8,040	9,350	12,270	22,610	25,680
6. Sales taxes and freight[g]	640	750	980	1,810	2,050
7. Total purchased equipment[h]	8,680	10,100	13,250	24,420	27,730
8. Installation[i]	11,870	12,340	13,740	20,840	20,590
9. Startup[j]	90	100	130	240	280
10. Total capital cost[k]	20,600	22,500	27,100	45,500	48,600

[a]Mist eliminator sizes are ranked from the lowest gas flow rate (Column A) to the highest gas flow rate (Column E).

[b]Gas stream temperature is 27°C (80°F), gas stream moisture content is 2 percent, and altitude is 305 m (1,000 ft).

[c]Static pressures were estimated by the vendor.

[d]Vendor A provided motor sizes based on the static pressures and gas flow rates specified above.

[e]Capital costs presented in this table are based on Vendor A estimates only. Vendor A provided base equipment and installation costs in October 1986 dollars. Costs were updated to November 1988 dollars and were rounded to nearest $10.

[f]Sum of 1 through 4.

[g]Sales taxes and freight costs are 3 and 5 percent, respectively, of base equipment costs.

[h]Sum of 5 and 6.

[i]Includes all costs associated with installing instrumentation, electrical components, and piping; erection and contingencies; and fee. Assumed that control devices are installed on the roof of a plant that is 6.1 m (20 ft) high and no structural modifications are necessary.

[j]One percent of total purchased equipment cost.

[k]Sum of 7, 8, and 9. Costs were rounded to nearest $100.

TABLE F-5. CAPITAL COSTS OF CHEVRON-BLADE MIST ELIMINATOR (DOUBLE SETS OF BLADES)

	Mist eliminator size[a]				
	A	B	C	D	E
Control device parameters					
Design gas flow rate, m^3/min (ft^3/min)[b]	280 (10,000)	340 (12,000)	510 (18,000)	990 (35,000)	1,130 (40,000)
Pressure drop, kPa (in. w.c.)	0.5 (2)	0.5 (2)	0.5 (2)	0.5 (2)	0.5 (2)
Fan static pressure, kPa (in. w.c.)[c]	0.87 (3.5)	1.0 (4.0)	1.1 (4.5)	1.6 (6.5)	1.5 (6.0)
Fan motor size, hp (kW)[d]	10 (7.5)	15 (11)	25 (19)	60 (45)	60 (45)
Cost data[e]					
1. Basic mist eliminator	3,080	3,910	4,970	8,380	9,260
2. Inlet and outlet transition	640	660	840	1,800	1,980
3. Fan and motor	4,380	5,250	6,760	15,230	14,880
4. Stack	590	720	910	1,180	1,230
5. Base equipment[f]	8,690	10,540	13,480	26,590	27,350
6. Sales taxes and freight[g]	690	850	1,070	2,130	2,190
7. Total purchased equipment[h]	9,380	11,390	14,550	28,720	29,540
8. Installation[i]	12,310	12,340	14,120	20,840	20,590
9. Startup[j]	90	110	150	290	300
10. Total capital cost[k]	21,800	23,800	28,800	49,900	50,400

[a]Mist eliminator sizes are ranked from the lowest gas flow rate (Column A) to the highest gas flow rate (Column E).

[b]Gas stream temperature is 27°C (80°F), gas stream moisture content is 2 percent, and altitude is 305 m (1,000 ft).

[c]Static pressures were estimated by the vendor.

[d]Vendor A provided motor sizes based on the static pressures and gas flow rates specified above.

[e]Capital costs presented in this table are based on Vendor A estimates only. Vendor A provided base equipment and installation costs in October 1986 dollars. Costs were updated to November 1988 dollars and were rounded to nearest $10.

[f]Sum of 1 through 4.

[g]Sales taxes and freight costs are 3 and 5 percent, respectively, of base equipment costs.

[h]Sum of 5 and 6.

[i]Includes all costs associated with installing instrumentation, electrical components, and piping; erection and contingencies; and fee. Assumed that control devices are installed on the roof of a plant that is 6.1 m (20 ft) high and no structural modifications are necessary.

[j]One percent of total purchased equipment cost.

[k]Sum of 7, 8, and 9. Costs were rounded to nearest $100.

TABLE F-6. CAPITAL COSTS OF SINGLE PACKED-BED HORIZONTAL-FLOW SCRUBBER

	Scrubber size[a]				
	A	B	C	D	E
Control device parameters					
Design gas flow rate, m^3/min (ft^3/min)[b]	280 (10,000)	340 (12,000)	510 (18,000)	990 (35,000)	1,130 (40,000)
Pressure drop, kPa (in. w.c.)	0.5 (2)	0.5 (2)	0.5 (2)	0.5 (2)	0.5 (2)
Fan static pressure, kPa (in. w.c.)[c]	0.87 (3.5)	1.0 (4.0)	1.1 (4.5)	1.6 (6.5)	1.5 (6.0)
Fan motor size, hp (kW)[d]	10 (7.5)	15 (11)	25 (19)	60 (45)	60 (45)
Amount of packing, m^3 (ft^3)	0.68 (24)	0.82 (29)	1.2 (42)	2.1 (74)	2.4 (86)
Cost data[e]					
1. Basic scrubber[f]	7,160	8,530	12,250	20,340	23,260
2. Inlet and outlet transition	900	1,000	1,860	3,900	4,540
3. Fan and motor	4,380	5,250	6,760	15,230	14,880
4. Remote recirculation tank	410	410	770	840	840
5. Recirculation water pump and motor	2,070	2,180	2,210	2,290	3,450
6. Stack	590	720	910	1,180	1,230
7. Base equipment[g]	15,510	18,090	24,760	43,780	48,200
8. Sales taxes and freight[h]	1,250	1,440	1,980	3,500	3,860
9. Total purchased equipment[i]	16,760	19,530	26,740	47,280	52,060
10. Installation[j]	16,560	16,990	18,590	26,430	26,090
11. Startup[k]	170	200	270	470	520
12. Total capital cost[l]	33,500	36,700	45,600	74,200	78,700

[a]Scrubber sizes are ranked from the lowest gas flow rate (Column A) to the highest gas flow rate (Column E).
[b]Gas stream temperature is 27°C (80°F), gas stream moisture content is 2 percent, and altitude is 305 m (1,000 ft).
[c]Static pressures were estimated by the vendor.
[d]Vendor A provided motor sizes based on the static pressures and gas flow rates specified above.
[e]Capital costs presented in this table are based on Vendor A estimates only. Vendor A provided base equipment and installation costs in October 1986 dollars. Costs were updated to November 1988 dollars and were rounded to nearest $10.
[f]Includes cost of initial packing material.
[g]Sum of 1 through 6.
[h]Sales taxes and freight costs are 3 and 5 percent, respectively, of base equipment costs.
[i]Sum of 7 and 8.
[j]Includes all costs associated with installing instrumentation, electrical components, and piping; erection and contingencies; and fee. Assumed that control devices are installed on the roof of a plant that is 6.1 m (20 ft) high and no structural modifications are necessary.
[k]One percent of total purchased equipment cost.
[l]Sum of 9, 10, and 11. Costs were rounded to nearest $100.

TABLE F-7. CAPITAL COSTS OF DOUBLE PACKED-BED HORIZONTAL-FLOW SCRUBBER

	Scrubber size[a]				
	A	B	C	D	E
Control device parameters					
Design gas flow rate, m^3/min (ft^3/min)[b]	280 (10,000)	340 (12,000)	510 (18,000)	990 (35,000)	1,130 (40,000)
Pressure drop, kPa (in. w.c.)	0.75 (3)	0.75 (3)	0.75 (3)	0.75 (3)	0.75 (3)
Fan static pressure, kPa (in.w.c.)[c]	1.1 (4.5)	1.2 (5.0)	1.4 (5.5)	1.9 (7.5)	1.7 (7.0)
Fan motor size, hp (kW)[d]	15 (11)	15 (11)	30 (22)	75 (56)	75 (56)
Amount of packing, m^3 (ft^3)	1.4 (48)	1.6 (58)	2.4 (84)	4.19 (148)	4.87 (172)
Cost data[e]					
1. Basic scrubber[f]	9,530	11,160	15,780	27,120	31,030
2. Inlet and outlet transition	960	1,060	1,960	4,140	4,800
3. Fan and motor	4,650	5,250	6,740	17,490	15,880
4. Remote recirculation tank	520	640	850	1,230	1,320
5. Recirculation water pump and motor	2,210	2,270	3,450	4,030	4,190
6. Stack	590	720	910	1,180	1,230
7. Base equipment[g]	18,460	21,100	29,690	55,190	58,450
8. Sales taxes and freight[h]	1,470	1,690	2,370	4,420	4,670
9. Total purchased equipment[i]	19,930	22,790	32,060	59,610	63,120
10. Installation[j]	16,560	16,990	18,590	26,430	26,090
11. Startup[k]	200	230	320	600	630
12. Total capital cost[l]	36,700	40,000	51,000	86,600	89,800

[a]Scrubber sizes are ranked from the lowest gas flow rate (Column A) to the highest gas flow rate (Column E).
[b]Gas stream temperature is 27°C (80°F), gas stream moisture content is 2 percent, and altitude is 305 m (1,000 ft).
[c]Static pressures were estimated by the vendor.
[d]Vendor A provided motor sizes based on the static pressures and gas flow rates specified above.
[e]Capital costs presented in this table are based on Vendor A estimates only. Vendor A provided base equipment and installation costs in October 1986 dollars. Costs were updated to November 1988 dollars and were rounded to nearest $10.
[f]Includes cost of packing material.
[g]Sum of 1 through 6.
[h]Sales taxes and freight costs are 3 and 5 percent, respectively, of base equipment costs.
[i]Sum of 7 and 8.
[j]Includes all costs associated with installing instrumentation, electrical components, and piping; erection and contingencies; and fee. Assumed that control devices are installed on the roof of a plant that is 6.1 m (20 ft) high and no structural modifications are necessary.
[k]One percent of total purchased equipment cost.
[l]Sum of 9, 10, and 11. Costs were rounded to the nearest $100.

TABLE F-8. ANNUALIZED COSTS OF CHEVRON-BLADE MIST ELIMINATOR (SINGLE SET OF BLADES)

	Scrubber size[a]						
	A	B_1	B_2	C	D_1	D_2	E
Control device parameters							
Design gas flow rate, m^3/min (ft^3/min)	280 (10,000)	340 (12,000)	340 (12,000)	510 (18,000)	990 (35,000)	990 (35,000)	1,130 (40,000)
Operating hours/yr	6,000	2,000	4,000	6,000	3,500	6,000	6,000
Frequency of washdown, No. times/8 hr of operation[b]	2	2	2	2	2	2	2
Volume of water per washdown, L (gal)[b]	38 (10)	57 (15)	57 (15)	57 (15)	95 (25)	95 (25)	114 (30)
Incremental fan motor size, hp[b c]	2.5	0	0	5	10	10	0
Maintenance hours/yr[b]	75	25	50	75	53	90	90
Life expectancy, yr[b]	20	20	20	20	20	20	20
Cost data[d]							
1. Utilities	530	10	10	1,050	1,220	2,090	30
2. Operator and maintenance labor[e]	1,290	830	1,060	1,290	1,080	1,430	1,430
3. Maintenance materials	690	230	460	690	480	830	830
4. Indirect costs[f]	2,010	1,540	1,810	2,270	2,760	3,180	3,300
5. Capital recovery	2,410	2,630	2,630	3,170	5,320	5,320	5,690
6. Total annualized cost, $[g]	6,900	5,200	6,000	8,500	10,900	12,900	11,300

[a]Mist eliminator sizes are ranked from the lowest gas flow rate (Column A) to the highest gas flow rate (Column E). Columns B_1 and B_2 present annualized costs for the 340-m^3/min (12,000-ft^3/min) unit based on operating times of 2,000 and 4,000 hours/year, respectively. Columns D_1 and D_2 present annualized costs for the 990-m^3/min (35,000-ft^3/min) unit based on operating times of 3,500 and 6,000 hours/year, respectively.

[b]Value for parameter provided by Vendor A.

[c]The incremental fan motor size is the additional horsepower required to operate the control device over the horsepower required to operate the ventilation system.

[d]Annualized costs are presented in November 1988 dollars and were calculated from the control device parameters provided by Vendor A and the operating hours specified above. All costs were rounded to the nearest $10.

[e]Includes operator, supervisor, and maintenance labor.

[f]Includes overhead, property tax, insurance, and administration.

[g]Numbers may not add exactly due to independent rounding. Cost data were rounded to nearest $100.

TABLE F-9. ANNUALIZED COSTS OF CHEVRON-BLADE MIST ELIMINATOR (DOUBLE SETS OF BLADES)

	Mist eliminator size[a]						
	A	B_1	B_2	C	D_1	D_2	E
Control device parameters							
Design gas flow rate, m^3/min (ft^3/min)	280 (10,000)	340 (12,000)	340 (12,000)	510 (18,000)	990 (35,000)	990 (35,000)	1,130 (40,000)
Operating hours/yr	6,000	2,000	4,000	6,000	3,500	6,000	6,000
Frequency of washdown, No. times/8 hr of operation[b]	3	3	3	3	3	3	3
Volume of water per washdown, L (gal)[b]	38 (10)	57 (15)	57 (15)	57 (15)	95 (25)	95 (25)	114 (30)
Incremental fan motor size, hp[b c]	5	5	5	10	20	20	10
Maintenance hours/yr[b]	75	25	50	75	53	90	90
Life expectancy, yr[b]	20	20	20	20	20	20	20
Cost data[d]							
1. Utilities	1,050	350	710	2,090	2,440	4,170	2,110
2. Operator and maintenance labor[e]	1,290	830	1,060	1,290	1,080	1,430	1,430
3. Maintenance materials	690	230	460	690	480	830	830
4. Indirect costs[f]	2,060	1,590	1,860	2,340	2,940	3,360	3,380
5. Capital recovery	2,550	2,780	2,780	3,370	5,840	5,840	5,900
6. Total annualized cost, $[g]	7,600	5,800	6,900	9,800	12,800	15,600	13,700

[a]Mist eliminator sizes are ranked from the lowest gas flow rate (Column A) to the highest gas flow rate (Column E). Columns B_1 and B_2 present annualized costs for the 340-m^3/min (12,000-ft^3/min) unit based on operating times of 2,000 and 4,000 hours/year, respectively. Columns D_1 and D_2 present annualized costs for the 990-m^3/min (35,000-ft^3/min) unit based on operating times of 3,500 and 6,000 hours/year, respectively.
[b]Value for parameter provided by Vendor A.
[c]The incremental fan motor size is the additional horsepower required to operate the control device over the horsepower required to operate the ventilation system.
[d]Annualized costs are presented in November 1988 dollars and were calculated from the control device parameters provided by Vendor A and the operating hours specified above. All costs were rounded to the nearest $10.
[e]Includes operator, supervisor, and maintenance labor.
[f]Includes overhead, property tax, insurance, and administration.
[g]Numbers may not add exactly due to independent rounding. Cost data were rounded to nearest $100.

TABLE F-10. ANNUALIZED COSTS OF SINGLE PACKED-BED HORIZONTAL-FLOW SCRUBBER

	Scrubber size[a]						
	A	B_1	B_2	C	D_1	D_2	E
Control device parameters							
Design gas flow rate, m^3/min (ft^3/min)	280 (10,000)	340 (12,000)	340 (12,000)	510 (18,000)	990 (35,000)	990 (35,000)	1,130 (40,000)
Operating hours/yr	6,000	2,000	4,000	6,000	3,500	6,000	6,000
Incremental fan motor size, hp[b c]	5	5	5	10	20	20	10
Volume of remote recirculation tank, L (gal)[b]	454 (120)	454 (120)	454 (120)	1,010 (290)	1,500 (396)	1,500 (396)	1,500 (396)
Recirculation pump motor, hp[b]	1	1.5	2	3	3	3	5
Maintenance hours/yr[b]	150	50	100	150	110	195	210
Life expectancy (unit), yr[b]	20	20	20	20	20	20	20
Life expectancy (packing), yr[b]	10	10	10	10	10	10	10
Cost data[d]							
1. Utilities	1,730	630	1,280	3,390	3,760	6,400	4,980
2. Operator and maintenance labor[e]	2,590	1,670	2,130	2,590	2,260	3,010	3,140
3. Maintenance materials	1,380	460	920	1,380	1,050	1,800	1,930
4. Packing material replacement[f]	130	160	160	210	380	380	430
5. Indirect costs[g]	3,720	2,750	3,300	4,200	4,960	5,860	6,190
6. Capital recovery	3,920	4,290	4,290	5,340	8,680	8,680	9,210
7. Total annualized cost, $[h]	13,500	10,000	12,100	17,100	21,100	26,200	25,900

[a]Packed-bed scrubber sizes are ranked from the lowest gas flow rate (Column A) to the highest gas flow rate (Column E). Columns B_1 and B_2 present annualized costs for the 340-m^3/min (12,000-ft^3/min) unit based on operating times of 2,000 and 4,000 hours/year, respectively. Columns D_1 and D_2 present annualized costs for the 990-m^3/min (35,000-ft^3/min) unit based on operating times of 3,500 and 6,000 hours/year, respectively.
[b]Value for parameter provided by Vendor A.
[c]The incremental fan motor size is the additional horsepower required to operate the control device over the horsepower required to operate the ventilation system.
[d]Annualized costs are presented in November 1988 dollars and were calculated from the control device parameters provided by Vendor A and the operating hours specified above. All costs were rounded to the nearest $10.
[e]Includes operator, supervisor, and maintenance labor.
[f]Includes cost of packing replacement and disposal and transportation of old packing.
[g]Includes overhead, property tax, insurance, and administration.
[h]Numbers may not add exactly due to independent rounding. Cost data were rounded to nearest $100.

TABLE F-11. ANNUALIZED COSTS OF DOUBLE PACKED-BED HORIZONTAL-FLOW SCRUBBER

	Scrubber size[a]						
	A	B_1	B_2	C	D_1	D_2	E
Control device parameters							
Design gas flow rate, m^3/min (ft^3/min)	280 (10,000)	340 (12,000)	340 (12,000)	510 (18,000)	990 (35,000)	990 (35,000)	1,130 (40,000)
Operating hours/yr	6,000	2,000	4,000	6,000	3,500	6,000	6,000
Incremental fan motor size, hp[b c]	10	5	5	15	35	35	25
Volume of remote recirculation tank, L (gal)[b]	680 (180)	830 (220)	830 (220)	1,225 (324)	2,385 (630)	2,385 (630)	2,725 (720)
Recirculation pump motor, hp[b]	2	3	3	5	7.5	7.5	7.5
Maintenance hours/yr[b]	225	75	150	225	175	300	300
Life expectancy (unit), yr[b]	20	20	20	20	20	20	20
Life expectancy (packing material), yr[b]	10	10	10	10	10	10	10
Cost data[d]							
1. Utilities	3,410	930	1,850	5,820	7,020	12,040	10,450
2. Operator and maintenance labor[e]	3,280	1,900	2,590	3,820	2,820	3,970	3,970
3. Maintenance materials	2,070	690	1,380	2,070	1,610	2,760	2,760
4. Packing material replacement[f]	260	320	320	430	760	760	860
5. Indirect costs[g]	4,680	3,150	3,980	5,250	6,120	7,500	7,630
6. Capital recovery	4,290	4,680	4,680	5,970	10,130	10,130	10,510
7. Total annualized cost, $[h]	18,000	11,700	14,800	22,800	28,500	37,200	36,200

[a]Packed-bed scrubber sizes are ranked from the lowest gas flow rate (Column A) to the highest gas flow rate (Column E). Columns B_1 and B_2 present annualized costs for the 340-m^3/min (12,000-ft^3/min) unit based on operating times of 2,000 and 4,000 hours/year, respectively. Columns D_1 and D_2 present annualized costs for the 990-m^3/min (35,000-ft^3/min) unit based on operating times of 3,500 and 6,000 hours/year, respectively.
[b]Value for parameter provided by Vendor A.
[c]The incremental fan motor size is the additional horsepower required to operate the control device over the horsepower required to operate the ventilation system.
[d]Annualized costs are presented in November 1988 dollars and were calculated from the control device parameters provided by Vendor A and the operating hours specified above. All costs were rounded to the nearest $10.
[e]Includes operator, supervisor, and maintenance labor.
[f]Includes cost of packing replacement and disposal and transportation of old packing.
[g]Includes overhead, property tax, insurance, and administration.
[h]Numbers may not add exactly due to independent rounding. Cost data were rounded to nearest $100.

TABLE F-12. CAPITAL COSTS OF MIST ELIMINATORS AND PACKED-BED SCRUBBERS FOR HARD CHROMIUM PLATING MODEL PLANTS[a]
(November 1988 Dollars)

	Chevron-blade mist eliminator		Scrubber	
Model plant size	Single set of blades	Double set of blades	Single packed bed	Double packed bed
Small[b]				
Purchased equipment	10,100	11,400	19,500	22,800
Installation	12,300	12,300	17,000	17,000
Startup[c]	100	100	200	200
Total capital cost[d]	22,500	23,800	36,700	40,000
Medium[e]				
Purchased equipment	24,400	28,700	47,300	59,600
Installation	20,800	20,800	26,400	26,400
Startup[c]	200	300	500	600
Total capital cost[d]	45,400	49,800	74,200	86,600
Large[f]				
Purchased equipment	48,800	57,400	94,600	119,200
Installation	41,700	41,700	52,900	52,900
Startup[c]	500	600	900	1,200
Total capital cost[d]	91,000	99,700	148,400	173,300

[a]Capital costs for mist eliminators are form Tables F-4 and F-5, and capital costs for scrubbers are from Tables F-6 and F-7.
[b]Small model plant costs for each control device type are from Column B in Tables F-4 through F-7.
[c]Startup costs are based on 1 percent of the purchased equipment cost.
[d]Total capital cost is the sum of purchased equipment, installation, and startup costs. Costs were rounded to the nearest $100.
[e]Medium model plant costs for each control device type are from Column D in Tables F-4 through F-7.
[f]Large model plant costs for each control device type are two times medium model plant costs.

TABLE F-13. CAPITAL COSTS OF MIST ELIMINATORS AND PACKED-BED SCRUBBERS FOR DECORATIVE PLATING MODEL PLANTS[a]
(November 1988 Dollars)

Model plant size	Chevron-blade mist eliminator: Single set of blades	Chevron-blade mist eliminator: Double set of blades	Scrubber: Single packed bed	Scrubber: Double packed bed
Small[b]				
Purchased equipment	10,100	11,400	19,500	22,800
Installation	12,300	12,300	17,000	17,000
Startup[c]	100	100	200	200
Total capital cost[d]	22,500	23,800	36,700	40,000
Medium[e]				
Purchased equipment	20,200	22,800	39,100	45,600
Installation	24,700	24,700	34,000	34,000
Startup[c]	200	200	400	500
Total capital cost[d]	45,100	47,700	73,500	80,100
Large[f]				
Purchased equipment	35,200	38,500	70,200	84,100
Installation	39,400	40,600	53,700	53,700
Startup[c]	400	400	700	800
Total capital cost[d]	75,000	79,500	124,600	136,600

[a]Capital costs for mist eliminators are form Tables F-4 and F-5, and capital costs for scrubbers are from Tables F-6 and F-7.
[b]Small model plant costs for each control device type are from Column B in Tables F-4 through F-7.
[c]Startup costs are based on 1 percent of the purchased equipment cost.
[d]Total capital cost is the sum of purchased equipment, installation, and startup costs. Costs were rounded to the nearest $100.
[e]Medium model plant cots are two times small model plant costs.
[f]Large model plant costs are two times the control device costs in Column C plus the control device costs in Column A from Tables F-4 through F-7.

TABLE F-14. CAPITAL COSTS OF MIST ELIMINATORS AND PACKED-BED SCRUBBERS FOR CHROMIC ACID ANODIZING MODEL PLANTS[a]
(November 1988 Dollars)

Model plant size	Chevron-blade mist eliminator: Single set of blades	Chevron-blade mist eliminator: Double set of blades	Scrubber: Single packed bed	Scrubber: Double packed bed
Small[b]				
Purchased equipment	10,100	11,400	19,500	22,800
Installation	12,300	12,300	17,000	17,000
Startup[c]	100	100	200	200
Total capital cost[d]	22,500	23,800	36,700	40,000
Large[f]				
Purchased equipment	27,700	29,500	52,100	63,100
Installation	20,600	20,600	26,100	26,100
Startup[c]	300	300	500	600
Total capital cost[d]	48,600	50,400	78,700	89,800

[a]Capital costs for mist eliminators are form Tables F-4 and F-5, and capital costs for scrubbers are from Tables F-6 and F-7.
[b]Small model plant costs for each control device type are from Column B in Tables F-4 through F-7.
[c]Startup costs are based on 1 percent of the purchased equipment cost.
[d]Total capital cost is the sum of purchased equipment, installation, and startup costs. Costs were rounded to the nearest $100.
[e]Large model plant costs for each control device type are from Column E in Tables F-4 through F-7.

TABLE F-15. ANNUALIZED COST OF MIST ELIMINATORS AND PACKED-BED SCRUBBERS FOR HARD CHROMIUM PLATING MODEL PLANTS[a]
(November 1988 Dollars)

	Chevron-blade mist eliminator		Scrubber	
Model plant size	Single set of blades	Double set of blades	Single packed-bed	Double packed-bed
Small[b]				
Utilities[c]	0	400	600	900
Operator and maintenance labor[d]	800	800	1,700	1,900
Maintenance materials	200	200	500	700
Packing replacement[e]	–	–	200	300
Indirect costs[f]	1,500	1,600	2,800	3,200
Capital recovery	2,600	2,800	4,300	4,700
Annualized cost	5,100	5,800	10,100	11,700
Chromic acid recovery[g]	(300)	(300)	(300)	(300)
Net annualized costs[h]	4,800	5,500	9,800	11,400
Medium[i]				
Utilities[c]	1,200	2,400	3,800	7,000
Operator and maintenance labor[d]	1,100	1,100	2,300	2,800
Maintenance materials	500	500	1,100	1,600
Packing replacement[e]	–	–	400	800
Indirect costs[f]	2,800	2,900	5,000	6,100
Capital recovery	5,300	5,800	8,700	10,100
Annualized cost	10,900	12,700	21,300	28,400
Chromic acid recovery[g]	(2,400)	(2,500)	(2,600)	(2,600)
Net annualized costs[h]	8,500	10,200	18,700	25,800
Large[i]				
Utilities[c]	4,200	8,300	12,900	24,100
Operator and maintenance labor[d]	1,900	1,900	3,900	5,200
Maintenance materials	1,700	1,700	3,600	5,500
Packing replacement[e]	–	–	800	1,500
Indirect costs[f]	5,800	6,100	10,400	13,300
Capital recovery	10,600	11,700	17,400	20,300
Annualized cost	24,200	29,700	49,000	69,900
Chromic acid recovery[g]	(9,100)	(9,600)	(10,000)	(10,000)
Net annualized costs[h]	15,100	20,100	39,000	59,900

[a]Annualized costs for mist eliminators are form Tables F-8 and F-9, and annualized costs for scrubbers are from Tables F-10 and F-11.

[b]Small model plant cost for each control device type are from Column B_1 in Tables F-8 through F-11.

[c]Utility costs for mist eliminators were rounded to zero if utility costs were less than or equal to $50 per year.

[d]Includes operator, supervisor, and maintenance labor.

[e]Packing replacement costs include the cost associated with purchasing new packing material and transportation and disposal of old material.

[f]Includes overhead, property tax, insurance, and administration.

[g]Chromic acid recovery credit for the mist eliminator with a single set of blades is based on a control efficiency of 90 percent. Chromic acid recovery credit for the mist eliminator with double sets of blades is based on a control efficiency of 95 percent. Chromic acid recovery credit for packed-bed scrubbers is based on a control efficiency of 99 percent. Parenthesis indicated negative values. Rounded to nearest $100.

[h]Numbers may not add exactly due to independent rounding. Cost data were rounded to nearest $100.

[i]Medium model plant costs for each control device type are from Column D_1 in Tables F-8 through F-11.

[j]Large model plant costs (except for labor requirements and labor-related costs) for each control device type are two times the annualized costs from Column D_2 in Tables F-8 through F-11. Labor costs are calculated based on the assumption that the labor required to maintain and operate more than one control device increases the labor requirement by only 30 percent for each additional control device.

TABLE F-16 ANNUALIZED COST OF MIST ELIMINATORS AND PACKED-BED SCRUBBERS FOR DECORATIVE CHROMIUM ELECTROPLATING MODEL PLANTS[a] (November 1988 Dollars)

Model plant size	Chevron-blade mist eliminator: Single set of blades	Chevron-blade mist eliminator: Double set of blades	Scrubber: Single packed-bed	Scrubber: Double packed-bed
Small[b]				
Utilities[c]	0	400	600	900
Operator and maintenance labor[d]	800	800	1,700	1,900
Maintenance materials	200	200	500	700
Packing replacement[e]	–	–	200	300
Indirect costs[f]	1,500	1,600	2,800	3,200
Capital recovery	2,600	2,800	4,300	4,700
Annualized cost	5,100	5,800	10,100	11,700
Chromic acid recovery[g]	(0)	(0)	(0)	(0)
Net annualized costs[h]	5,100	5,800	10,1000	11,700
Medium[i]				
Utilities[c]	0	1,400	2,600	3,700
Operator and maintenance labor[d]	1,400	1,400	2,800	3,400
Maintenance materials	900	900	1,800	2,800
Packing replacement[e]	–	–	300	600
Indirect costs[f]	3,200	3,300	5,700	6,900
Capital recovery	5,300	5,600	8,600	9,400
Annualized cost	10,800	12,600	21,800	26,800
Chromic acid recovery[g]	(100)	(100)	(200)	(200)
Net annualized costs[h]	10,700	12,500	21,600	26,600
Large[i]				
Utilities[c]	2,600	5,200	8,500	15,100
Operator and maintenance labor[d]	2,100	2,100	4,100	5,200
Maintenance materials	2,100	2,100	4,100	6,200
Packing replacement[e]	–	–	600	1,100
Indirect costs[f]	5,500	5,700	10,000	12,400
Capital recovery	8,800	9,300	14,600	16,200
Annualized cost	21,100	24,400	41,900	56,200
Chromic acid recovery[g]	(1,400)	(1,400)	(1,500)	(1,500)
Net annualized costs[h]	19,700	23,000	40,400	54,700

[a]Annualized costs for mist eliminators are from Tables F-8 and F-9, and annualized costs for scrubbers are from Tables F-10 and F-11.

[b]Small model plant cost for each control device type are from Column B_1 in Tables F-8 through F-11.

[c]Includes operator, supervisor, and maintenance labor.

[d]Packing replacement costs include the cost associated with purchasing new packing material and transportation and disposal of old material.

[e]Includes overhead, property tax, insurance, and administration.

[f]Chromic acid recovery credit for single-blade chevron-blade mist eliminators is based on a control efficiency of 90 percent. Chromic acid recovery credit for double-blade chevron-lade mist eliminators is based on a control efficiency of 95 percent. Chromic acid recovery credit for packed-bed scrubbers is based on a control efficiency of 97 percent. Parentheses indicate negative values. Rounded to nearest $100.

[g]Numbers may not add exactly due to independent rounding. Cost were rounded to nearest $100.

[h]Medium model plant (except for labor requirements and labor-related costs)are two times the cost present in Column B_2 in Tables F-8 through F-11. Labor costs are calculated based on the assumption that the labor required to maintain and operate more than one control device increases the labor requirement by only 30 percent for each additional control device.

[i]Large model plant costs (except for labor requirements and labor-related costs) are two times the costs from Column C plus the costs in Column A in Tables F-8 through F-11. Labor costs are calculated based on the assumption that the labor required to maintain and operate more than one control device increases the labor requirement by only 30 percent for each additional control device.

TABLE F-17 ANNUALIZED COST OF MIST ELIMINATORS AND PACKED-BED SCRUBBERS FOR DECORATIVE CHROMIUM ELECTROPLATING MODEL PLANTS[a] (November 1988 Dollars)

	Chevron-blade mist eliminator		Scrubber	
Model plant size	Single set of blades	Double set of blades	Single packed-bed	Double packed-bed
Small[b]				
Utilities[c]	0	400	600	900
Operator and maintenance labor[d]	800	800	1,700	1,900
Maintenance materials	200	200	500	700
Packing replacement[e]	--	--	200	300
Indirect costs[f]	1,500	1,600	2,800	3,200
Capital recovery	2,600	2,800	4,300	4,700
Annualized cost	5,100	5,800	10,100	11,700
Chromic acid recovery[g]	(0)	(0)	(0)	(0)
Net annualized costs[h]	5,100	5,800	10,1000	11,700
Large[j]				
Utilities[c]	0	2,100	5,000	10,500
Operator and maintenance labor[d]	1,400	1,400	3,100	4,000
Maintenance materials	800	800	1,900	2,800
Packing replacement[e]	--	--	400	900
Indirect costs[f]	3,300	3,400	6,200	7,600
Capital recovery	5,700	5,900	9,200	10,500
Annualized cost	11,200	13,600	25,800	36,300
Chromic acid recovery[g]	(200)	(200)	(300)	(300)
Net annualized costs[h]	11,000	13,400	25,500	36,000

[a]Annualized costs for mist eliminators are from Tables F-8 and F-9, and annualized costs for scrubbers are from Tables F-10 and F-11.

[b]Small model plant cost for each control device type are from Column B_1 in Tables F-8 through F-11.

[c]Utility costs for mist eliminators were rounded to zero if utility costs were less than or equal to $50 per year.

[d]Includes operator, supervisor, and maintenance labor.

[e]Packing replacement costs include the cost associated with purchasing new packing material and transportation and disposal of old material.

[f]Includes overhead, property tax, insurance, and administration.

[g]Chromic acid recovery credit for single-blade chevron-blade mist eliminators is based on a control efficiency of 90 percent. Chromic acid recovery credit for double-blade chevron-lade mist eliminators is based on a control efficiency of 95 percent. Chromic acid recovery credit for packed-bed scrubbers is based on a control efficiency of 97 percent. Parentheses indicate negative values. Rounded to nearest $100.

[h]Numbers may not add exactly due to independent rounding. Cost data were rounded to nearest $100.

[i]Large model plant costs (except for labor requirements and labor-related costs) are two times the costs from Column C_2 plus the costs in Column A in Tables F-8 through F-11. Labor costs are calculated based on the assumption that the labor required to maintain and operate more than one control device increases the labor requirement by only 30 percent for each additional control device.

TABLE F-18. MODEL PLANT PARAMETERS FOR THE HARD AND DECORATIVE CHROMIUM PLATING AND CHROMIC ACID ANODIZING MODEL PLANTS - MESH-PAD MIST ELIMINATORS

Model operation	Plant size: Small	Medium	Large
Hard chromium plating			
Operating time, hr/yr	2,000	3,500	6,000
Percent time electrodes are energized	70	70	80
Total ampere-hours per year	5.0×10^6	42×10^6	160×10^6
No. of tanks	1	4	8
Dimensions of tanks (l,w,d), m (ft)	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	1.2, 1.2, 3.0 (4.0, 4.0, 10.0) 2 @ 3.6, 1.2, 1.8 (12.0, 4.0, 6.0) 7.6, 0.9, 1.8 (25.0, 3.0, 6.0)	2 @ 1.2, 1.2, 3.0 (4.0, 4.0, 10.0) 4 @ 3.6, 1.2, 1.8 (12.0, 4.0, 6.0) 2 @ 7.6, 0.9, 1.8 (25.0, 3.0, 6.0)
Ventilation rate per tank m^3/min (ft^3/min)	297 (10,500)	57 (2,000) 2 @ 170 (6,000) 531 (18,750)	2 @ 57 (2,000) 4 @ 170 (6,000) 2 @ 531 (18,750)
No. of control devices	1	4	8
Size of each control device, m^3/min (ft^3/min)	297 (10,500)	170 (6,000) 230 (8,000) 2 @ 280 (10,000)	2 @ 170 (6,000)) 2 @ 230 (8,000) 4 @ 280 (10,000)
Uncontrolled hexavalent chromium emission rate, kg/yr (lb/yr)	50 (110)	420 (925)	1,600 (3,530)
Decorative chromium plating			
Operating time, hr/yr	2,000	4,000	6,000
Percent time electrodes are energized	60	60	60
Total ampere-hours per year	3.0×10^6	12×10^6	120×10^6
No. of tanks	1	2	5
Dimensions of tanks (l, s,d), m (ft)	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	2 @ 3.6, 1.1, 1.8 (12.0, 3.5, 6.0) 2 @ 297 (10,500)	5 @ 3.6, 1.8, 2.7 (12.0, 6.0, 9.0) 5 @ 255 (9,000)
Ventilation rate per tank, m^3/min (ft^3/min)	297 (10,500)		
No. of control devices	1	2	5
Size of each control device, m^3/min (ft^3/min)	297 (10,500)	2 @ 297 (10,500)	5 @ 297 (10,500)
Uncontrolled hexavalent chromium emission rate, kg/yr (lb/yr)	6.0 (13.0)	24 (53)	240 (530)
Chromic acid anodizing			
Operating time, hr/yr	2,000		6,000
Percent time electrodes are energized	70		40
No. of tanks	1		2
Dimensions of tanks (l, s,d), m (ft)	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)		2 @ 9.1, 1.5, 2.7 (30.0, 5.0, 9.0)
Ventilation rate per tank, m^3/min (ft^3/min)	297 (10,500)		2 @ 531 (18,750)
No. of control devices	1		4
Size of each control device, m^3/min (ft^3/min)	297 (10,500)		4 @ 280 (10,000))
Uncontrolled hexavalent chromium emission rate, kg/yr (lb/yr)	3.3 (7.2)		40 (88)

TABLE F-19. ANNUAL OPERATING COST FACTORS

Cost categories	Cost factors
Direct operating costs	
1. Operating labor	
a. Operating[10]	$8.37/hr
b. Supervisor[5]	15 percent of 1a
2. Maintenance	
a. Labor[10,11]	$9.21/hr
b. Materials[5]	100 percent of 3a
3. Replacement parts (mesh pad)[5,16]	31.5 percent of capital cost of mesh pad materia @ $300/ft[3a]
4. Transportation and disposal of used mesh pads[9]	$50/drum disposal (plus 10 percent tax) $40/drum transportation
5. Utilities	
a. Electricity[6]	$0.0461/kWh
b. Water[7]	$0.77/1,000 gal
Indirect operating costs	
6. Overhead[5]	60 percent of 1a + 1b + 3a + 3b
7. Property tax[5]	1 percent of capital cost
8. Insurance[5]	1 percent of capital cost
9. Administration[5]	2 percent of capital cost
10. Capital recovery[5]	16.3 percent of capital cost of mesh-pad mist eliminator[b]
Credits	
Chromic acid recovery[12]	$3.28/kg

[a]Based on an interest rate of 10 percent and a mesh pad life of 4 years.

[b]Based on an interest rate of 10 percent and an equipment life of 10 years.

TABLE F-20. CAPITAL COSTS OF MESH-PAD MIST ELIMINATORS

	Mist eliminator size[a]			
	A	B	C	D
Control device parameter				
Design gas flow rate, actual m^3/min (ft^3/min)[b]	170 (6,000)	230 (8,000)	280 (10,000)	240 (12,000)
Pressure drop, kPa (in. w.c.)[c]	0.75 (3.0)	0.75 (3.0)	0.75 (3.0)	0.75 (3.0)
Fan static pressure, kPa (in. w.c.)[c]	1.2 (5)	1.2 (5)	1.2 (5)	1.2 (5)
Fan motor size, hp (kW)[c]	7.5 (5.6)	10 (7.5)	15 (11)	15 (11)
Cost data[d]				
1. Basic mist eliminator	4,000	5,300	5,500	6,000
2. Inlet and outlet transition	------------Included in basic mist eliminator------------			
3. Fan and motor	3,600	3,900	4,500	5,100
4. Washdown water pump and motor	700	800	900	1,000
5. Stack	300	400	700	800
6. Base equipment[e]	8,600	10,400	11,600	12,900
7. Sales taxes and freight[f]	690	830	930	1,040
8. Total purchased equipment[g]	9,290	11,230	12,530	13,940
9. Installation[h]	2,000	2,000	2,000	2,000
10. Startup[i]	90	110	130	140
11. Total capital cost[j]	11,400	13,300	14,700	16,100

[a]Mist eliminator size are ranked from the lowest gas flow rate (Column A) to the highest gas flow rate (Column D).

[b]Gas stream temperature is 27°C (80°F), gas stream moisture content is 2 percent, and altitude is 305 m (1,000 ft).

[c]Parameter provided by Vendor I.

[d]Capital costs presented in this table are based on Vendor I estimates. Vendor I provide base equipment and installation costs in November 1988 dollars. Costs were rounded to nearest $10.

[e]Sum of 1 through 5.

[f]Sales taxes and freight costs are 3 and 5 percent, respectively, of base equipment costs.

[g]Sum of 6 and 7.

[h]Includes all costs associated with installing instrumentation, electrical components, and piping; and erection. Does not include cost of engineering services, contractor fee, or contingencies. Assumed that control devices are installed on the roof of a plant that is 6.1 m (21 ft) high and no structural modifications are necessary.

[i]One percent of total purchased equipment cost.

[j]Sum of 8, 9, and 10. Costs were rounded to nearest $100.

TABLE F-21. ANNUALIZED COSTS OF MESH-PAD MIST ELIMINATORS

	Mist eliminator size[a]							
	A_1	A_2	B_1	B_2	C_1	C_2	D_1	D_2
Control device parameters								
Gas flow rate, actual m^3/min (ft^3/min)	170 (6,000)	170 (6,000)	230 (8,000)	230 (8,000)	280 (10,000)	280 (10,000)	340 (12,000)	340 (12,000)
Operating time, hr/yr	3,500	6,000	3,500	6,000	3,500	6,000	3,500	6,000
Frequency of washdown, No. times/8 hr of operation[b]	1	1	1	1	1	1	1	1
Volume of water per washdown, liters (gal)[b]	38 (10)	38 (10)	76 (20)	76 (20)	95 (25)	95 (25)	95 (25)	95 (25)
Incremental fan motor size, kW (hp)[b c]	1.9 (2.5)	1.9 (2.5)	3.7 (5)	3.7 (5)	5.6 (7.5)	5.6 (7.5)	5.6 (7.5)	5.6 (7.5)
Operator hours, hr/yr[b]	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5
Maintenance, hr/yr	70	120	70	120	70	120	40	80
Life expectancy of pad material, yr[b]	4	4	4	4	4	4	4	4
Life expectancy of unit, yr[b]	10	10	10	10	10	10	10	10
Volume of pad material, m^3 (ft^3)	0.13 (4.7)	0.13(4.7)	0.17 (6.0)	0.17 (6.0)	0.21 (7.4)	0.21 (7.4)	0.26 (9.2)	0.26 (9.2)
Cost data[d]								
1. Utilities	300	530	610	1,040	910	1,560	520	1,040
2. Operator, supervisor, and maintenance labor	1,240	1,710	1,240	1,710	1,240	1,710	970	1,340
3. Maintenance material	640	1,110	640	1,110	640	1,110	370	740
4. Mesh pad replacement[e]	470	470	590	590	750	750	930	930
5. Indirect costs[f]	1,590	2,150	1,660	2,220	1,720	2,280	1,440	1,890
6. Capital recovery	1,860	1,860	2,170	2,170	2,400	2,400	2,620	2,620
7. Total annualized costs, $[g]	6,100	7,800	6,900	8,800	7,700	9,800	6,900	8,600

[a]Mist eliminator sizes are ranked from the lowest gas flow rate (Column A_1) to the highest gas flow rate (Column D_2). Columns A_1 and A_2 present annualized costs for the 170 m^3/min (6,000 ft^3/min) unit based on operating times of 3,500 and 6,000 hr/yr, respectively. Columns B_1 and B_2 present annualized costs for the 230 m^3/min (8,000 ft^3/min) unit based on operating times of 3,500 and 6,000 hr/yr, respectively. Columns C_1 and C_2 present annualized costs for the 280 m^3/min (10,000 ft^3/min) unit based on operating times of 3,500 and 6,000 hr/yr, respectively. Columns D_1 and D_2 present annualized costs for the 340 m^3/min (12,000 ft^3/min) unit based on operating times of 2,000 and 4,000 hr/yr, respectively.

[b]Value for parameter provided by Vendor I.

[c]The incremental fan motor size is the additional horsepower required to operate with the control device over the horsepower required to operate the ventilation system only.

[d]Annualized costs are presented in November 1988 dollars and were calculated from the control device parameters provided by Vendor I and the operating hours specified above. Cost factors are presented in Table F-19. All costs were rounded to nearest $10.

[e]Includes pad replacement and transportation and disposal costs for used pads.

[f]Includes overhead, property tax, insurance, and administration.

[g]All costs were rounded to the nearest $100. Numbers may not add exactly due to independent rounding.

TABLE F-22. MODEL PLANT CAPITAL COST ESTIMATES FOR MESH-PAD MIST ELIMINATORS[a]
(November 1988 Dollars)

	Model plant size		
Type of operation	Small	Medium	Large
Hard chromium plating[b]			
Total purchased equipment (TPE)	13,900	45,600	91,200
Incremental ductwork cost[c]	0	4,900	9,800
Installation cost[d]	9,000	15,000	23,000
Startup (1 percent of TPE)	100	500	900
Total capital costs, $	23,000	66,000	124,900
Decorative chromium plating[e]			
Total purchased equipment (TPE)	13,900	27,900	62,700
Incremental ductwork cost[c]	0	0	6,800
Installation cost[d]	9,000	11,000	17,000
Startup (1 percent of TPE)	100	300	700
Total capital costs, $	23,000	39,200	87,200
Chromic acid anodizing[f]			
Total purchased equipment (TPE)	13,900		50,100
Incremental ductwork cost[c]	0		26,100
Installation cost[d]	9,000		15,000
Startup (1 percent of TPE)	100		500
Total capital costs, $	23,000		91,700

[a]All cost data were rounded to the nearest $100.
[b]Small model plant costs are equal to costs presented in Column D; and medium model plant costs are equal to sum of Columns A and B plus two times Column C in Table F-20. Large model plant costs are twice the cost of the medium model plant.
[c]Estimated cost of additional ductwork required to modify typical capture system to accommodate installation of mesh-pad mist eliminator.
[d]Installation costs include the direct cost of the installation of each unit plus an indirect cost of $7,000 per plant that covers the cost of engineering services, contractors fees, and contingencies.
[e]Small model plant costs equal to the costs presented in Column D; medium model plant costs are two times the costs presented in Column D; large model plant costs are equal to five times the costs presented in Column C in Table F-20.
[f]Small model plant costs are equal to the costs presented in Column D. Large model plant costs are equal to four times the costs presented in Column C in Table F-20.

TABLE F-23. MODEL PLANT ANNUALIZED COST ESTIMATES FOR MESH-PAD MIST ELIMINATORS[a]
(November 1988 Dollars)

Type of operation	Model plant size: Small	Medium	Large
Hard chromium plating			
Utilities	500	2,700	9,400
Operator and maintenance labor[b]	1,000	2,400	5,300
Maintenance materials	400	2,600	8,900
Mesh pad replacement[c]	900	2,600	5,100
Indirect costs[d]	1,700	5,600	13,500
Capital recovery[e]	3,800	10,800	20,400
Annualized cost	8,300	26,700	62,600
Chromic acid recovery[f]	(0)	(2,600)	(10,000)
Net annualized cost	8,300	24,100	52,600
Decorative chromium plating			
Utilities	500	2,100	7,800
Operator and maintenance labor[b]	1,000	1,700	3,800
Maintenance materials	400	1,500	5,600
Mesh pad replacement[c]	900	1,900	3,800
Indirect costs[d]	1,700	3,500	9,100
Capital recovery[e]	3,800	6,400	14,200
Annualized cost	8,300	17,100	44,300
Chromic acid recovery[g]	(0)	(200)	(1,500)
Net annualized cost	8,300	16,900	42,800
Chromic acid anodizing			
Utilities	500		6,200
Operator and maintenance labor[b]	1,000		3,200
Maintenance materials	400		4,400
Mesh pad replacement[c]	900		3,000
Indirect costs[d]	1,700		8,300
Capital recovery[e]	3,800		15,000
Annualized cost	8,300		40,100
Chromic acid recovery[g]	(0)		(300)
Net annualized cost	8,300		39,800

[a]All costs are rounded to the nearest $100.
[b]Includes operator, supervisor, and maintenance labor.
[c]Mesh pad replacement costs are based on a 4-year life for the pad material. Includes cost of mesh pad replacement and transportation and disposal costs of used pads.
[d]Includes overhead, property tax, insurance, and administration.
[e]Capital recovery includes cost of capital for mesh-pad mist eliminator unit(s) plus cost of capital for incremental ductwork
[f]Chromic acid recovery credits are based on a removal efficiency of 99 percent for mesh-pad mist eliminators used in hard chromium plating processes. Parenthesis indicate negative values.
[g]Chromic acid recovery credits are based on a removal efficiency of 97 percent for mesh-pad mist eliminators used in decorative chromium and chromium acid anodizing operations.

TABLE F-24. RETROFIT CAPITAL COSTS FOR MODEL PLANTS[a b]
(November 1988 Dollars)

Process/control device	Model plant size		
	Small	Medium	Large
Hard chromium plating			
Chevron-blade mist eliminator (single set of blades)	28,100	56,900	113,800
Chevron-blade mist eliminator (double set of blades)	29,800	62,400	124,800
Single packed-bed horizontal flow scrubber	45,900	92,800	185,500
Double packed-bed horizontal flow scrubber	50,000	108,300	216,500
Mesh-pad mist eliminator	28,900	82,500	156,300
Decorative chromium plating			
Chevron-blade mist eliminator (single set of blades)	28,100	56,300	93,500
Chevron-blade mist eliminator (double set of blades)	29,800	59,500	99,300
Single packed-bed horizontal flow scrubber	45,900	91,800	155,900
Double packed-bed horizontal flow scrubber	50,000	100,000	173,400
Mesh-pad mist eliminator	28,900	49,000	109,100
Chromic acid anodizing			
Chevron-blade mist eliminator (single set of blades)	28,100		60,800
Chevron-blade mist eliminator (double set of blades)	29,800		63,000
Single packed-bed horizontal flow scrubber	45,900		98,400
Double packed-bed horizontal flow scrubber	50,000		112,300
Mesh-pad mist eliminator	28,900		114,900

[a]All costs rounded to nearest $100. Retrofit costs are the installed capital costs of the system, including the cost of removal, transportation, and disposal of any existing control device and any necessary retrofit modifications.

[b]Note: Retrofit cost estimates were calculated using the basic control device costs per model plant and, therefore, may not equal the installed model plant capital costs for new facilities multiplied by 1.25.

TABLE F-25. RETROFIT ANNUALIZED COSTS FOR MODEL PLANTS[a] [b]
(November 1988 Dollars)

Process/control device	Model plant size: Small	Medium	Large
Hard chromium plating			
Chevron-blade mist eliminator (single set of blades)	6,100	12,700	27,800
Chevron-blade mist eliminator (double set of blades)	6,700	14,700	33,600
Single packed-bed horizontal flow scrubber	11,500	24,200	54,800
Double packed-bed horizontal flow scrubber	13,300	31,900	76,700
Mesh-pad mist eliminator	9,500	29,900	69,000
Decorative chromium plating			
Chevron-blade mist eliminator (single set of blades)	6,100	12,500	23,900
Chevron-blade mist eliminator (double set of blades)	6,700	14,500	27,500
Single packed-bed horizontal flow scrubber	11,500	24,600	46,700
Double packed-bed horizontal flow scrubber	13,300	29,900	61,700
Mesh-pad mist eliminator	9,500	19,100	48,800
Chromic acid anodizing	6,100		
Chevron-blade mist eliminator (single set of blades)	6,700		13,100
Chevron-blade mist eliminator (double set of blades)	11,500		15,600
Single packed-bed horizontal flow scrubber	13,300		28,900
Double packed-bed horizontal flow scrubber	9,500		39,800
Mesh-pad mist eliminator			44,700

[a]All costs rounded to nearest $100.

TABLE F-26. RETROFIT CAPITAL COSTS FOR MODEL PLANTS[a] [b]
(November 1988 Dollars)

Process/control device	Model plant size: Small	Medium	Large
Hard chromium plating			
Chevron-blade mist eliminator (single set of blades)	5,800	10,300	18,700
Chevron-blade mist eliminator (double set of blades)	6,400	12,200	24,000
Single packed-bed horizontal flow scrubber	11,200	21,600	44,800
Double packed-bed horizontal flow scrubber	13,000	29,300	66,700
Mesh-pad mist eliminator	9,200	27,300	59,000
Decorative chromium plating			
Chevron-blade mist eliminator (single set of blades)	6,100	12,400	22,500
Chevron-blade mist eliminator (double set of blades)	6,700	14,400	26,100
Single packed-bed horizontal flow scrubber	11,500	24,400	45,200
Double packed-bed horizontal flow scrubber	13,300	29,700	60,200
Mesh-pad mist eliminator	9,500	18,900	47,300
Chromic acid anodizing			
Chevron-blade mist eliminator (single set of blades)	6,100		12,900
Chevron-blade mist eliminator (double set of blades)	6,700		15,400
Single packed-bed horizontal flow scrubber	11,500		28,600
Double packed-bed horizontal flow scrubber	13,300		39,500
Mesh-pad mist eliminator	9,500		44,400

[a]All costs rounded to nearest $100.

TABLE F-27. LIST OF MANUFACTURERS WHO PROVIDED COST INFORMATION ON INDIVIDUAL FUME SUPPRESSANTS

Manufacturer/brands	Type of fume suppressant
Vendor D[20]	
Product 1[a]	Temporary/foam blanket[b,c]
Product 2	Permanent/combination[d,e]
Product 3[f]	Permanent/combination
Vendor E[21]	
Product 4	Permanent/wetting agent[g]
Product 5	Permanent/foam blanket
Product 6	Permanent/combination
Product 7	Temporary/foam blanket
Vendor F[22]	
Product 8	Permanent/combination
Product 9	Permanent/combination
Product 10	Permanent/wetting agent
Vendor F[23]	
Product 11	Temporary/foam blanket
Product 12	Temporary/foam blanket
Product 13	Permanent/combination
Product 14	Permanent/combination
Product 15	Permanent/combination
Vendor H[24]	
Product 16[a]	Permanent/foam blanket

[a]Cost data were not included in development of annual costs for fume suppressants.
[b]Temporary fume suppressants are depleted from drag-out and decomposition of the fume suppressants.
[c]Foam blankets produce a layer of foam on the surface of the plating solution to entrap chromic acid mist.
[d]Permanent fume suppressants are depleted mainly from drag-out of the fume suppressant.
[e]Combination fume suppressants are a combination of wetting agents and foam blankets.
[f]Cost data were not included in development of annual costs of fume suppressants for decorative plating operations but were used in development of fume suppressant annual costs for anodizing operations.
[g]Wetting agents reduce the amount of chromic acid mist by lowering the surface tension of the bath.

TABLE F-28. PARAMETERS FOR DECORATIVE CHROMIUM PLATING MODEL TANKS

Model tank information	Model tank			
	$42\text{-}ft^2$ [a]	$42\text{-}ft^2$ [b]	$72\text{-}ft^2$ [a]	$72\text{-}ft^2$ [b]
Tank dimensions, ft	12.0, 3.5, 6.0	12.o, 3.5, 6.0	12.0, 6.0, 9.0	12.0, 6.0, 9.0
Tank capacity, gal	1,730	1,730	4,580	4,580
Operating voltage, V	6-7.5	6	16	10
Operating current, A	4,000	2,600	6,000	6,800
Current density, A/ft^2	72-360	124	72-360	124
Temperature, °F	100-115	100-115	100-115	100-115
Chromic acid concentration, oz/gal	35-40	40	35-40	40
Chromic acid: sulfuric acid ratio	170:1	100:1	170:1	100:1
Plant operating time, hr/yr	2,000	2,000	6,000[c]	6,000
Time electrodes are energized, %	80	60	80	60
Tank operating time, hr/yr[d]	1,600	1,200	4,800	3,600

[a]Fume suppressant cost data obtained from manufacturers were based on the original model tank parameters.
[b]Adjusted model tank parameters.
[c]The original model plant operating time was actually 6,240 hr/yr, but for simplicity 6,000 hr/yr was the value submitted to vendors.
[d]To obtain the tank operating time, multiply the plant operating time by the percent time electrodes are energized.

TABLE F-29. PARAMETERS FOR CHROMIC ACID ANODIZING MODEL TANKS

	Model tank			
Model tank information	42-ft[2a]	42-ft[2b]	150-ft[2a]	150-ft[2b]
Tank dimensions, ft	12.0, 3.5, 6.0	12.0, 3.5, 6.0	30.0, 5.0, 9.0	30.0, 5.0, 9.0
Tank capacity, gal	1,730	1,730	4,580	4,580
Operating voltage, (step-wise), V	6-7.5	6	16	10
Current density, A/ft^2	4,000	2,600	6,000	6,800
Temperature, °F	100-115	100-115	100-115	100-115
Chromic acid concentration, oz/gal	35-40	40	35-40	40
Chromic acid: sulfuric acid ratio	170:1	100:1	170:1	100:1
Plant operating time, hr/yr	2,000	2,000	6,000[c]	6,000
Time electrodes are energized, %	80	60	80	60
Tank operating time, hr/yr	1,600	1,200	4,800	3,600

[a]Fume suppressant cost data obtained from manufacturers were based on the original model tank parameters.
[b]Adjusted model tank parameters.
[c]The original model plant operating time was actually 6,240 hr/yr, but for simplicity 6,00 hr/yr was the value submitted to vendors.
[c]To obtain the tank operating time, multiply the plant operating time by the percent time electrodes are energized.

TABLE F-30. PERMANENT FUME SUPPRESSANT MAKEUP AND MAINTENANCE COST DATA FOR THE 42-ft^2 DECORATIVE CHROMIUM PLATING MODEL TANK (1986 Dollars)

Manufacturer/ fume suppressant brand	Purchase cost, \$/gal or \$/lb	Initial makeup, gal or lb	Initial makeup cost, \$	Annual tank maintenance consumption, gal or lb	Maintenance cost, \$/yr[a]
Vendor G					
Product 13[a]	32.78	5.00	163.90	58.00	1,901
Product 14[c]	68.38	2.50	170.95	23.00	1,572
Product 15[c]	59.12	2.50	147.80	23.00	1,360
Vendor D					
Product 2[b]	23.50	8.50	199.75	44.00	1,031
Vendor E					
Product 4[b]	25.00	5.10	127.50	24.00	600
Product 5[b]	21.00	2.50	52.20	36.00	756
Product 6[b]	22.00	6.80	149.60	24.00	528
Vendor F					
Product 10[c]	49.00	3.46	169.54	12.30	600
Product 8[c]	53.50	3.46	185.11	12.30	660
Product 9[c]	56.50	3.46	195.49	12.30	690
AVERAGE			156.00		970

[a]Maintenance costs are based on a tank operating time of 1,600 hours per year.
[b]Cost data and solution makeup additions are in pounds.
[c]Cost data and solution makeup additions are in gallons.

TABLE F-31. TEMPORARY FUME SUPPRESSANT MAKEUP AND MAINTENANCE COST DATA FOR THE 42-ft^2 DECORATIVE CHROMIUM PLATING MODEL TANK
(1986 Dollars)

Manufacturer/ fume suppressant brand	Purchase cost, $/gal	Initial makeup, gal	Initial makeup cost, $	Annual tank maintenance consumption, gal	Maintenance cost, $/yr[a]
Vendor G					
Product 11	19.31	0.63	12.17	70.00	1,351
Product 12	22.31	0.42	9.37	70.00	1,560
Vendor E					
Product 7	13.00	1.70	22.10	30.00	390
AVERAGE			15.00		1,100

[a]Maintenance costs are based on a tank operating time of 1,600 hours per year.

TABLE F-32. PERMANENT FUME SUPPRESSANT MAKEUP AND MAINTENANCE COST DATA FOR THE 72-ft^2 DECORATIVE CHROMIUM PLATING MODEL TANK (1986 Dollars)

Manufacturer/ fume suppressant brand	Purchase cost, $/gal or $/lb	Initial makeup, gal or lb	Initial makeup cost, $	Tank maintenance consumption, gal or lb	Maintenance cost, $/yr[a]
Vendor G					
Product 13[b]	32.78	14.00	458.92	157.00	5,146
Product 14[c]	68.38	6.90	471.82	62.00	4,239
Product 15[c]	59.12	6.90	407.93	62.00	3,665
Vendor D					
Product 2[b]	23.50	22.90	538.15	238.00	5,593
Vendor E					
Product 4[b]	25.00	13.50	337.50	90.00	2,250
Product 5[b]	21.00	6.80	142.80	108.00	2,268
Product 6[b]	22.00	18.00	396.00	60.00	1,320
Vendor F					
Product 10[c]	49.00	9.16	448.84	97.60	4,780
Product 8[c]	53.50	9.16	490.06	97.60	5,220
Product 9[c]	56.50	9.16	517.54	97.60	5,510
AVERAGE			420.00		4,000

[a]Maintenance costs are based on a tank operating time of 4,800 hours per year.
[b]Cost data and solution makeup and maintenance additions are in pounds.
[c]Cost data and solution makeup and maintenance additions are in gallons.

TABLE F-33. TEMPORARY FUME SUPPRESSANT MAKEUP AND MAINTENANCE COST DATA FOR THE 72-ft^2 DECORATIVE CHROMIUM PLATING MODEL TANK (1986 Dollars)

Manufacturer/ fume suppressant brand	Purchase cost, $/gal	Initial makeup, gal	Initial makeup cost, $	Tank maintenance consumption, gal	Maintenance cost, $/yr[a]
Vendor G					
Product 11	19.31	1.69	32.63	189.00	3,649
Product 12	22.31	1.15	25.66	189.00	4,216
Vendor E					
Product 7	13.00	4.00	52.00	90.00	1,170
AVERAGE			37.00		3,012

[a]Maintenance costs are based on a tank operating time of 4,800 hours per year.

TABLE F-34. PERMANENT FUME SUPPRESSANT MAKEUP AND MAINTENANCE COST DATA FOR THE CHROMIC ACID ANODIZING MODEL TANKS (1986 Dollars)

Model tank information	Model tank $42-ft^2$	Model tank $150-ft^2$
1. Vendor D - Product 3		
a. Purchase cost, $/lb	23	23
b. Initial makeup, lb	2.6	14.6
c. Makeup cost, $	59.80	335.80
d. Maintenance consumption, lb/yr	15	219
e. Maintenance cost, $/yr	345	5,037
2. Vendor E - Product $		
a. Purchase cost, $/lb	25	25
b. Initial makeup, lb	5.5	32
c. Makeup cost, $	137.50	800
d. Maintenance consumption, lb/yr	24	96
e. Maintenance cost, $/yr	600	2,400

TABLE F-35 AVERAGE ANNUAL COST OF PERMANENT FUME SUPPRESSANTS FOR DECORATIVE CHROMIUM PLATING MODEL PLANTS[a]

Component	Cost data		
A. Model tank data[b]			
1. Surface area of model tank, ft^2	42		72
2. Average makeup cost of fume suppressant, $[c]	170		460
3. Average maintenance cost of fume suppressant, $/yr[c]	1,060		4,360
4. Operating time basis, hr/yr[d]	1,600		4,800
B. Model plant data[d]	Small	Medium	Large
1. No. of model tanks	1	2	5
2. Surface area of model tanks, ft^2	42	42	72
3. Operating hours, hr/yr[d]	1,200	2,400	3,600
4. Makeup cost of fume suppressant, $[c] (A2 x B1)	170	340	2,300
5. Maintenance cost of fume suppressant, $/yr[c] [f] (A3 x B1)(b3/A4)	80	3,180	16,350
6. Annual cost of fume suppressant, $/yr[g] (B4 + B5)	1,000	3,500	18,700

[a]All costs presented in November 1988 dollars.
[b]Fume suppressant cost basis (original model tank parameters).
[c]Cost data were rounded to the nearest $10.
[d]Operating time of tanks = (operating time of plant, hr/yr) multiplied by (percent time electrodes energized).
[e]Based on revised model plant parameters.
[f]Maintenance cost is adjusted by applying a ratio that corrects for the difference between the operating time of the model tanks upon which the cost data are based and the revised operating time of the model tanks.
[g]Cost data were rounded to nearest $100.

TABLE F-36. AVERAGE ANNUAL COST OF TEMPORARY FUME SUPPRESSANTS FOR DECORATIVE CHROMIUM PLATING MODEL PLANTS[a]

Component	Cost data		
A. Model tank data[b]			
1. Surface area of model tank, ft^2	42		72
2. Average makeup cost of fume suppressant, $[c]	200		50
3. Average maintenance cost of fume suppressant, $/yr[c]	1,200		3,280
4. Operating time basis, hr/yr[d]	1,600		4,800
B. Model plant data[d]	Small	Medium	Large
1. No. of model tanks	1	2	5
2. Surface area of model tanks, ft^2	42	42	72
3. Operating hours, hr/yr[d]	1,200	2,400	3,600
4. Makeup cost of fume suppressant, $[c] (A2 x B1)	20	40	200
5. Maintenance cost of fume suppressant, $/yr[c] [f] (A3 x B1)(b3/A4)	900	3,600	12,300
6. Annual cost of fume suppressant, $/yr[g] (B4 + B5)	900	3,600	12,500

[a]All costs presented in November 1988 dollars.
[b]Fume suppressant cost basis (original model tank parameters).
[c]Cost data were rounded to the nearest $10.
[d]Operating time of tanks = (operating time of plant, hr/yr) multiplied by (percent time electrodes energized).
[e]Based on revised model plant parameters.
[f]Maintenance cost is adjusted by applying a ratio that corrects for the difference between the operating time of the model tanks upon which the cost data are based and the revised operating time of the model tanks.
[g]Cost data were rounded to nearest $100.

TABLE F-37. AVERAGE ANNUAL COST OF PERMANENT FUME SUPPRESSANTS FOR CHROMIC ACID ANODIZING MODEL PLANTS[a]

Component	Cost data	
A. Model tank data[b]		
1. Surface area of model tank, ft^2	42	150
2. Average makeup cost of fume suppressant, $[c]	110	620
3. Average maintenance cost of fume suppressant, $/yr[c]	520	4,050
4. Operating time basis, hr/yr[d]	500	5,760
B. Model plant data[d]		
1. No. of model tanks	1	2
2. Surface area of model tanks, ft^2	42	150
3. Operating hours, hr/yr[d]	1,400	2,400
4. Makeup cost of fume suppressant, $[c] (A2 x B1)	110	1,240
5. Maintenance cost of fume suppressant, $/yr[c f] (A3 x B1)(b3/A4)	1,460	3,380
6. Annual cost of fume suppressant, $/yr[g] (B4 + B5)	1,600	4,600

[a]All costs presented in November 1988 dollars.
[b]Fume suppressant cost basis (original model tank parameters).
[c]Cost data were rounded to the nearest $10.
[d]Operating time of tanks = (operating time of plant, hr/yr) multiplied by (percent time electrodes energized).
[e]Based on revised model plant parameters.
[f]Maintenance cost is adjusted by applying a ratio that corrects for the difference between the operating time of the model tanks upon which the cost data are based and the revised operating time of the model tanks.
[g]Cost data were rounded to nearest $100.

TABLE F-38. LIST OF MANUFACTURERS WHO PROVIDED COST INFORMATION ON DECORATIVE TRIVALENT CHROMIUM ELECTROPLATING PROCESSES

Manufacturer	Trivalent process
Vendor F	Product 17[a]
Vendor E	Product 18[a]
Vendor D	Product 19[b]
Vendor H	Product 20[b]

[a]Single-cell process.
[b]Double-cell process.

TABLE F-39. VENDOR CAPITAL COST ESTIMATES FOR CONVERTING THE 42-ft^2 MODEL TANK FROM A HEXAVALENT CHROMIUM PROCESS TO A TRIVALENT CHROMIUM PROCESS (1986 Dollars)

	Vendor cost data			
Component	F[a]	E[a]	D[b]	H[b]
New equipment costs				
1. Anode boxes	NA[c]	NA	7,200	13,200
2. Anodes and hangers	3,000	4,600	NA	NA
3. Passivation tank				
a. Capital cost of tank	NA	NA	5,000	NA
b. Cost of initial makeup solution	NA	NA	500	NA
4. Tank liner	2,000	2,000	1,500	NA
5. Ampere-hour meter or controller	200	NA	1,500	NA
6. Filter	7,000	NA	NA	NA
7. Chiller	NA	8,500	NA	NA
Subtotal	12,200	15,100	15,700	13,200
Modification costs				
1. Tank cleaning	d	400	200	NA
2. Plating line modification	NA	3,000	NA	NA
3. Modifications to electrical supply[e]	NA	NA	NA	NA
4. Modifications to cooling system[f]	NA	NA	NA	NA
5. Initial makeup cost of Cr^{+3} solution	10,000	10,700	11,300	14,700
Subtotal	10,000	14,100	11,500	14,700
Installation costs				
1. Labor costs, $/hr	576	2,520	36	NA
2. Process downtime	3	5	1	NA
3. Indirect costs	NA	NA	NA	NA
Subtotal	576	2,520	36	0
Total[h]	22,800	31,700	27,200	27,900

[a]Single-cell process.
[b]Double-cell process.
[c]NA = not applicable.
[d]Tank cleaning cost is included in the installation cost.
[e]Assumes tank is equipped with 12-volt rectifiers.
[f]Assumes tank is equipped with external shell-and-tube heat exchangers with water used as the coolant.
[g]Assume plant is converted during a normal holiday shutdown or over a nonworking weekday. 1 day = 8-hour shift.
[h]The total capital cost provided by each individual vendor is lower than the capital cost estimated for the model tanks because vendors were basing the estimates on their trivalent chromium process and did not include all of the optional equipment. Also, the vendor data were not always complete.

TABLE F-40. VENDOR CAPITAL COST ESTIMATES FOR CONVERTING THE $72-ft^2$ MODEL TANK FROM A HEXAVALENT CHROMIUM PROCESS TO A TRIVALENT CHROMIUM PROCESS (1986 Dollars)

	Vendor cost data			
Component	F[a]	E[a]	D[b]	H[b]
New equipment costs				
1. Anode boxes	NA[c]	NA	7,200	19,200
2. Anodes and hangers	8,000	7,500	NA	NA
3. Passivation tank				
a. Capital cost of tank	NA	NA	12,000	NA
b. Cost of initial makeup solution	NA	NA	1,200	NA
4. Tank liner	3,300	3,500	3,000	NA
5. Ampere-hour meter or controller	200	NA	1,500	NA
6. Filter	10,000	NA	NA	NA
7. Chiller	NA	13,000	NA	NA
Subtotal	21,500	24,000	24,900	19,200
Modification costs				
1. Tank cleaning	d	600	200	NA
2. Plating line modification	NA	3,600	NA	NA
3. Modifications to electrical supply[e]	NA	NA	NA	NA
4. Modifications to cooling system[f]	NA	NA	NA	NA
5. Initial makeup cost of Cr^{+3} solution	24,600	28,400	29,900	38,900
Subtotal	24,600	32,000	30.100	38,900
Installation costs				
1. Labor costs, $/hr	576	2,520	36	NA
2. Process downtime	3	5	1	NA
3. Indirect costs	NA	NA	NA	NA
Subtotal	576	2,520	36	0
Total[h]	46,700	58,500	55,00	58,100

[a]Single-cell process.
[b]Double-cell process.
[c]NA = not applicable.
[d]Tank cleaning cost is included in the installation cost.
[e]Assumes tank is equipped with 12-volt rectifiers.
[f]Assumes tank is equipped with external shell-and-tube heat exchangers with water used as the coolant.
[g]Assume plant is converted during a normal holiday shutdown or over a nonworking weekday. 1 day = 8-hour shift.
[h]The total capital cost provided by each individual vendor is lower than the capital cost estimated for the model tanks because vendors were basing the estimates on their trivalent chromium process and did not include all of the optional equipment. Also, the vendor data were not always complete.

TABLE F-41. MODEL TANK PARAMETERS FOR DECORATIVE CHROMIUM PLATING MODEL TANKS

Model tank information	Model tank	
	$42\text{-}ft^2$	$72\text{-}ft^2$
Tank dimensions, ft	12.0, 3.5, 6.0	12.0, 6.0, 9.0
Tank capacity, gal	1,730	4,580

TABLE F-42. CAPITAL COST OF CONVERTING HEXAVALENT CHROMIUM PROCESS TO TRIVALENT CHROMIUM PROCESS FOR EACH MODEL TANK (November 1988 Dollars)

Component	Model tank	
	42-ft[2]	72-ft[2]
Startup (tank conversion)		
Initial trivalent chromium solution purchase[27]	10,900	27,300
Initial passivation solution purchase[a,30]	500	1,300
Waste disposal cost of hexavalent chromium solution[b,34]	3,700	8,200
Subtotal	15,100	36,800
Purchased equipment costs		
Ampere-hour controller[30]	1,600	1,600
Tank liner[27]	2,200	3,600
Replacement anodes and hangers[27]	3,300	8,700
Anode boxes[c,30]	7,800	7,800
Chiller[d,28]	9,300	14,200
Filter[d,27]	7,600	10,900
Subtotal	31,800	46,800
Taxes and freight[e,36]	2,500	3,700
TOTAL	34,300	50,500
Installation/modification[f,35]	6,900	10,100
Indirect costs[g,36]	10,600	15,700
Total cost[h]	66,900	113,100

[a]Passivation solution is required for some trivalent chromium processes.

[b]Waste disposal costs include treatment and transportation. The treatment cost was estimated to be $86.00 per 55-gallon drum and the transportation cost was $909.00 per truckload. Any fraction of a load was costed out as a full load.

[c]Anode boxes are required for all double-cell processes.

[d]Optional equipment.

[e]Taxes and freight are estimated to be 3 and 5 percent of the base equipment cost, respectively.

[f]Installation/modification costs are based on 20 percent of purchased equipment costs.

[g]Indirect costs include costs associated with engineering and supervision (10 percent), process startup (1 percent), and contingencies (20 percent) and are estimated to be 31 percent of the purchased equipment cost.

[h]The total capital cost is not solely attributable to air pollution control but also to process improvement.

TABLE F-43. CAPITAL COST OF CONVERTING HEXAVALENT CHROMIUM PROCESS TO TRIVALENT CHROMIUM PROCESS FOR MODEL PLANT (November 1988 Dollars)

Component	Model tank		
	Small	Medium	Large
Startup (tank conversion)			
Initial trivalent chromium solution purchase[27]	10,900	21,800	136,500
Initial passivation solution purchase[a,30]	500	1,000	6,500
Waste disposal cost of hexavalent chromium solution[b,34]	3,700	7,400	41,00
Subtotal	15,100	30,200	184,000
Purchased equipment costs			
Ampere-hour controller[30]	1,600	3,200	8,000
Tank liner[27]	2,200	4,400	18,000
Replacement anodes and hangers[27]	3,300	6,600	43,500
Anode boxes[c,30]	7,800	15,600	39,000
Chiller[b,28]	9,300	18,600	71,000
Filter[b,27]	7,600	15,200	54,500
Subtotal	31,800	63,600	234,000
Taxes and freight[c,36]	2,500	5,100	18,700
TOTAL	34,300	68,700	252,700
Installation/modification[d,35]	6,900	13,700	50.500
Indirect costs[e,36]	10,600	21,300	78,300
Total cost[f]	66,900	133,900	565,500

[a]Startup costs include the initial makeup of the trivalent chromium solution, and the disposal cost of the hexavalent chromium plating solution.
[b]Optional equipment.
[c]Taxes and freight are estimated to be 3 and 5 percent of the base equipment cost, respectively.
[d]Installation/modification costs are based on 20 percent of purchased equipment costs.
[e]Indirect costs include costs associated with engineering and supervision (10 percent), process startup (1 percent), and contingencies (20 percent), and are estimated to be 31 percent of the purchased equipment cost.
[f]The total capital cost is not solely attributable to air pollution control but also to process improvement.

TABLE F-44. INCREMENTAL CAPITAL COST ASSOCIATED WITH INSTALLING A TRIVALENT CHROMIUM PROCESS INSTEAD OF A HEXAVALENT CHROMIUM PROCESS AT NEW PLANTS (November 1988 Dollars)

Component	Model tank		
	Small	Medium	Large
Startup (plating tank[s]) cost[a,27]	2,800	5,500	27,500
Initial passivation solution[b]	500	1,000	6,500
Subtotal	3,300	6,500	34,000
Purchased equipment costs			
Ampere-hour controller[30]	1,600	3,200	8,000
Tank liner[27]	7,800	15,600	39,000
Replacement anodes and hangers[27]	9,300	18,600	71,000
Anode boxes[c,30]	7,600	15,200	54,500
Chillers[d,28]	26,300	52,600	172,500
Filter[d,27]	2,100	4,200	13,800
Subtotal	28,400	56,800	186,300
Taxes and freight[e,36]			
TOTAL			
Installation/modification[f,35]	4,300	8,500	27,900
Indirect costs[g,36]	8,800	17,600	57,800
Total cost	44,800	89,400	306,000
Wastewater treatment cost savings[h,37]	-19,600[i]	-29,400[j]	-41,400[j]
Net cost[k]	25,200	60,000	264,600

[a]Startup cost for new plant would only consist of the incremental cost of the trivalent chromium bath solution over the hexavalent chromium bath solution. The cost differential between the trivalent chromium plating solution and the hexavalent plating solution is $1.60 per gallon of plating solution for the small and medium model plants and $1.20 per gallon for the large model plant.[1]

[b]Passivation solution is required for some trivalent chromium processes.

[c]Anode boxes are required for all double-cell processes.

[d]Optional equipment.

[e]Taxes and freight are estimated to be 3 to 5 percent of the base equipment cost, respectively.

[f]Installation costs are based on 15 percent of the purchased equipment.

[g]Indirect costs include costs associated with engineering and supervision (10 percent), process startup (1 percent), and contingencies (20 percent), and are based on 31 percent of the purchased equipment costs.

[h]Represents the capital cost of a hexavalent chromium reduction unit for the wastewater volume associated with each model plant.

[i]Batch process.

[j]Continuous process.

[k]The total capital cost is not solely attributable to air pollution control but also to process improvement.

TABLE F-45. PLANT PARAMETERS FOR THE TRIVALENT CHROMIUM FACILITIES THAT PROVIDED COST DATA

Plant information	Plant 1	Plant 2	Plant 3
No. of plating lines or tanks	1	1	3
Dimensions of tanks, ft	12.0, 3.0, 6.0	4.6, 3.8, 5.5	2 @ 16.5, 3.8, 7.2, 10.0, 2.5, 5.5
Tank capacity, gal	1,480	650	2 @ 3,140 935
Trivalent chromium process and type	Product 19 Vendor D	Product 18 Vendor E	Product 17 Vendor F
	(Double-cell process)	(Single-cell process)	(Single-cell process)
Operating time, hr/yr	4,000	2,880	2,700

TABLE F-46. CAPITAL COST ESTIMATES FOR CONVERTING FROM A HEXAVALENT PROCESS TO A TRIVALENT CHROMIUM PROCESS FOR THE TRIVALENT CHROMIUM PLATING FACILITIES (1986 Dollars)

Component	1	2	3
New equipment costs			
1. Anode boxes	15,680	NA[a]	NA
2. Anodes and hangers	2,895	1,800	17,800
3. Passivation tank			
a. Capital cost of tank	1,400	NA	NA
b. Cost of initial makeup solution	650	NA	NA
4. Tank liner	NA	NA	3,000
5. Ampere-hour meter or controller	1,200	NA	2,200
6. Filter	3,800	5,000	NA
7. Chiller or cooling coils	NA	4,200	31,400
8. Plating tank	6,150	NA	NA
9. Rectifiers	NA	15,000	39,600
10. Automatic pH and temperature controllers	2,025	NA	NA
Subtotal	33,980	26,000	94,000
Modification costs			
1. Tank cleaning	2,000	NA	NA
2. Plating line modification	2,170	NA	NA
3. Modifications to electrical supply[e]	100	NA	NA
4. Modifications to cooling system[f]	400	NA	NA
5. Initial makeup cost of Cr^{+3} solution	9,450	NA	NA
Subtotal	13,800	4,500	24,500
	27,920	4,500	24,500
Installation costs	5,160	NA	NA
Total[h]	67,100	30,500	118,500

[a]NA = Not applicable.
[b]Numbers were rounded to nearest $100.

TABLE F-47. COMPARISON OF PLANT CAPITAL COST DATA AND MODEL PLANT CAPITAL COST DATA (November 1988 Dollars)

Plant	Total capital cost, $
Plant data	
Plant 1 (small)[a]	71,800
Plant 2 (small)[b]	32,900
Plant 3 (medium)[c]	138,600
Model plant data	
Small	66,900
Medium	133,900
Large	565,500

[a]Process was installed in November 1987. The CE Plant Index for 1987 was 323.8. Ratio of CE Plant Indices was 1.07.

[b]Process was installed in 1984. The CE Plant Index for 1984 was 322.7. Ratio of CE Plant Indices was 1.08.

[c]Process was installed in 1981. The CE Plant Index for 1981 was 297.0. Ratio of CE Plant Indices was 1.17.

F.6 REFERENCES FOR APPENDIX F

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3. Cost Enclosure for Control Equipment: Vendor C. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. August 25, 1987.

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5. EAB Control Cost Manual (Third Edition), U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. Publication No. EPA 450/5-87-001A. February 1987. pp. 2-1 through 2-33.

6. Monthly Energy Review. Energy Information Administration. Department of Energy. Washington, D.C. October 1988.

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13. Letter and cost enclosure from Vendor I, to R. Barker, Midwest Research Institute. November 24, 1988. p. 1.

14. Reference 13, pp. 3-6.

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16. Telecon. Barker, R., MRI, to Vendor I. February 21, 1989. Information concerning mesh-pad mist eliminator cost data.

17. Telecon. R. Barker, MRI, with Vendor A. April 28, 1989. Retrofit costs as a percentage of new facility costs.

18. Telecon. M. J. Caldwell, MRI, with Vendor I. May 1, 1989. Retrofit costs as a percentage of new facility costs.

19. Telecon. M. J. Caldwell, MRI, with Vendor C. May 1, 1989. Retrofit costs as a percentage of new facility costs.

20. Cost Enclosure for Fume Suppressant Vendors: Vendor D. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. February 20, 1987. p. 2-3.

21. Cost Enclosure for Fume Suppressant Vendors: Vendor E. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. February 26, 1987. p. 2-3.

22. Cost Enclosure for Fume Suppressant Vendors: Vendor F. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. January 20, 1987. p. 2-3.

23. Cost Enclosure for Fume Suppressant Vendors: Vendor G. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. January 20, 1987. p. 2-3.

24. Cost Enclosure for Fume Suppressant Vendors: Vendor H. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. February 9, 1987. p. 2-3.

25. Reference 20, p. 6.

26. Reference 21, p. 6.

27. Cost Enclosure for Decorative Chromium Electroplating Processes: Vendor F. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. June 22, 1987. p. 4.

28. Cost Enclosure for Decorative Chromium Electroplating Processes: Vendor E. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. June 5, 1987. p. 4.

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APPENDIX G.

ANALYSIS OF ANNUAL PLATING LINE COSTS FOR THE TRIVALENT CHROMIUM PLATING PROCESS VERSUS THE HEXAVALENT CHROMIUM PLATING PROCESS

APPENDIX G. ANALYSIS OF ANNUAL PLATING LINE COSTS FOR THE TRIVALENT CHROMIUM PLATING PROCESS VERSUS THE HEXAVALENT CHROMIUM PLATING PROCESS

G.1 INTRODUCTION

This appendix presents an analysis of the plating line costs for specific end products associated with the operation of the hexavalent chromium and trivalent chromium plating processes for each decorative chromium plating model plant. The trivalent chromium process applies only to decorative chromium plating operations because the process can plate only up to a thickness of 1 mil (thousandth of an inch), which is less than the thicknesses required in hard chromium plating. Vendors of the trivalent chromium process state that operations that have converted from the hexavalent chromium process to the trivalent chromium process have experienced substantial reductions in production costs.[1-4] During visits made to facilities that had converted from the hexavalent chromium process to the trivalent chromium process, plant personnel indicated that the trivalent chromium process was less costly to operate than the hexavalent chromium process.[5-9] The purpose of this model plant analysis was to determine the extent of the cost reduction attributable to the trivalent chromium process for specific end products at each of the model plants.

The following sections present background information on the trivalent chromium process, procedures used to estimate the costs of both the hexavalent and trivalent chromium processes, and the results of applying the costing procedures to selected model plants. In addition, incremental capital and capital recovery costs associated with the conversion from the hexavalent process to the trivalent chromium process are presented for each model plant.

G.2 BACKGROUND INFORMATION ON THE TRIVALENT CHROMIUM PROCESS

There are two types of trivalent chromium processes available for decorative chromium plating: the single cell and the double cell. In the single-cell process, anodes are in direct contact with the plating solution. In the double-cell process, anodes are encased in boxes that are lined with a permeable (ion-selective) membrane and that contain a dilute solution of sulfuric acid. The membrane allows positively charged hydrogen ions to pass through but not other positively charged ions (such as ions of trivalent chromium) present in the plating solution. This mechanism prevents undesirable side reactions (such as oxidation of trivalent chromium to hexavalent chromium) from occurring at the anode. The use of a weak solution of sulfuric acid in the anode box facilitates the passage of hydrogen ions through the membrane (away from the anode) to compensate for hydrogen gas evolution at the cathode. The only difference in the configuration of a plating line that has been converted from a hexavalent chromium process to a trivalent chromium process is the addition of a rinse tank prior to the chromium plating tank. In the case of the double-cell process, a passivation solution is also used after the parts leave the chromium plating tank.[1-4]

One vendor estimated that there are approximately 100 operations currently using trivalent chromium processes.[10] Vendors of single-cell processes include Vendor E and Vendor F. Vendors of double-cell processes include Vendor D and Vendor H.

Benefits associated with these processes, as compared to the hexavalent chromium process, are derived from (1) higher productivity due to superior throwing and covering power, with the resultant ability to plate more parts per rack; (2) improved plating efficiency resulting in lower reject rates, and thus fewer parts requiring rework; (3) elimination of the need for replacement anodes required with hexavalent chromium processes;

(4) elimination of exhaust ventilation systems because trivalent chromium processes produce essentially no mist, and the bath can tolerate only trace amounts of hexavalent chromium; and (5) reduced wastewater treatment requirements because of lower chromium concentrations and the absence of hexavalent chromium in the wastewater.[1-4]

G.3 COMPARATIVE COST MODEL

A cost model was developed to compare total plating line costs (total cost to operate the plating line) between the hexavalent and trivalent chromium processes. In developing the model, emphasis was placed on operational factors that differ between the two processes and that affect overall production costs. These factors include differences in chemical usage and cost, production efficiency, operation and maintenance requirements, energy requirements, and wastewater treatment requirements. Information on these factors was obtained directly from facilities that use hexavalent and trivalent chromium processes, from vendors that manufacture both processes, and from firms that supply wastewater treatment systems. The model, which is presented in Table G-1, consists of 10 sections.

The first four sections allow for the specification of input parameters pertaining to the part being plated, the model plant size, unit cost factors, and production rates. The remaining six sections contain the mathematical expressions used to calculate the cost estimates. A description of each section and its function in the cost model is given below:

A. End-Product (Part) Parameters

In this section, the part and its plating parameters are specified. The parameters include surface area of the part, plating time, current density, and plating thickness. These parameters are used to calculate the required current, in ampere-hours, needed to plate each part or each square foot of part surface area. Ampere-hours are obtained by multiplying the current density (amperes per square foot) by the plating time (hours) and the surface area of the part (square feet). The required current (ampere-hours per square foot) is used to determine the chemical costs. For this analysis, it is assumed that the current density and plating time are the same for both the hexavalent and trivalent chromium processes.

B. Model Plant Parameters

In this section, parameters that define the size of the plating facility are specified. These parameters include number of plating lines, annual operating time, percent of time electrodes are energized, fan horsepower required for ventilation, and chromium wastewater flow rates. These parameters are used along with the end-product parameters to determine production capacity as well as the wastewater treatment and fan electrical requirements.

C. Cost Factors

This section specifies the cost factors, expressed in dollars per unit of consumption, for wastewater treatment, process chemicals, and electricity. These factors are used to estimate the cost of individual components that, combined, make up the total plating line costs.

D. Production Parameters

This section identifies key parameters that establish production efficiency. These parameters include the rework rate for both processes (the percentage of total parts produced per year that requires replating because of flaws in the original finish) and the percent increase in productivity associated with the trivalent chromium process. The rework rates for each process are the most critical variables in the cost model.

Also identified in this section is the maximum annual production rate for the hexavalent chromium process. The maximum annual production rate is an ideal value based on the assumption that no parts require reworking. The maximum annual production rate considers the type of part plated and the size of the plating tank(s). The size of the plating tank(s) limits the number of racks that can be processed, while the part size and plating specifications limit the number of parts that can be put on a rack (rack population).

E. Production Rates

This section of the model calculates production rates. The maximum annual production rate for the trivalent chromium process equals the maximum annual production rate of the hexavalent chromium process plus the percent increase in productivity specified in Section D. The total number of parts a facility can sell or distribute as final end products is less than the maximum annual production rate because of reworked parts that are replated. The number of parts that are replated each year equals the maximum annual production rate times the rework rate. Once the number of reworked parts per year is known, the number of parts that were plated and did not require reworking (once-through parts) and the total annual production rate can be determined. The number of once-through parts is equal to the maximum annual production rate minus twice the number of reworked parts, since all reworked parts are plated two times. The total annual production rate then equals the sum of the number of once-through parts and the number of reworked parts. A basic assumption used in determining the total annual production rate is that all reworked parts are replated only once.

F. Chemical Cost

This section of the model calculates the chemical costs on a unit basis. Chemical costs are calculated by multiplying the chemical cost factor ($/Ah) for each process as specified in Section C by the amount of current required per square foot of part surface area (Ah/ft^2) as specified in Section A. This product, in terms of dollars per square foot, is then multiplied by the surface area of each part to obtain the chemical cost per part. The chemical cost difference between the two processes is then calculated and subsequently used to determine the unit plating costs (plating cost per part) for the trivalent chromium process.

G. Plating Costs

This section provides estimates of annual plating costs for both processes. First, the unit plating costs are calculated. The plating cost factor ($\$/ft^2$) for hexavalent chromium plating is a known input for the type of part selected. The unit plating cost for hexavalent chromium plating is calculated by multiplying the plating cost factor ($\$/ft^2$) by the surface area ($ft^2$) of the part or end product to be plated. The unit plating cost includes costs associated with process chemicals, utilities, and maintenance and labor. The unit plating cost for trivalent chromium is assumed to equal the unit plating cost calculated for hexavalent chromium plus the incremental cost for chemicals associated with the trivalent chromium process (calculated in Section F). This assumption is valid because the only component of unit plating costs that differs between the two processes is the chemical cost. For both processes, the rework unit plating cost is twice the original plating cost because reworked parts are plated twice.

Annual plating costs for once-through and reworked parts are calculated by multiplying the unit plating costs for once-through parts by the number of once-through parts and adding the result to the product of the unit plating cost for reworked parts times the number of reworked parts.

H. Wastewater Treatment Costs

In this section, the volume of wastewater to be treated and the associated treatment costs are calculated based on the size of the plating operations. The volume of wastewater treated per year is the product of the wastewater flow rate for each plating line (Section B), number of plating lines (Section B), and annual operating time (Section B). This value (gal/yr) is then multiplied by the wastewater treatment cost factor ($/gal), specified in Section C for each process, to yield the total annual wastewater treatment costs.

I. Fan Electrical Costs

This section presents calculations for fan electrical costs associated with the operation of fans needed for exhaust ventilation. Fan electrical costs apply only to the hexavalent chromium process because trivalent chromium processes do not require ventilation. Annual fan electrical costs are calculated by multiplying annual fan electrical requirements (kWh) by the unit electrical cost ($/kWh) specified in Section C. The fan electrical requirements are based on the horsepower requirements for the exhaust ventilation system and the annual facility operating hours specified in Section B.

J. Plating Line Costs

Annual costs for plating, wastewater treatment, and fan electrical requirements are summed to obtain an estimate of the total annual plating line cost. The total annual plating line costs are then divided by total annual production for each process to obtain unit plating line costs for each process. The unit plating line cost for the trivalent chromium process is then subtracted from the unit plating line cost of the hexavalent chromium process to obtain the cost difference. This cost difference is then multiplied by the total number of parts produced per year with the hexavalent chromium process to yield the incremental annual cost or savings associated with the trivalent chromium process.

G.4 OVERVIEW OF COST ANALYSIS

The purpose of the cost analysis is to obtain estimates of incremental costs or savings associated with the conversion from hexavalent to trivalent chromium plating processes. For the purpose of this analysis, three representative end products were selected: ratchets, faucets, and bumpers. These end products were chosen because they are reasonably representative of the type of parts that receive decorative chromium plate. Three model plants (small, medium, and large) that represent existing decorative chromium plating operations were selected to compare process costs. Ratchets and faucets were assumed to be produced at the small and medium model plants and bumpers were assumed to be produced only at the large model plant.

The first focus in the cost analysis was to determine the major production parameters that affect the process cost differential. This determination was made by holding all the input parameters constant and varying the values of each production parameter to determine its impact on the costs. As a result of this analysis, the rework rate was determined to be the most critical production parameter influencing the process costs. Therefore, it was imperative to obtain reasonable estimates for the rework rates associated with each process and end product.

Rework rates obtained from hexavalent chromium facilities varied significantly from 1 to 15 percent, with most plants in the range between 3 and 10 percent, whereas rework rates supplied by plants for the trivalent chromium process ranged from 0 to 2 percent, with an average rework rate of 1 percent.[5-9,11-13] As a result of the broad variability in rework rates and the sensitivity of the analysis to the rework rates, the decision was made to conduct the cost analysis on three different production scenarios that would represent the range of hexavalent chromium rework rates identified. For each scenario, the trivalent chromium rework rate was constant at 1 percent, while the rework rate for the hexavalent chromium process varied. In each scenario, the small, medium, and large model plants were assumed to be plating ratchets, faucets, and bumpers, respectively. In the first scenario, the rework rates for the hexavalent chromium process were set at the values provided by the individual plants that plated the parts selected. In the second scenario, the rework rate for all parts was set at the average rework rate given by the plants using the hexavalent chromium process. In addition, a third production scenario was developed to determine the break-even point between the two processes for each end product examined. This point was determined by forcing the annual plating cost differential to zero and computing the hexavalent chromium rework rate for that condition.

G.5 COST MODEL INPUTS

The inputs used in the cost model for this analysis are described in the following sections.

A. <u>End-Product (Part) Parameters</u>

The three end products (ratchets, faucets, and bumpers) selected for analysis were chosen because they are reasonably representative of the range of parts that receive decorative chromium plate. Values for each end product parameter specified in the model are presented in Table G-2. These values were obtained from three plants that currently plate these parts using the conventional hexavalent chromium process.[11-13] The parameters include the plating time, current density, surface area, and plating thickness for each part.

B. Model Plant Parameters

Parameters for the three model plant sizes used in the analysis are provided in Table G-3. The bases for their selection are presented in BID Chapters 5 and 6. In addition, the estimate of the volume of chromium wastewater generated from each plating line was obtained from information supplied by two plants that operate hexavalent and trivalent chromium plating lines similar in size to the plating lines in the model plants.[14-15]

C. Cost Factors

Cost factors required to exercise the model are presented in Table G-4. The chemical cost factors are based on information obtained from four vendors of the hexavalent and trivalent chromium processes.[1-4] The chemical cost factor is expressed as dollars per ampere-hour rather than dollars per gallon because the rate of chemical consumption is directly related to the amount of work processed or current applied. The chemical costs for the hexavalent chromium process include costs only for the chromic acid plating bath. The chemical costs for the trivalent chromium process include costs for the trivalent chromium plating bath and a passivation bath. As indicated in Table G-4, chemical costs associated with the trivalent chromium process are substantially higher (about 13 times) than those for the hexavalent chromium process. Because chemicals for all nonchromium plating line operations are the same for both processes, they were not considered in this analysis.

The cost factors for treatment ($/gal) of the hexavalent chromium process wastewaters are based on information obtained from two wastewater treatment firms.[16-17] No treatment cost estimates for the trivalent chromium process wastewaters were available from wastewater treatment firms. Therefore, the wastewater treatment cost factor associated with the trivalent chromium process was developed from the breakdown of the individual cost components for treatment of hexavalent chromium wastewaters. The costs associated with wastewater treatment for the hexavalent chromium process include labor costs and process and equipment costs (chemical consumption, electrical costs, etc.). The labor component of the wastewater treatment cost is approximately 30 percent of the total cost. The amount of labor required for each process was assumed to be the same because the amount of wastewater treated per year is the same for both processes. The cost associated with chemical consumption and equipment operation was assumed to be 15 percent of the hexavalent chromium treatment cost because the amount of chromium present in the trivalent chromium wastewaters is only 13 percent of the amount found in hexavalent chromium wastewaters. In addition, the chromium in trivalent chromium wastewaters is already in the trivalent chromium state so the reduction step (converting hexavalent chromium to trivalent chromium) in the wastewater treatment process is not needed. Therefore, the treatment cost factor associated with the trivalent chromium process is assumed to be equal to 45 percent (30 percent for labor plus 15 percent for process operation) of that for the hexavalent chromium process.

The electrical cost factor ($/kWh) was obtained from the October 1988 issue of Monthly Energy Review.[18]

Plating cost factors for the hexavalent chromium plating process ($\$/ft^2$) are based on an average of costs supplied by three facilities that plate the selected parts.[11-13] Plating cost factors for the trivalent chromium process were not available on a per-unit basis. Therefore, plating cost factors for this process were estimated. It was assumed that the unit plating cost calculated from the plating cost factor for the hexavalent chromium process plus the difference in unit chemical cost between the two processes would yield a valid estimate of unit plating costs for the trivalent chromium process. This assumption should be valid because the only difference in the costs between the two plating processes is associated with the operation of the chromium plating step since all other process steps are the same regardless of which plating process is used.

D. Production Parameters

The production parameters and the productivity increase for the trivalent chromium process were derived from information obtained from plants that use the hexavalent and trivalent chromium processes. The rework rates supplied by plants that use the hexavalent chromium process ranged from 1 to 15 percent, with most plants in the range between 3 and 10 percent.[5-7,11-13] The rework rates supplied by plants for the trivalent chromium process ranged from 0 to 2.0 percent.[5-9] Based on information obtained from two trivalent chromium plants, it is assumed that production increases by 20 percent for the trivalent chromium process over the hexavalent chromium process because of the higher efficiency of the trivalent chromium process, which allows more parts to be plated simultaneously.[6-7]

The production rates for the hexavalent chromium process are based on production parameters provided by the plants that plated the parts selected for analysis. These production parameters are shown in Table G-5.[11-13] The model plant production rates calculated from these parameters are presented in Table G-6. The production rate calculations are presented in Attachment 1. Ratchets and faucets were assumed to be produced at the small and medium model plants, and bumpers were assumed to be produced only at the large model plant.

G.6 RESULTS

The most critical parameter affecting the plating line costs is the hexavalent chromium rework rate. Table G-7 presents the cost differential ($\$/ft^2$) obtained for each of 10 hexavalent chromium rework rates (1 to 10 percent) examined.

For the three end products evaluated, the plating line cost differential increased as the hexavalent chromium rework rate increased. This increase is a result of the increase in costs associated with the higher rework rates for the hexavalent chromium process. As shown in Table G-7, the difference in the cost per square foot between the hexavalent and trivalent chromium processes for all parts plated ranges from an additional cost of a few cents at low hexavalent chromium rework rates to a savings of a few cents at high rework rates. At the low rework rates, the increased chemical costs associated with the trivalent chromium process are not offset by the decrease in the number of reworked parts and the lower wastewater treatment requirement. However, at high hexavalent chromium rework rates, the increased chemical costs associated with the trivalent chromium process are more than offset by the reduction in the number of reworked parts and the lower wastewater treatment costs. Therefore, there is a break-even point (which is dependent upon the type of part plated) above which a plant will realize a savings from the trivalent chromium process. This break-even point is between 2 and 3 percent for ratchets, 4 and 5 percent for faucets, and 6 and 7 percent for bumpers. For any rework rate above this break-even point, a plating facility would realize a savings with the trivalent chromium process. It should be noted that, for any given hexavalent and trivalent chromium rework rate and part plated, the cost differential between the processes is the same regardless of plant size (i.e., production rate).

Total annualized costs associated with the operation of the trivalent chromium process were calculated under three cost scenarios representing the full range of hexavalent chromium rework rates encountered. For each scenario, the trivalent chromium rework rate was constant at 1 percent, while the rework rate for the hexavalent chromium process varied. The small, medium, and large model plants were assumed to be plating ratchets, faucets, and bumpers, respectively.

In the first scenario, the trivalent chromium rework rate was constant at 1 percent, while the rework rates for the hexavalent chromium process were set at the values provided by the individual plants that plated the parts selected. The corresponding hexavalent chromium rework rates for the first scenario were 1, 3, and 15 percent for ratchets, faucets, and bumpers, respectively. Table G-8 presents the model plant plating line cost analysis for this scenario. Under this scenario, the small and medium model plants were predicted to have increased costs associated with the operation of the trivalent chromium process, whereas a large cost savings was predicted for the large model plant. The increase in cost per part for the small and medium model plants was $0.002/part and $0.007/part, respectively, whereas the cost savings per part for the large model plant was $1.04/part. The annual costs predicted for the small and medium model plants were $10,300 and $2,700, respectively. The annual savings predicted for the large model plant was $2,389,100.

In the second scenario, the rework rate for all parts was set at the average rework rate (7 percent) given by the hexavalent chromium process plants. The results of the model plant plating line cost analysis for this scenario are presented in Table G-9. Under this scenario, annual cost savings were predicted at each model plant. The cost savings were $0.005/part, $0.012/part, and $0.029/part for the small, medium, and large model plants, respectively. The annual savings were $24,200, $4,500, and $72,800 for the small, medium, and large model plants, respectively.

A third scenario, shown in Table G-10, was developed for informational purposes only. This scenario was developed to determine the hexavalent chromium rework rates at the break-even point. The hexavalent chromium rework rates at the break-even point for ratchets, faucets, and bumpers were 2.85, 4.5, and 6.75, respectively. This scenario demonstrates how the type of part plated influences the process cost differential because the break-even point was different for each product selected.

G.7 CAPITAL RECOVERY COSTS

Costs of capital recovery were calculated for both new and existing facilities. Capital costs representative of the process installation at new facilities and the process conversion at existing facilities are shown in Tables G-11 and G-12, respectively. The cost of capital recovery calculated from these capital expenditures is presented in Table G-13. The cost of capital recovery for equipment purchases was calculated based on the following equation and assumptions:

$$CRC = TCC[i(1 + i)^n/(1 + i)^n - 1]$$

where:

i = interest rate, 10 percent;

n = equipment life, yrs;

TCC = total capital cost of equipment; and

CRC = capital recovery costs, $/yr.

The equipment life was estimated by a vendor of the trivalent and hexavalent chromium processes.[19] The equipment purchases include such items as the chillers, filters, anode boxes, and tank liners. Capital investments (other than equipment purchases) include costs of the initial trivalent chromium solution, disposal of the hexavalent chromium solution, and cleaning of the hexavalent chromium plating tank. The capital recovery costs for these items were calculated by the equation above, but, instead of the life of the equipment, a loan life of 10 years was assumed.

For new facilities, the incremental capital cost to install the trivalent chromium process instead of the hexavalent chromium process includes a credit for not installing wastewater treatment equipment that reduces the hexavalent chromium to trivalent chromium. These credits were spread over 10 years. These annual credits were then subtracted from the capital recovery costs to obtain a net capital recovery cost for each model plant.

G.8 INCREMENTAL ANNUALIZED COSTS ASSOCIATED WITH THE TRIVALENT CHROMIUM PROCESS

The incremental annualized costs associated with the trivalent chromium process were calculated by adding the capital recovery costs to the incremental annual cost or savings per year associated with the operation of a trivalent chromium plating process at each model plant. The incremental annualized costs for all three scenarios are presented in Table G-14.

TABLE G-1. COMPARATIVE PLATING LINE COST MODEL USED TO DETERMINE COST DIFFERENTIAL BETWEEN THE HEXAVALENT AND TRIVALENT CHROMIUM PROCESS

PRODUCTION FACTORS	
A. END-PRODUCT PARAMETERS	
PART PLATED	INPUT
PLATING TIME, MIN	INPUT
CURRENT DENSITY, AMPS/FT2	INPUT
SURFACE AREA OF PART, FT2	INPUT
PLATING THICKNESS, MILS	INPUT
AMPERE-HOURS/FT2	(current density, A/ft2)(plating time, h)
AMPERE-HOURS/PART	(current density, A/ft2)(plating time, h)(surface area of part, ft2)
B. MODEL PLANT PARAMETERS	
NO. OF PLATING LINES	INPUT
OPERATING TIME, H/YR	INPUT
% TIME ELECTRODES ARE ENERGIZED, %	INPUT
FAN HORSEPOWER REQUIREMENT, HP	INPUT
CHROMIUM WASTEWATER FLOW RATE, GPM/PLATING LIN	INPUT
C. COST FACTORS	
CR+6 WASTEWATER TREATMENT COSTS, $/1000 GAL	INPUT
CR+3 WASTEWATER TREATMENT COSTS, $/1000 GAL	INPUT
CR+6 CHEMICAL COSTS, $/AH	INPUT
CR+3 CHEMICAL COSTS, $/AH	INPUT

TABLE G-1. (Continued)

PRODUCTION FACTORS	
FAN ELECTRICAL COSTS, $/KWH	INPUT
D. PRODUCTION PARAMETERS	
1. Rework rates	
a. Hexavalent Chromium Process, %	INPUT
b. Trivalent Chromium Process, %	INPUT
2. Trivalent Chromium Productivity Increase, %	INPUT
3. Hexavalent Chromium Maximum Production Rate, parts/yr	INPUT
E. PRODUCTION RATES	
1. HEXAVALENT CHROMIUM PROCESS	
a. Maximum surface area per year, ft2/yr	(hexavalent chromium maximum production rate, parts/yr)(surface area of part, ft2)
b. Total # of parts produced, parts/yr	(hexavalent chromium maximum production rate, parts/yr)(1-rework decimal percent)
c. No. of once-through parts, parts/yr	(hexavalent chromium maximum production rate, parts/yr)(1-(2*rework decimal percent))
d. No. of rework parts (parts processed twice), parts/yr	(hexavalent chromium maximum production rate, parts/yr)(rework decimal percent)
2. TRIVALENT CHROMIUM PROCESS	
a. Maximum surface area per year, ft2/yr	(trivalent chromium maximum production rate, parts/yr)(surface area of part, ft2)
b. Maximum # of parts plated per year, parts/yr	(hexavalent chromium maximum production rate, parts/yr)(1+decimal percent increase in productivity)
c. Total # of parts produced, parts/yr	(trivalent chromium maximum production rate, parts/yr)(1-rework decimal percent)
d. No. of once-through parts, parts/yr	(trivalent chromium maximum production rate, parts/yr)(1-(2*rework decimal percent))
e. No. of rework parts (parts processed twice), parts/yr	(trivalent chromium maximum production rate, parts/yr)(rework decimal percent)
F. CHEMICAL COST	
HEXAVALENT CHROMIUM SOLUTION, $/FT2	(hexavalent chromium chemical cost, $/AH)(ampere-hours required per part surface area, AH/ft2)
HEXAVALENT CHROMIUM SOLUTION, $/PART	(hexavalent chromium chemical cost, $/ft2)(surface area of part, ft2)

TABLE G-1. (Continued)

PRODUCTION FACTORS	
TRIVALENT CHROMIUM PROCESS, $/FT2	(trivalent chromium chemical cost, $/AH)(ampere-hours required per part surface area, AH/ft2)
TRIVALENT CHROMIUM PROCESS, $/PART	(trivalent chromium chemical cost, $/ft2)(surface area of part, ft2)
G. ANNUAL PLATING COST	
1. UNIT PLATING COSTS	
a. Hexavalent Chromium Process	
1)plating cost, $/part	(plating cost, $/ft2)(surface area of part, ft2)
2)plating cost, $/ft2	INPUT
3)rework plating cost, $/part	(plating cost, $/part)(2)
b. Trivalent Chromium Process	
1)plating cost, $/part	(plating cost, $/ft2)(surface area of part, ft2)
2)plating cost, $/ft2	(hexavalent chromium plating cost, $/ft2)+(CR+3 chemical cost, $/ft2 - CR+6 chemical cost, $/ft2)
3)rework plating cost, $/part	(plating cost, $/part)(2)
2. ANNUAL PLATING COSTS	
a. Hexavalent Chromium Process	
1)plating costs-once-through parts, $/yr	(No. of once-through parts)(original plating cost, $/part)
2)plating costs-rework, $/yr	(No. of rework parts)(rework plating cost, $/part)
3)annual plating costs, $/yr	Sum of annual plating costs for once-through and reworked parts
b. Trivalent Chromium Process	
1)plating costs-once-through parts, $/yr	(No. of once-through parts)(original plating cost, $/part)
2)plating costs-rework, $/yr	(No. of rework parts)(rework plating cost, $/part)
3)annual plating costs, $/yr	Sum of annual plating costs for once-through and reworked parts
H. WASTEWATER TREATMENT COSTS	
1. HEXAVALENT CHROMIUM PROCESS	
a)WASTEWATER VOLUMES, GAL/YR	(number of plating lines)(wastewater volume per plating line, gpm/line)(60 min/hr)(operating hours per year)
b)TREATMENT COSTS, $/YR	(chromium wastewater treatment volume, gals/yr)(hexavalent chromium wastewater treatment costs, $/gal)

TABLE G-1. (Continued)

PRODUCTION FACTORS	
2. TRIVALENT CHROMIUM PROCESS	
a)WASTEWATER VOLUMES, GAL/YR	(number of plating lines)(wastewater volume per plating line, gpm/line)(60 min/hr)(operating hours per year)
b)TREATMENT COSTS, $/YR	(chromium wastewater treatment volume, gals/yr)(trivalent chromium wastewater treatment costs, $/gal)
I. FAN ELECTRICAL COSTS	
HEXAVALENT CHROMIUM PROCESS	
a) FAN ELECTRICAL USAGE, KWH/YR	(fan horsepower requirements, hp)(0.746hp/kw)(operating time per year)
b) FAN ELECTRICAL COSTS, $/YR	(fan electrical requirements, kwh/yr)(electrical cost, $/kwh)
J. PLATING LINE COSTS	
1. HEXAVALENT CHROMIUM PROCESS	
a)annual plating costs, $/yr	sum of plating costs for once-through and reworked parts
b)wastewater treatment costs, $/yr	(chromium wastewater treatment volume, gals/yr)(hexavalent chromium wastewater treatment costs, $/gal)
c)fan electrical costs, $/yr	(fan electrical requirements, kwh/yr)(electrical cost, $/kwh)
d)total plating line costs, $/yr	(total plating costs + wastewater treatment costs + fan electrical costs)
e)total plating line costs, $/part	(total plating line costs, $/yr)/(total production, parts/yr)
2. TRIVALENT CHROMIUM PROCESS	
a)annual plating costs, $/yr	sum of plating costs for once-through and reworked parts
b)wastewater treatment costs, $/yr	(chromium wastewater treatment volume, gals/yr)(trivalent chromium wastewater treatment costs, $/gal)
c)total plating line cost, $/yr	(total plating costs + wastewater treatment costs + fan electrical costs)
d)total plating line costs, $/part	(total plating line costs, $/yr)/(total production, parts/yr)
COST DIFFERENTIAL BETWEEN THE PROCESSES, $/PART (a	(trivalent chromium unit plating cost, $/part)-(hexavalent chromium unit plating cost, $/part)
COST DIFFERENTIAL BETWEEN THE PROCESSES, $/FT2 (b)	(cost differential, $/part)(surface area of part, ft2)
ANNUAL COST DIFFERENTIAL, $/YR (c)	(cost differential, $/part)(total hexavalent chromium production rate, parts/yr)

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TABLE G-2. END-PRODUCT (PART) PARAMETERS

		End products		
		Ratchets	Faucets	Bumpers
A.	End-product parameters			
	1. Current density, A/ft^2	50	125	200
	2. Plating time, min	3.00	3.55	2.25
	3. Surface area of part, ft^2	0.128	0.540	12.81
	4. Plating thickness, mil	0.001	0.00031	0.014
B.	Calculated parameters			
	1. Ampere-hours/ft^2 (A1 + A2/60)	2.50	7.40	7.50
	2. Ampere-hours/part (B3 + A1)	0.32	3.99	96.08

TABLE G-3. MODEL PLANT PARAMETERS USED AS INPUTS FOR THE PLATING LINE COST MODEL

	Model plant size		
Parameter	Small	Medium	Large
No. of plating lines	1	2	5
Plating tank capacity, gal	1,730	2 @ 1,730	5 @ 4,580
Operating time, hr/yr	2,000	4,000	6,000
Percent time electrodes are energized, %	60	60	60
Total fan horsepower requirements, hp	10	20	35
Chromium wastewater flow rate, gal/min per plating line	6	6	12

TABLE G-4. COST FACTORS USED IN THE COST MODEL

Factor	Cost
Wastewater treatment costs, $/1,000 gal	
Hexavalent chromium process	0.75
Trivalent chromium process	0.34
Chemical cost, $/Ah	
Hexavalent chromium process	0.00052
Trivalent chromium process	0.007
Fan electrical cost, $/kWh	0.0461

TABLE G-5. PRODUCTION RATE PARAMETERS FOR THE SELECTED PARTS USED IN THE COST MODEL[11-13]

Production parameters	End products		
	Ratchets	Faucets	Bumpers
Tank capacity, gal[a]	1,800	1,550	16,160
No. of components[b]	1	3	1
No. of racks/hr	108	2 components @ 13 1 component @ 2	47
No. of parts/rack	40	2 components @ 21 1 component @ 110	10
Rack capacity of plating tank	6	5	3

[a]Plating tank capacity that formed the basis for the production parameters.
[b]Refers to the number of components the part is plated in before assembling into one part.

TABLE G-6. MODEL PLANT PRODUCTION RATES

	Production rates, parts/yr Model plant size		
	Small	Medium	Large
Ratchets	5,200,000	20,700,000	--
Faucets	10,080	404,330	--
Bumpers	--	--	2,700,000

TABLE G-7. PLATING LINE COST DIFFERENTIAL BETWEEN THE TRIVALENT CHROMIUM PROCESS AND THE HEXAVALENT CHROMIUM PROCESS AT VARIOUS REWORK RATES, $\$/ft^2$

Hexavalent chromium rework rates, percent[a]	Model plant size: End-product[b]				
	Small:	Small:	Medium:	Medium:	Large:
	Ratchets	Faucets	Ratchets	Faucets	Bumpers
1	-0.015	-0.029	-0.015	-0.029	-0.049
2	-0.007	-0.021	-0.007	-0.021	-0.041
3	0.001	-0.013	0.001	-0.013	-0.032
4	0.010	-0.004	0.010	-0.004	-0.024
5	0.018	0.005	0.018	0.005	-0.015
6	0.027	0.014	0.027	0.014	-0.007
7	0.036	0.023	0.036	0.023	0.002
8	0.045	0.032	0.045	0.032	0.011
9	0.054	0.042	0.054	0.042	0.021
10	0.064	0.052	0.064	0.052	0.030

[a]The trivalent chromium rework rate remained constant at 1 percent.

[b]Negative values represent an increase in cost associated with the trivalent chromium process.

TABLE G-8. SCENARIO I-PLATING LINE COSTS FOR EACH MODEL PLANT BASED ON THE ACTUAL HEXAVALENT CHROMIUM REWORK RATES

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
A. END-PRODUCT PARAMETERS			
PART PLATED	Ratchets	Faucets	Bumpers
PLATING TIME, MIN	3.00	3.55	2.25
CURRENT DENSITY, A/FT2	50.00	125.00	200.00
SURFACE AREA OF PART, FT2	0.128	0.540	12.810
PLATING THICKNESS, MILS	0.011	0.00031	0.014
AMPERE-HOURS/FT2	2.50	7.40	7.50
AMPERE-HOURS/PART	0.32	3.99	96.08
B. MODEL PLANT PARAMETERS			
NO. OF PLATING LINES	1	2	5
OPERATING TIME, H/YR	2000	4000	6000
% TIME ELECTRODES ARE ENERGIZED, %	60	60	60
FAN HORSEPOWER REQUIREMENT, HP	10	20	35
CHROMIUM WASTEWATER FLOW RATE, GPM/PLATING LINE	6	6	12
C. COST PARAMETERS			
CR+6 WASTEWATER TREATMENT COSTS, $/1000 GAL	0.75	0.75	0.75
CR+3 WASTEWATER TREATMENT COSTS, $/1000 GAL	0.34	0.34	0.34
CR+6 CHEMICAL COSTS, $/AH	0.00052	0.00052	0.00052
CR+3 CHEMICAL COSTS, $/AH	0.007	0.007	0.007
FAN ELECTRICAL COSTS, $/KWH	0.0461	0.0461	0.0461

TABLE G-8 (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
D. PRODUCTION PARAMETERS			
1. REWORK RATES			
a) Hexavalent Chromium Process, %	1.000	3.000	15.000
b) Trivalent Chromium Process, %	1.0	1.0	1.0
2. TRIVALENT CHROMIUM PRODUCTIVITY INCREASE, %	20	20	20
3. HEXAVALENT CHROMIUM MAXIMUM PRODUCTION RATE, PARTS/YR	5.20E+06	4.04E+05	2.70E+06
E. PRODUCTION RATES			
1. HEXAVALENT CHROMIUM PROCESS			
a. Maximum surface area per year, ft2/yr	6.66E+05	2.18E+05	3.46E+07
b. Total # of parts produced, parts/yr	5.15E+06	3.92E+05	2.30E+06
c. No. of once-through parts, parts/yr	5.10E+06	3.80E+05	1.89E+06
d. No. of rework parts (parts processed twice), parts/yr	5.20E+04	1.21E+04	4.05E+05
2. TRIVALENT CHROMIUM PROCESS			
a. Maximum surface area per year, ft2/yr	7.99E+05	2.62E+05	4.15E+07
b. Maximum # of parts plated per year, parts/yr	6.24E+06	4.85E+05	3.24E+06
c. Total # of parts produced, parts/yr	6.18E+06	4.80E+05	3.21E+06
d. No. of once-through parts, parts/yr	6.12E+06	4.75E+05	3.18E+06
e. No. of rework parts (parts processed twice), parts/yr	6.24E+04	4.85E+03	3.24E+04
F. CHEMICAL COST			
HEXAVALENT CHROMIUM SOLUTION, $/FT2	0.0013	0.0038	0.0039
HEXAVALENT CHROMIUM SOLUTION, $/PART	0.0002	0.0021	0.0500
TRIVALENT CHROMIUM PROCESS, $/FT2	0.0175	0.0518	0.0525
TRIVALENT CHROMIUM PROCESS, $/PART	0.0022	0.0280	0.6725

TABLE G-8 (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
G. ANNUAL PLATING COST			
1. UNIT PLATING COSTS			
a. Hexavalent Chromium Process			
1)plating cost, $/part	$0.100	$0.421	$9.992
2)plating cost, $/ft2	$0.780	$0.780	$0.780
3)rework plating cost, $/part	0.200	0.842	19.984
b. Trivalent Chromium Process			
1)plating cost, $/part	$0.102	$0.447	$10.614
2)plating cost, $/ft2	0.796	0.828	0.829
3)rework plating cost, $/part	0.204	0.894	21.229
2. ANNUAL PLATING COSTS			
a. Hexavalent Chromium Process			
1)plating costs—once-through parts, $/yr	$508,581	$160,085	$18,884,502
2)plating costs—rework, $/yr	$10,379	$10,218	$8,093,358
3)annual plating costs, $/yr	$518,960	$170,303	$26,977,860
b. Trivalent Chromium Process			
1)plating costs—once-through parts, $/yr	$623,139	$212,592	$33,702,843
2)plating costs—rework, $/yr	$12,717	$4,339	$687,813
3)annual plating costs, $/yr	$635,856	$216,931	$34,390,656
H. WASTEWATER TREATMENT COSTS			
1. HEXAVALENT CHROMIUM PROCESS			
a) Wastewater volumes, gal/yr	720,000	2,880,000	21,600,000
b) Treatment costs, $/yr	$540	$2,160	$16,200
2. TRIVALENT CHROMIUM PROCESS			
a) Wastewater volumes, gal/yr	720,000	2,880,000	21,600,000
b) Treatment costs, $/yr	$240	$970	$7,290

TABLE G-8 (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
I. FAN ELECTRICAL COSTS			
HEXAVALENT CHROMIUM PROCESS			
a) Fan electrical usage, kWh/yr	14,920	59,680	156,660
b) Fan electrical costs, $/yr	$688	$2,751	$7,222
J. PLATING LINE COSTS			
1. HEXAVALENT CHROMIUM PROCESS			
a)annual plating costs, $/yr	$518,960	$170,303	$26,977,860
b)wastewater treatment costs, $/yr	$540	$2,160	$16,200
c)fan electrical costs, $/yr	$688	$2,751	$7,222
d)total plating line costs, $/yr	$520,188	$175,214	$27,001,282
e)total plating line costs, $/part	0.1010	0.4467	11.7653
2. TRIVALENT CHROMIUM PROCESS			
a)annual plating costs, $/yr	$635,856	$216,931	$34,390,656
b)wastewater treatment costs, $/yr	$240	$970	$7,290
c)total plating line cost, $/yr	$636,096	$217,901	$34,397,946
d)total plating line costs, $/part	0.1030	0.4536	10.7239
COST DIFFERENTIAL BETWEEN THE PROCESSES, $/PART (a)	-0.0020	-0.0070	1.0410
COST DIFFERENTIAL BETWEEN THE PROCESSES, $/FT2 (b)	-0.0156	-0.0130	0.0813
ANNUAL COST DIFFERENTIAL, $/YR (c)	($10,300)	($2,700)	$2,389,100

(a) Obtained from G.1.e minus G.2.d Numbers were independently rounded.

(b) Obtained by dividing the $/part value by the surface area of the part.

(c) Based on hexavalent chromium production rates.

TABLE G-9. SCENARIO II-PLATING LINE COSTS FOR EACH MODEL PLANT BASED ON THE AVERAGE HEXAVALENT CHROMIUM REWORK RATES

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
A. END-PRODUCT PARAMETERS			
PART PLATED	Ratchets	Faucets	Bumpers
PLATING TIME, MIN	3.00	3.55	2.25
CURRENT DENSITY, A/FT2	50.00	125.00	200.00
SURFACE AREA OF PART, FT2	0.128	0.540	12.810
PLATING THICKNESS, MILS	0.011	0.00031	0.014
AMPERE-HOURS/FT2	2.50	7.40	7.50
AMPERE-HOURS/PART	0.32	3.99	96.08
B. MODEL PLANT PARAMETERS			
NO. OF PLATING LINES	1	2	5
OPERATING TIME, H/YR	2000	4000	6000
% TIME ELECTRODES ARE ENERGIZED, %	60	60	60
FAN HORSEPOWER REQUIREMENT, HP	10	20	35
CHROMIUM WASTEWATER FLOW RATE, GPM/PLATING LINE	6	6	12
C. COST PARAMETERS			
CR+6 WASTEWATER TREATMENT COSTS, $/1000 GAL	0.75	0.75	0.75
CR+3 WASTEWATER TREATMENT COSTS, $/1000 GAL	0.34	0.34	0.34
CR+6 CHEMICAL COSTS, $/AH	0.00052	0.00052	0.00052
CR+3 CHEMICAL COSTS, $/AH	0.007	0.007	0.007
FAN ELECTRICAL COSTS, $/KWH	0.0461	0.0461	0.0461

TABLE G-9 (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
D. PRODUCTION PARAMETERS			
1. REWORK RATES			
a) Hexavalent Chromium Process, %	7.000	7.000	7.000
b) Trivalent Chromium Process, %	1.0	1.0	1.0
2. TRIVALENT CHROMIUM PRODUCTIVITY INCREASE, %	20	20	20
3. HEXAVALENT CHROMIUM MAXIMUM PRODUCTION RATE, PARTS/YR	5.20E+06	4.04E+05	2.70E+06
E. PRODUCTION RATES			
1. HEXAVALENT CHROMIUM PROCESS			
a. Maximum surface area per year, ft2/yr	6.66E+05	2.18E+05	3.46E+07
b. Total # of parts produced, parts/yr	4.84E+06	3.76E+05	2.51E+06
c. No. of once-through parts, parts/yr	4.47E+06	3.48E+05	2.32E+06
d. No. of rework parts (parts processed twice), parts/yr	3.64E+05	2.83E+04	1.89E+05
2. TRIVALENT CHROMIUM PROCESS			
a. Maximum surface area per year, ft2/yr	7.99E+05	2.62E+05	4.15E+07
b. Maximum # of parts plated per year, parts/yr	6.24E+06	4.85E+05	3.24E+06
c. Total # of parts produced, parts/yr	6.18E+06	4.80E+05	3.21E+06
d. No. of once-through parts, parts/yr	6.12E+06	4.75E+05	3.18E+06
e. No. of rework parts (parts processed twice), parts/yr	6.24E+04	4.85E+03	3.24E+04
F. CHEMICAL COST			
HEXAVALENT CHROMIUM SOLUTION, $/FT2	0.0013	0.0038	0.0039
HEXAVALENT CHROMIUM SOLUTION, $/PART	0.0002	0.0021	0.0500
TRIVALENT CHROMIUM PROCESS, $/FT2	0.0175	0.0518	0.0525
TRIVALENT CHROMIUM PROCESS, $/PART	0.0022	0.0280	0.6725

TABLE G-9 (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
G. ANNUAL PLATING COST			
1. UNIT PLATING COSTS			
a. Hexavalent Chromium Process			
1)plating cost, $/part	$0.100	$0.421	$9.992
2)plating cost, $/ft2	$0.780	$0.780	$0.780
3)rework plating cost, $/part	0.200	0.842	19.984
b. Trivalent Chromium Process			
1)plating cost, $/part	$0.102	$0.447	$10.614
2)plating cost, $/ft2	0.796	0.828	0.829
3)rework plating cost, $/part	0.204	0.894	21.229
2. ANNUAL PLATING COSTS			
a. Hexavalent Chromium Process			
1)plating costs—once-through parts, $/yr	$446,306	$146,461	$23,200,960
2)plating costs—rework, $/yr	$72,654	$23,842	$3,776,900
3)annual plating costs, $/yr	$518,960	$170,303	$26,977,860
b. Trivalent Chromium Process			
1)plating costs—once-through parts, $/yr	$623,139	$212,592	$33,702,843
2)plating costs—rework, $/yr	$12,717	$4,339	$687,813
3)annual plating costs, $/yr	$635,856	$216,931	$34,390,656
H. WASTEWATER TREATMENT COSTS			
1. HEXAVALENT CHROMIUM PROCESS			
a) Wastewater volumes, gal/yr	720,000	2,880,000	21,600,000
b) Treatment costs, $/yr	$540	$2,160	$16,200
2. TRIVALENT CHROMIUM PROCESS			
a) Wastewater volumes, gal/yr	720,000	2,880,000	21,600,000
b) Treatment costs, $/yr	$240	$970	$7,290

TABLE G-9 (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
I. FAN ELECTRICAL COSTS			
HEXAVALENT CHROMIUM PROCESS			
a) Fan electrical usage, kWh/yr	14,920	59,680	156,660
b) Fan electrical costs, $/yr	$688	$2,751	$7,222
J. PLATING LINE COSTS			
1. HEXAVALENT CHROMIUM PROCESS			
a)annual plating costs, $/yr	$518,960	$170,303	$26,977,860
b)wastewater treatment costs, $/yr	$540	$2,160	$16,200
c)fan electrical costs, $/yr	$688	$2,751	$7,222
d)total plating line costs, $/yr	$520,188	$175,214	$27,001,282
e)total plating line costs, $/part	0.1076	0.4660	10.7532
2. TRIVALENT CHROMIUM PROCESS			
a)annual plating costs, $/yr	$635,856	$216,931	$34,390,656
b)wastewater treatment costs, $/yr	$240	$970	$7,290
c)total plating line cost, $/yr	$636,096	$217,901	$34,397,946
d)total plating line costs, $/part	0.1030	0.4536	10.7239
COST DIFFERENTIAL BETWEEN THE PROCESSES, $/PART (a)	0.0050	0.0120	0.0290
COST DIFFERENTIAL BETWEEN THE PROCESSES, $/FT2 (b)	0.0391	0.0222	0.0023
ANNUAL COST DIFFERENTIAL, $/YR (c)	$24,200	$4,500	$72,800

(a) Obtained from G.1.e minus G.2.d. Numbers were independently rounded.

(b) Obtained by dividing the $/part value by the surface area of the part.

(c) Based on hexavalent chromium production rates.

TABLE G-10. SCENARIO III-PLATING LINE COSTS FOR EACH MODEL PLANT BASED ON THE BREAK-EVEN HEXAVALENT CHROMIUM REWORK RATES

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
A. END-PRODUCT PARAMETERS			
PART PLATED	Ratchets	Faucets	Bumpers
PLATING TIME, MIN	3.00	3.55	2.25
CURRENT DENSITY, A/FT2	50.00	125.00	200.00
SURFACE AREA OF PART, FT2	0.128	0.540	12.810
PLATING THICKNESS, MILS	0.011	0.00031	0.014
AMPERE-HOURS/FT2	2.50	7.40	7.50
AMPERE-HOURS/PART	0.32	3.99	96.08
B. MODEL PLANT PARAMETERS			
NO. OF PLATING LINES	1	2	5
OPERATING TIME, H/YR	2000	4000	6000
% TIME ELECTRODES ARE ENERGIZED, %	60	60	60
FAN HORSEPOWER REQUIREMENT, HP	10	20	35
CHROMIUM WASTEWATER FLOW RATE, GPM/PLATING LINE	6	6	12
C. COST PARAMETERS			
CR+6 WASTEWATER TREATMENT COSTS, $/1000 GAL	0.75	0.75	0.75
CR+3 WASTEWATER TREATMENT COSTS, $/1000 GAL	0.34	0.34	0.34
CR+6 CHEMICAL COSTS, $/AH	0.00052	0.00052	0.00052
CR+3 CHEMICAL COSTS, $/AH	0.007	0.007	0.007
FAN ELECTRICAL COSTS, $/KWH	0.0461	0.0461	0.0461

TABLE G-10 (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
D. PRODUCTION PARAMETERS			
1. REWORK RATES			
a) Hexavalent Chromium Process, %	2.850	4.500	6.750
b) Trivalent Chromium Process, %	1.0	1.0	1.0
2. TRIVALENT CHROMIUM PRODUCTIVITY INCREASE, %	20	20	20
3. HEXAVALENT CHROMIUM MAXIMUM PRODUCTION RATE, PARTS/YR	5.20E+06	4.04E+05	2.70E+06
E. PRODUCTION RATES			
1. HEXAVALENT CHROMIUM PROCESS			
a. Maximum surface area per year, ft2/yr	6.66E+05	2.18E+05	3.46E+07
b. Total # of parts produced, parts/yr	5.05E+06	3.86E+05	2.52E+06
c. No. of once-through parts, parts/yr	4.90E+06	3.68E+05	2.34E+06
d. No. of rework parts (parts processed twice), parts/yr	1.48E+05	1.82E+04	1.82E+05
2. TRIVALENT CHROMIUM PROCESS			
a. Maximum surface area per year, ft2/yr	7.99E+05	2.62E+05	4.15E+07
b. Maximum # of parts plated per year, parts/yr	6.24E+06	4.85E+05	3.24E+06
c. Total # of parts produced, parts/yr	6.18E+06	4.80E+05	3.21E+06
d. No. of once-through parts, parts/yr	6.12E+06	4.75E+05	3.18E+06
e. No. of rework parts (parts processed twice), parts/yr	6.24E+04	4.85E+03	3.24E+04
F. CHEMICAL COST			
HEXAVALENT CHROMIUM SOLUTION, $/FT2	0.0013	0.0038	0.0039
HEXAVALENT CHROMIUM SOLUTION, $/PART	0.0002	0.0021	0.0500
TRIVALENT CHROMIUM PROCESS, $/FT2	0.0175	0.0518	0.0525
TRIVALENT CHROMIUM PROCESS, $/PART	0.0022	0.0280	0.6725

TABLE G-10 (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
G. ANNUAL PLATING COST			
1. UNIT PLATING COSTS			
a. Hexavalent Chromium Process			
1)plating cost, $/part	$0.100	$0.421	$9.992
2)plating cost, $/ft2	$0.780	$0.780	$0.780
3)rework plating cost, $/part	0.200	0.842	19.984
b. Trivalent Chromium Process			
1)plating cost, $/part	$0.102	$0.447	$10.614
2)plating cost, $/ft2	0.796	0.828	0.829
3)rework plating cost, $/part	0.204	0.894	21.229
2. ANNUAL PLATING COSTS			
a. Hexavalent Chromium Process			
1)plating costs—once-through parts, $/yr	$489,379	$154,976	$23,335,849
2)plating costs—rework, $/yr	$29,581	$15,327	$3,642,011
3)annual plating costs, $/yr	$518,960	$170,303	$26,977,860
b. Trivalent Chromium Process			
1)plating costs—once-through parts, $/yr	$623,139	$212,592	$33,702,843
2)plating costs—rework, $/yr	$12,717	$4,339	$687,813
3)annual plating costs, $/yr	$635,856	$216,931	$34,390,656
H. WASTEWATER TREATMENT COSTS			
1. HEXAVALENT CHROMIUM PROCESS			
a) Wastewater volumes, gal/yr	720,000	2,880,000	21,600,000
b) Treatment costs, $/yr	$540	$2,160	$16,200
2. TRIVALENT CHROMIUM PROCESS			
a) Wastewater volumes, gal/yr	720,000	2,880,000	21,600,000
b) Treatment costs, $/yr	$240	$970	$7,290

TABLE G-10 (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
I. FAN ELECTRICAL COSTS			
HEXAVALENT CHROMIUM PROCESS			
a) Fan electrical usage, kWh/yr	14,920	59,680	156,660
b) Fan electrical costs, $/yr	$688	$2,751	$7,222
J. PLATING LINE COSTS			
1. HEXAVALENT CHROMIUM PROCESS			
a)annual plating costs, $/yr	$518,960	$170,303	$26,977,860
b)wastewater treatment costs, $/yr	$540	$2,160	$16,200
c)fan electrical costs, $/yr	$688	$2,751	$7,222
d)total plating line costs, $/yr	$520,188	$175,214	$27,001,282
e)total plating line costs, $/part	0.1030	0.4538	10 7244
2. TRIVALENT CHROMIUM PROCESS			
a)annual plating costs, $/yr	$635,856	$216,931	$34,390,656
b)wastewater treatment costs, $/yr	$240	$970	$7,290
c)total plating line cost, $/yr	$636,096	$217,901	$34,397,946
d)total plating line costs, $/part	0.1030	0.4536	10.7239
COST DIFFERENTIAL BETWEEN THE PROCESSES, $/PART (a)	0.0000	0.0000	0.0000
COST DIFFERENTIAL BETWEEN THE PROCESSES, $/FT2 (b)	0.0000	0.0000	0.0000
ANNUAL COST DIFFERENTIAL, $/YR (c)	$0	$0	$0

(a) Obtained from G.1.e minus G.2.d. Numbers were independently rounded.

(b) Obtained by dividing the $/part value by the surface area of the part.

(c) Based on hexavalent chromium production rates.

TABLE G-11. INCREMENTAL CAPITAL COST ASSOCIATED WITH INSTALLING A TRIVALENT CHROMIUM PROCESS INSTEAD OF A HEXAVALENT CHROMIUM PROCESS AT NEW PLANTS

	Model plant size		
Component	Small	Medium	Large
Startup (plating tank[s]) cost[a]	2,800	5,500	27,500
Initial passivation solution[b]	500	1,000	6,500
Subtotal	3,300	6,500	34,000
Purchased equipment cost			
Ampere-hour controller	1,600	3,200	8,000
Anode boxes[c]	7,800	15,600	39,000
Chillers[d]	9,300	18,600	71,000
Filter[d]	7,600	15,200	54,500
Subtotal	26,300	52,600	172,500
Taxes and freight[e]	2,100	4,200	13,800
TOTAL	28,400	56,800	186,300
Installation[f]	4,300	8,500	27,900
Indirect costs[g]	8,800	17,600	57,800
Total cost	44,800	89,400	306,000
Wastewater treatment cost savings[h]	-19,600[i]	-29,400[j]	-41,400[j]
Net cost[k]	25,200	60,000	264,600

[a]Startup costs for new plants would consist only of the incremental cost of the trivalent chromium bath solution over the hexavalent chromium bath solution. The cost differential between the trivalent chromium plating solution and the hexavalent plating solution is $1.60 per gallon of plating solution for the small and medium model plants and $1.20 per gallon for the large model plant.[1]

[b]Passivation solution is required for some trivalent chromium processes.

[c]Anode boxes are required for all double-cell processes.

[d]Optional equipment.

[e]Taxes and freight are estimated to be 3 and 5 percent of the base equipment cost, respectively.

[f]Installation costs are based on 15 percent of the purchased equipment costs.

[g]Indirect costs include costs associated with engineering and supervision (10 percent), process startup (1 percent), and contingencies (20 percent), and are based on 31 percent of the purchased equipment costs.

[h]Represents the capital cost of a hexavalent chromium reduction unit for the wastewater volume associated with each model plant.

[i]Batch process.

[j]Continuous process.

[k]The total capital cost is not solely attributable to air pollution control but also to process improvement.

TABLE G-12. CAPITAL COST OF CONVERTING HEXAVALENT CHROMIUM PROCESS TO TRIVALENT CHROMIUM PROCESS AT EXISTING FACILITIES

Component	Model plant size		
	Small	Medium	Large
Startup (tank conversion)[a]			
Initial trivalent chromium solution purchase	10,900	21,800	136,500
Initial passivation solution purchase	500	1,000	6,500
Waste disposal cost of hexavalent chromium solution	3,700	7,400	41,000
Subtotal	15,100	30,200	184,000
Purchased equipment cost			
Ampere-hour meter	1,600	3,200	8,000
Tank liner	2,200	4,400	18,000
Replacement anodes and hangers	3,300	6,600	43,500
Anode boxes	7,800	15,600	39,000
Chiller[b]	9,300	18,600	71,000
Filter[b]	7,600	15,200	54,500
Subtotal	31,800	63,600	234,000
Taxes and freight[c]	2,500	5,100	18,700
TOTAL	34,300	68,700	252,700
Installation/modification[d]	6,900	13,700	50,500
Indirect[e]	10,600	21,300	78,300
Total cost[f]	66,900	133,900	565,500

[a]Startup costs include the initial makeup of the trivalent chromium solution and the disposal cost of the hexavalent chromium plating solution.
[b]Optional equipment.
[c]Taxes and freight are estimated to be 3 and 5 percent of the base equipment cost, respectively.
[d]Installation/modification costs are based on 20 percent of purchased equipment costs.
[e]Indirect costs include costs associated with engineering and supervision (10 percent), process startup (1 percent), and contingencies (20 percent), and are estimated to be 31 percent of the purchased equipment cost.
[f]The total capital cost is not solely attributable to air pollution control but also to process improvement.

TABLE G-13. CAPITAL RECOVERY COSTS FOR EACH MODEL PLANT REPRESENTATIVE OF BOTH NEW AND EXISTING FACILITIES

	Model plant size		
Capital recovery costs, $/yr	Small	Medium	Large
Existing facility	13,200	26,300	108,900
New facility	6,000	3,400	54,000

TABLE G-14. INCREMENTAL ANNUALIZED COSTS ASSOCIATED WITH THE USE OF THE TRIVALENT CHROMIUM PROCESS

	Model plant size: End-product[a]		
	Small: Ratchets	Medium: Faucets	Large: Bumpers
Annualized cost components			
Capital recovery values, $/yr			
1. Existing facility	13,200	26,300	108,900
2. New facility	6,000	13,400	54,000
Process cost differential, $/yr			
1. Scenario 1[b]	10,300	2,700	(2,389,100)
2. Scenario 2[c]	(24,200)	(4,500)	(72,800)
3. Scenario 3[d]	0	0	0
Incremental annualized costs, $/yr			
1. Scenario 1			
a. Existing facility	23,500	29,000	(2,280,200)
b. New facility	16,300	16,100	(2,335,100)
2. Scenario 2			
a. Existing facility	(11,000)	21,800	36,100
b. New facility	(18,200)	8,900	(18,800)
3. Scenario 3			
a. Existing facility	13,200	26,300	108,900
b. New facility	6,000	13,400	54,000

[a]Parentheses indicate a cost savings.
[b]Hexavalent chromium reject rate was set at the value given by the plants that produce the end product selected.
[c]Hexavalent chromium reject rate was set at the average of the values given by the plants.
[d]Hexavalent chromium reject rate was set so that a process cost differential of zero was obtained.

G.9 REFERENCES FOR APPENDIX G

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18. Monthly Energy Review. Energy Information Administration, Department of Energy, Washington, D.C. October 1988.

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ATTACHMENT 1

PRODUCTION RATE CALCULATIONS

PRODUCTION RATE CALCULATIONS BASED ON THE PLATING OF RATCHETS

The following production rate parameters were obtained from the plant that plated ratchets:

No. of racks per hour = 108
No. of ratchets per rack = 40

This information is based on a chromium plating tank with a capacity of 1,800 gallons. This tank has approximately the same capacity as the model plating tanks (1,730 gallons) used in the small and medium model plants. Therefore, the production rates of ratchets at the small and medium model plants are computed from the following equation:

No. of ratchets/yr = (No. of racks/hr)(No. of ratchets/rack) (No. of plating tanks)(operating time, hr/yr)(percent time electrodes are energized)

Small model plant parameters	Medium model plant parameters
No. of plating tanks = 1	No. of plating lines = 2
Operating time, hr/yr = 2,000	Operating time, hr/yr = 4,000
Percent time electrodes are energized = 60	Percent time electrodes are energized = 60

Small Model Plant - Production Rate Calculation

No. of ratchets/yr = (108 racks/hr)(40 ratchets/rack) (1 plating tank)(2,000 hr/yr)(0.60) = 5,200,000 ratchets/yr

Medium Model Plant - Production Rate Calculation

No. of ratchets/yr = (108 racks/hr)(40 ratchets/rack) (2 plating tanks)(4,000 hr/yr)(0.60) = 20,700,000 ratchets/yr

PRODUCTION RATE CALCULATIONS BASED ON THE PLATING OF FAUCETS

The following production parameters were obtained from the plant that plated faucets:

No. of components = 3
No. of racks/hr = 13 for 2 components
2 for 1 component
No. of parts/rack = 21 for 2 components
110 for 1 component

These parameters are based on a plating tank with a capacity of 1,550 gallons. This capacity is similar to the capacity of the model plating tanks (1,730 gallons) used in the small and medium model plants. Therefore, these parameters can be used to determine the production rate for the model plants.

To obtain an equal number of components so that an equivalent number of faucets can be assembled, the amount of operating time the plating tank is devoted to the production of each component needs to be determined. Three equations were developed for determining the operating time devoted to each component and the subsequent production rate of each component. These equations are shown below:

Equation 1

2(x) + y = (operating time, hr/yr)(percent time electrodes are energized),

Equation 2

(No. of racks/hr)(No. of parts/rack)(x) = z, and

Equation 3

(No. of racks/hr)(No. of parts/rack)(y) = z,

where, x = operating time for first 2 components,
y = operating time for third component, and
z = number of parts produced per year.

Small model plant parameters	Medium model plant parameters
No. of plating tanks = 1	No. of plating tanks = 2
Operating time, hr/yr = 2,000	Operating time, hr/yr = 4,000
Percent time electrodes are energized = 60	Percent time electrodes are energized = 60

Small Model Plant Production Rate

First solve equations 2 and 3 in terms of x and y:

Equation 2

$(13)(21)(x) = z$, therefore, $x = z/273$ and

Equation 3

$(2)(110)(y) = z$, therefore, $y = z/220$.

Then substitute these values for x and y into equation No. 1, and solve for z:

$2(z/273) + (z/220) = (2,000 \text{ hr/yr})(0.60)$,

$z = 101,080$ ratchets/year.

Then, solve equations 2 and 3 for x and y:

$x = 101,080/273$ and $y = 101,080/220$, or
$x = 370$ hr/yr and $y = 460$ hr/yr.

Medium Model Plant Production Rate

First solve equations 2 and 3 in terms of x and y, then substitute these values for x and y into equation No. 1 and solve for z:

$2(z/273) + (z/220) = (4,000 \text{ hr/yr})(0.60)$, so

$z = 202,165$ parts/yr.

Then, solve equations 2 and 3 for x and y:

$x = 202,165/273$ and $y = 202,165/220$, or
$x = 750$ hr/yr and $y = 920$ hr/yr.

Multiply z by the number of plating tanks to determine the model plant production rate for faucets:

Production rate, parts/yr = (202,165 parts/yr)(2) = 404,330 parts/yr.

PRODUCTION RATE CALCULATIONS BASED ON THE PLATING OF BUMPERS

The following production parameters were obtained from the plant that plated bumpers:

No. of racks/hr = 47
No. of bumpers/rack = 10
No. of racks/tank = 3

The plating tank capacity that these production parameters were based on is 16,160 gallons. The model plating tanks in the large model plant have a capacity of 4,580 gallons. Therefore, to obtain the production rate of bumpers at the large model plant, it was estimated that each plating tank used in the large model plant could only hold one rack of parts per tank instead of three racks of parts per tank. The number of racks processed per hour was then recalculated based on the rack capacity of the model tank from the following equation:

(No. of racks/hr)/(rack capacity, racks/tank) for the actual plant = (No. of racks/hr)/(rack capacity, racks/tank) for the model plant.

Therefore,

(47 racks/hr)/(3 racks/tank) = (x racks/hr)/(1 rack/tank), and

x = 15 racks/hr.

Large Model Plant Parameters

No. of plating tanks = 5
Operating time, hr/yr = 6,000
Percent time electrodes are energized = 60

Model Plant Production Rate for Bumpers

No. of bumpers per year = (No. of plating tanks)(No. of racks/hr) (operating time, hr/yr)(percent time electrodes are energized)(No. of bumpers/rack)

No. of bumpers per year = (5)(15)(6,000)(0.60)(10) = 2,700,000

APPENDIX H.

NATIONWIDE IMPACT ANALYSIS

APPENDIX H. NATIONWIDE IMPACT ANALYSIS

Tables H-1 through H-3 present the nationwide emission impact analyses for each control option for hard chromium plating, decorative chromium plating, and chromic acid anodizing operations. Tables H-4 through H-6 present the cost impact analyses, and Tables H-7 through H-9 present the cost effectiveness analyses for each control option associated with these operations.

TABLE H-1. REGULATORY IMPACT ANALYSES: JOB AND CAPTIVE SHOPS--HARD CHROMIUM PLATING

	MODEL PLANT Small	Medium	Large	Total
Production rate, amp-h/yr	5,000,000	42,000,000	160,000,000	
Uncontrolled emission factor, mg/amp-h	10	10	10	
Uncontrolled emission rate, kg/yr (amp-h/yr*mg/amp-h)/1,000,000 mg/kg	50	420	1,600	
No. of operations nationwide	1,080	310	150	1,540

CONTROL OPTION I (BASELINE): HEXAVALENT CHROMIUM EMISSION ESTIMATES

	Number of Operations		Uncontrolled Emission Rate Per Plant,		Nationwide Uncontrolled Emissions,		Existing Control Efficiency, Percent	Nationwide Emission Rate, KG/YR	Nationwide Emission Rate, LB/YR	Nationwide Emission Rate, MG/YR	Nationwide Emission Rate, TONS/YR
	Percent	Total	KG/YR	LB/YR	KG/YR	LB/YR					
	A	B=(A*No. Operats)	C	D=(C*2.2)	E=(B*C)	F=(E*2.2)	G	H=(E*(1-G))	I=(H*2.2)	J=(H/1,000)	K=(I/2,000)
Small Model Plant											
Level of Control											
Uncontrolled	30	324	50	110	16,200	35,640	0	16,200	35,640	16.20	17.82
Mist eliminator (single set of blades)	30	324	50	110	16,200	35,640	90	1,620	3,564	1.62	1.78
Packed-bed scrubber	40	432	50	110	21,600	47,520	97	648	1,426	0.65	0.71
Total	100	1,080			54,000	118,800	65.8	18,468	40,630	18.47	20.31
Medium Model Plant											
Level of Control:											
Uncontrolled	30	93	420	924	39,060	85,932	0	39,060	85,932	39.06	42.97
Mist eliminator (single set of blades)	30	93	420	924	39,060	85,932	90	3,906	8,593	3.91	4.30
Packed-bed scrubber	40	124	420	924	52,080	114,576	97	1,562	3,437	1.56	1.72
Total	100	310			130,200	286,440	65.8	44,528	97,962	44.53	48.99
Large Model Plant											
Level of Control:											
Uncontrolled	30	45	1,600	3,520	72,000	158,400	0	72,000	158,400	72.00	79.20
Mist eliminator (single set of blades)	30	45	1,600	3,520	72,000	158,400	90	7,200	15,840	7.20	7.92
Packed-bed scrubber	40	60	1,600	3,520	96,000	211,200	97	2,880	6,336	2.88	3.17
Total	100	150			240,000	528,000	65.8	82,080	180,576	82.08	90.29
Total					424,200	933,240		145,076	319,168	145.08	159.59

TABLE H-1. (Continued)

CONTROL OPTION II: BASED ON USE OF CHEVRON-BLADE MIST ELIMINATORS WITH A DOUBLE SET OF BLADES THAT REDUCE UNCONTROLLED EMISSIONS BY 95 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant,		Nationwide Uncontrolled Emissions,		Control Efficiency, Percent	Nationwide Emission Rate, KG/YR	Nationwide Emission Rate, LB/YR	Nationwide Emission Rate, MG/YR	Nationwide Emission Rate, TONS/YR
	Percent A	Total B=(A*No. Operats)	KG/YR C	LB/YR D=(C*2.2)	KG/YR E=(B*C)	LB/YR F=(E*2.2)	G	H=(E*(1-G))	I=(H*2.2)	J=(H/1,000)	K=(I/2,000)
Small Model Plant											
Level of Control:											
Chevron-blade mist eliminator	30	324	50	110	16,200	35,640	95	810	1,782	0.81	0.89
Chevron-blade mist eliminator	30	324	50	110	16,200	35,640	95	810	1,782	0.81	0.89
Packed-bed scrubber	40	432	50	110	21,600	47,520	97	648	1,426	0.65	0.71
Total	100	1,080			54,000	118,800	95.8	2,268	4,990	2.27	2.49
Medium Model Plant											
Level of Control:											
Chevron-blade mist eliminator	30	93	420	924	39,060	85,932	95	1,953	4,297	1.95	2.15
Chevron-blade mist eliminator	30	93	420	924	39,060	85,932	95	1,953	4,297	1.95	2.15
Packed-bed scrubber	40	124	420	924	52,080	114,576	97	1,562	3,437	1.56	1.72
Total	100	310			130,200	286,440	95.8	5,468	12,030	5.47	6.02
Large Model Plant											
Level of Control:											
Chevron-blade mist eliminator	30	45	1,600	3,520	72,000	158,400	95	3,600	7,920	3.60	3.96
Chevron-blade mist eliminator	30	45	1,600	3,520	72,000	158,400	95	3,600	7,920	3.60	3.96
Packed-bed scrubber	40	60	1,600	3,520	96,000	211,200	97	2,880	6,336	2.88	3.17
Total	100	150			240,000	528,000	95.8	10,080	22,176	10.08	11.09
Total					424,200	933,240		17,816	39,196	17.82	19.60

TABLE H-1. (Continued)

CONTROL OPTION IIIa: BASED ON USE OF PACKED-BED SCRUBBERS THAT REDUCE UNCONTROLLED EMISSIONS BY 99 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant,		Nationwide Uncontrolled Emissions,		Control Efficiency, Percent	Nationwide Emission Rate, KG/YR	Nationwide Emission Rate, LB/YR	Nationwide Emission Rate, MG/YR	Nationwide Emission Rate, TONS/YR
	Percent	Total	KG/YR	LB/YR	KG/YR	LB/YR					
Small Model Plant	A	B=(A*No. Operats)	C	D=(C*2 2)	E=(B*C)	F=(E*2.2)	G	H=(E*(1-G))	I=(H*2.2)	J=(H/1,000)	K=(I/2,000)
Level of Control:											
Packed-bed scrubber	30	324	50	110	16,200	35,640	99	162	356	0.16	0.18
Packed-bed scrubber	30	324	50	110	16,200	35,640	99	162	356	0.16	0.18
Packed-bed scrubber	40	432	50	110	21,600	47,520	99	216	475	0.22	0.24
Total	100	1,080			54,000	118,800	99	540	1,188	0.54	0.59
Medium Model Plant											
Level of Control:											
Packed-bed scrubber	30	93	420	924	39,060	85,932	99	391	859	0.39	0.43
Packed-bed scrubber	30	93	420	924	39,060	85,932	99	391	859	0.39	0.43
Packed-bed scrubber	40	124	420	924	52,080	114,576	99	521	1,146	0.52	0.57
Total	100	310			130,200	286,440	99	1,302	2,864	1.30	1.43
Large Model Plant											
Level of Control:											
Packed-bed scrubber	30	45	1,600	3,520	72,000	158,400	99	720	1,584	0.72	0.79
Packed-bed scrubber	30	45	1,600	3,520	72,000	158,400	99	720	1,584	0.72	0.79
Packed-bed scrubber	40	60	1,600	3,520	96,000	211,200	99	960	2,112	0.96	1.06
Total	100	150			240,000	528,000	99	2,400	5,280	2.40	2.64
Total					424,200	933,240		4,242	9,332	4.24	4.67

TABLE H-1. (Continued)

CONTROL OPTION IIIb: BASED ON USE OF MESH-PAD MIST ELIMINATORS THAT REDUCE UNCONTROLLED EMISSIONS BY 99 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant,		Nationwide Uncontrolled Emissions,		Control Efficiency,	Nationwide Emission Rate,	Nationwide Emission Rate,	Nationwide Emission Rate,	Nationwide Emission Rate,
	Percent	Total	KG/YR	LB/YR	KG/YR	LB/YR	Percent	KG/YR	LB/YR	MG/YR	TONS/YR
Small Model Plant	A	B=(A*No. Operats)	C	D=(C*2.2)	E=(B*C)	F=(E*2.2)	G	H=(E*(1-G))	I=(H*2.2)	J=(H/1,000)	K=(I/2,000)
Level of Control:											
Mesh-pad mist eliminator	30	324	50	110	16,200	35,640	99	162	356	0.16	0.18
Mesh-pad mist eliminator	30	324	50	110	16,200	35,640	99	162	356	0.16	0.18
Mesh-pad mist eliminator	40	432	50	110	21,600	47,520	99	216	475	0.22	0.24
Total	100	1,080			54,000	118,800	99	540	1,188	0.54	0.59
Medium Model Plant											
Level of Control:											
Mesh-pad mist eliminator	30	93	420	924	39,060	85,932	99	391	859	0.39	0.43
Mesh-pad mist eliminator	30	93	420	924	39,060	85,932	99	391	859	0.39	0.43
Mesh-pad mist eliminator	40	124	420	924	52,080	114,576	99	521	1,146	0.52	0.57
Total	100	310			130,200	286,440	99	1,302	2,864	1.30	1.43
Large Model Plant											
Level of Control:											
Mesh-pad mist eliminator	30	45	1,600	3,520	72,000	158,400	99	720	1,584	0.72	0.79
Mesh-pad mist eliminator	30	45	1,600	3,520	72,000	158,400	99	720	1,584	0.72	0.79
Mesh-pad mist eliminator	40	60	1,600	3,520	96,000	211,200	99	960	2,112	0.96	1.06
Total	100	150			240,000	528,000	99	2,400	5,280	2.40	2.64
Total					424,200	933,240		4,242	9,332	4.24	4.67

TABLE H-2. REGULATORY IMPACT ANALYSES: JOB AND CAPTIVE SHOPS--DECORATIVE CHROMIUM PLATING

MODEL PLANT

	Small	Medium	Large	Total
Production rate, amp-h/yr	3,000,000	12,000,000	120,000,000	
Uncontrolled emission factor, mg/amp-h	2	2	2	
Uncontrolled emission rate, kg/yr	6.00	24 00	240.00	
(amp-h/yr*mg/amp-h)/1,000,000 mg/kg				
No. of operations nationwide	2,240	420	140	2,800

CONTROL OPTION I (BASELINE): HEXAVALENT CHROMIUM EMISSION ESTIMATES

	Number of Operations		Uncontrolled Emission Rate Per Plant,		Nationwide Uncontrolled Emissions,		Existing Control Efficiency,	Nationwide Emission Rate,	Nationwide Emission Rate,	Nationwide Emission Rate,	Nationwide Emission Rate,
	Percent	Total	KG/YR	LB/YR	KG/YR	LB/YR	Percent	KG/YR	LB/YR	MG/YR	TONS/YR
Small Model Plant	A	B=(A*No. Operats)	C	D=(C*2.2)	E=(B*C)	F=(E*2.2)	G	H=(E*(1-G))	I=(H*2.2)	J=(H/1,000)	K=(I/2,000)
Level of Control:											
Uncontrolled	15	336	6.0	13.2	2,016	4,435	0	2,016	4,435	2.02	2.22
Fume suppressant	40	896	6.0	13.2	5,376	11,827	97	161	355	0.16	0.18
Fume suppressant + packed-bed scrubber	40	896	6 0	13.2	5,376	11,827	97	161	355	0.16	0.18
Packed bed scrubber	5	112	6 0	13.2	672	1,478	95	34	74	0.03	0.04
Total	100	2,240			13,440	29,568	82.4	2,372	5,219	2.37	2.61
Medium Model Plant											
Level of Control:											
Uncontrolled	15	63	24.0	52.8	1,512	3,326	0	1,512	3,326	1.51	1.66
Fume suppressant	40	168	24.0	52.8	4,032	8,870	97	121	266	0.12	0.13
Fume suppressant + packed-bed scrubber	40	168	24.0	52 8	4,032	8,870	97	121	266	0.12	0.13
Packed-bed scrubber	5	21	24.0	52.8	504	1,109	95	25	55	0.03	0.03
Total	100	420			10,080	22,176	82.4	1,779	3,914	1.78	1.96
Large Model Plant											
Level of Control:											
Uncontrolled	15	21	240 0	528.0	5,040	11,088	0	5,040	11,088	5.04	5.54
Fume suppressant	40	56	240.0	528.0	13,440	29,568	97	403	887	0.40	0.44
Fume suppressant + packed-bed scrubber	40	56	240.0	528.0	13,440	29,568	97	403	887	0.40	0.44
Packed-bed scrubber	5	7	240.0	528.0	1,680	3,696	95	84	185	0.08	0.09
Total	100	140			33,600	73,920	82.4	5,930	13,047	5.93	6 52
Total					57,120	125,664		10,082	22,180	10.08	11.09

TABLE H-2. (Continued)

CONTROL OPTION IIa: BASED ON USE OF PACKED-BED SCRUBBERS THAT REDUCE UNCONTROLLED EMISSIONS BY 97 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant,		Nationwide Uncontrolled Emissions,		Control Efficiency, Percent	Nationwide Emission Rate, KG/YR	Nationwide Emission Rate, LB/YR	Nationwide Emission Rate, MG/YR	Nationwide Emission Rate, TONS/YR
	Percent	Total	KG/YR	LB/YR	KG/YR	LB/YR					
Small Model Plant	A	B=(A*No. Operats)	C	D=(C*2.2)	E=(B*C)	F=(E*2.2)	G	H=(E*(1-G))	I=(H*2.2)	J=(H/1,000)	K=(I/2,000)
Level of Control:											
Packed-bed scrubber	15	336	6.0	13.2	2,016	4,435	97	60	133	0.06	0.07
Fume suppressant	40	896	6.0	13.2	5,376	11,827	97	161	355	0.16	0.18
Fume suppressant + packed-bed scrubber	40	896	6.0	13.2	5,376	11,827	97	161	355	0.16	0.18
Packed-bed scrubber	5	112	6.0	13.2	672	1,478	97	20	44	0.02	0.02
Total	100	2,240			13,440	29,568	97.0	403	887	0.40	0.44
Medium Model Plant											
Level of Control:											
Packed-bed scrubber	15	63	24 0	52 8	1,512	3,326	97	45	100	0.05	0 05
Fume suppressant	40	168	24.0	52.8	4,032	8,870	97	121	266	0.12	0.13
Fume suppressant + packed-bed scrubber	40	168	24 0	52.8	4,032	8,870	97	121	266	0.12	0.13
Packed-bed scrubber	5	21	24.0	52.8	504	1,109	97	15	33	0.02	0.02
Total	100	420			10,080	22,176	97.0	302	665	0.30	0.33
Large Model Plant											
Level of Control:											
Packed-bed scrubber	15	21	240.0	528.0	5,040	11,088	97	151	333	0.15	0.17
Fume suppressant	40	56	240.0	528.0	13,440	29,568	97	403	887	0.40	0.44
Fume suppressant + packed-bed scrubber	40	56	240.0	528.0	13,440	29,568	97	403	887	0.40	0.44
Packed-bed scrubber	5	7	240.0	528 0	1,680	3,696	97	50	111	0.05	0.06
Total	100	140			33,600	73,920	97.0	1,008	2,218	1.01	1.11
Total					57,120	125,664		1,714	3,770	1.71	1.88

TABLE H-2. (Continued)

CONTROL OPTION IIb: BASED ON USE OF MESH-PAD MIST ELIMINATORS THAT REDUCE UNCONTROLLED EMISSIONS BY 97 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant,		Nationwide Uncontrolled Emissions,		Control Efficiency, Percent	Nationwide Emission Rate, KG/YR	Nationwide Emission Rate, LB/YR	Nationwide Emission Rate, MG/YR	Nationwide Emission Rate, TONS/YR
	Percent A	Total B=(A*No. Operats)	KG/YR C	LB/YR D=(C*2.2)	KG/YR E=(B*C)	LB/YR F=(E*2.2)	G	H=(E*(1-G))	I=(H*2.2)	J=(H/1,000)	K=(I/2,000)
Small Model Plant											
Level of Control:											
Mesh-pad mist eliminator	15	336	6 0	13 2	2,016	4,435	97	60	133	0.06	0.07
Fume suppressant	40	896	6 0	13.2	5,376	11,827	97	161	355	0.16	0.18
Fume suppressant + packed bed scrubber	40	896	6 0	13 2	5,376	11,827	97	161	355	0.16	0.18
Packed bed scrubber	5	112	6 0	13 2	672	1,478	97	20	44	0 02	0.02
Total	100	2 240			13,440	29,568	97 0	403	887	0.40	0.44
Medium Model Plant											
Level of Control:											
Mesh-pad mist eliminator	15	63	24 0	52.8	1,512	3,326	97	45	100	0.05	0.05
Fume suppressant	40	168	24.0	52.8	4,032	8,870	97	121	266	0.12	0.13
Fume suppressant + packed-bed scrubber	40	168	24.0	52.8	4,032	8,870	97	121	266	0.12	0.13
Packed bed scrubber	5	21	24 0	52.8	504	1,109	97	15	33	0.02	0.02
Total	100	420			10,080	22,176	97.0	302	665	0.30	0.33
Large Model Plant											
Level of Control:											
Mesh-pad mist eliminator	15	21	240.0	528.0	5,040	11,088	97	151	333	0.15	0.17
Fume suppressant	40	56	240.0	528.0	13,440	29,568	97	403	887	0.40	0.44
Fume suppressant + packed-bed scrubber	40	56	240.0	528.0	13,440	29,568	97	403	887	0.40	0.44
Packed-bed scrubber	5	7	240.0	528.0	1,680	3,696	97	50	111	0.05	0.06
Total	100	140			33,600	73,920	97 0	1,008	2,218	1.01	1.11
Total					57,120	125,664		1,714	3,770	1.71	1.88

TABLE H-2. (Continued)

CONTROL OPTION III: BASED ON USE OF FUME SUPPRESSANTS THAT REDUCE UNCONTROLLED EMISSIONS BY 99.5 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant,		Nationwide Uncontrolled Emissions,		Control Efficiency, Percent	Nationwide Emission Rate, KG/YR	Nationwide Emission Rate, LB/YR	Nationwide Emission Rate, MG/YR	Nationwide Emission Rate, TONS/YR
	Percent	Total	KG/YR	LB/YR	KG/YR	LB/YR					
Small Model Plant	A	B=(A*No. Operats)	C	D=(C*2.2)	E=(B*C)	F=(E*2.2)	G	H=(E*(1-G))	I=(H*2.2)	J=(H/1,000)	K=(I/2,000)
Level of Control:											
Fume suppressant	15	336	6.0	13.2	2,016	4,435	99.5	10	22	0.01	0.01
Fume suppressant	42.5	952	6.0	13.2	5,712	12,566	99.5	29	63	0.03	0.03
Fume suppressant + packed-bed scrubber	42.5	952	6 0	13.2	5,712	12,566	99.5	29	63	0.03	0.03
Fume suppressant	0	0	6 0	13.2	0	0	99.5	0	0	0.00	0.00
Total	100	2,240			13,440	29,568	99.5	67	148	0.07	0.07
Medium Model Plant											
Level of Control:											
Fume suppressant	15	63	24.0	52 8	1,512	3,326	99.5	8	17	0.01	0.01
Fume suppressant	42 5	179	24 0	52.8	4,296	9,451	99.5	21	47	0.02	0.02
Fume suppressant + packed-bed scrubber	42.5	179	24.0	52.8	4,296	9,451	99.5	21	47	0.02	0.02
Fume suppressant	0	0	24 0	52.8	0	0	99.5	0	0	0.00	0.00
Total	100	421			10,104	22,229	99.5	51	111	0.05	0.06
Large Model Plant											
Level of Control:											
Fume suppressant	15	21	240.0	528.0	5,040	11,088	99.5	25	55	0.03	0.03
Fume suppressant	42.5	60	240.0	528.0	14,400	31,680	99.5	72	158	0.07	0.08
Fume suppressant + packed-bed scrubber	42.5	60	240 0	528 0	14,400	31,680	99.5	72	158	0.07	0.08
Fume suppressant	0	0	240.0	528.0	0	0	99.5	0	0	0.00	0.00
Total	100	141			33,840	74,448	99.5	169	372	0.17	0.19
Total					57,384	126,245		287	631	0.29	0.32

TABLE H-2. (Continued)

CONTROL OPTION IVa: (SCENARIO 1) BASED ON USE OF THE TRIVALENT CHROMIUM PROCESS THAT REDUCES UNCONTROLLED EMISSIONS BY 100 PERCENT

REJECT RATES OF 1, 3, AND 15 PERCENT, RESPECTIVELY, FOR EACH MODEL PLANT

	Number of Operations		Uncontrolled Emission Rate Per Plant,		Nationwide Uncontrolled Emissions,		Control Efficiency, Percent	Nationwide Emission Rate, KG/YR	Nationwide Emission Rate, LB/YR	Nationwide Emission Rate, MG/YR	Nationwide Emission Rate, TONS/YR
	Percent	Total	KG/YR	LB/YR	KG/YR	LB/YR					
Small Model Plant	A	B=(A*No. Operats)	C	D=(C*2.2)	E=(B*C)	F=(E*2.2)	G	H=(E*(1-G))	I=(H*2.2)	J=(H/1,000)	K=(I/2,000)
Level of Control:											
Trivalent chromium process	15	336	6.0	13.2	2,016	4,435	100	0	0	0.00	0.00
Trivalent chromium process	40	896	6.0	13.2	5,376	11,827	100	0	0	0.00	0.00
Trivalent chromium process	40	896	6.0	13.2	5,376	11,827	100	0	0	0.00	0.00
Trivalent chromium process	5	112	6.0	13.2	672	1,478	100	0	0	0.00	0.00
Total	100	2,240			13,440	29,568	100.0	0	0	0.00	0.00
Medium Model Plant											
Level of Control:											
Trivalent chromium process	15	63	24.0	52.8	1,512	3,326	100	0	0	0.00	0.00
Trivalent chromium process	40	168	24.0	52.8	4,032	8,870	100	0	0	0.00	0.00
Trivalent chromium process	40	168	24.0	52.8	4,032	8,870	100	0	0	0 00	0.00
Trivalent chromium process	5	21	24 0	52.8	504	1,109	100	0	0	0.00	0.00
Total	100	420			10,080	22,176	100.0	0	0	0.00	0 00
Large Model Plant											
Level of Control:											
Trivalent chromium process	15	21	240.0	528.0	5,040	11,088	100	0	0	0.00	0 00
Trivalent chromium process	40	56	240.0	528.0	13,440	29,568	100	0	0	0.00	0.00
Trivalent chromium process	40	56	240.0	528.0	13,440	29,568	100	0	0	0.00	0 00
Trivalent chromium process	5	7	240.0	528 0	1,680	3,696	100	0	0	0.00	0.00
Total	100	140			33,600	73,920	100.0	0	0	0.00	0.00
Total					57,120	125,664		0	0	0.00	0.00

TABLE H-2. (Continued)

CONTROL OPTION IVb: (SCENARIO 2) BASED ON USE OF THE TRIVALENT CHROMIUM PROCESS THAT REDUCES UNCONTROLLED EMISSIONS BY 100 PERCENT REJECT RATES OF 7 PERCENT FOR EACH MODEL PLANT

	Number of Operations		Uncontrolled Emission Rate Per Plant,		Nationwide Uncontrolled Emissions,		Control Efficiency,	Nationwide Emission Rate,	Nationwide Emission Rate,	Nationwide Emission Rate,	Nationwide Emission Rate,
	Percent	Total	KG/YR	LB/YR	KG/YR	LB/YR	Percent	KG/YR	LB/YR	MG/YR	TONS/YR
Small Model Plant	A	B=(A*No. Operats)	C	D=(C*2.2)	E=(B*C)	F=(E*2.2)	G	H=(E*(1-G))	I=(H*2.2)	J=(H/1,000)	K=(I/2,000)
Level of Control:											
Trivalent chromium process	15	336	6.0	13.2	2,016	4,435	100	0	0	0.00	0.00
Trivalent chromium process	40	896	6.0	13.2	5,376	11,827	100	0	0	0.00	0.00
Trivalent chromium process	40	896	6.0	13.2	5,376	11,827	100	0	0	0.00	0.00
Trivalent chromium process	5	112	6 0	13 2	672	1,478	100	0	0	0.00	0.00
Total	100	2,240			13,440	29,568	100.0	0	0	0.00	0.00
Medium Model Plant											
Level of Control:											
Trivalent chromium process	15	63	24.0	52.8	1,512	3,326	100	0	0	0.00	0.00
Trivalent chromium process	40	168	24 0	52.8	4,032	8,870	100	0	0	0.00	0.00
Trivalent chromium process	40	168	24.0	52.8	4,032	8,870	100	0	0	0.00	0.00
Trivalent chromium process	5	21	24 0	52.8	504	1,109	100	0	0	0.00	0.00
Total	100	420			10,080	22,176	100.0	0	0	0.00	0.00
Large Model Plant											
Level of Control:											
Trivalent chromium process	15	21	240 0	528 0	5,040	11,088	100	0	0	0.00	0.00
Trivalent chromium process	40	56	240.0	528.0	13,440	29,568	100	0	0	0 00	0.00
Trivalent chromium process	40	56	240 0	528.0	13,440	29,568	100	0	0	0.00	0.00
Trivalent chromium process	5	7	240.0	528.0	1,680	3,696	100	0	0	0.00	0.00
Total	100	140			33,600	73,920	100.0	0	0	0.00	0.00
Total					57,120	125,664		0	0	0.00	0.00

TABLE H-2. (Continued)

CONTROL OPTION IVc: (SCENARIO 3) BASED ON USE OF THE TRIVALENT CHROMIUM PROCESS THAT REDUCES UNCONTROLLED EMISSIONS BY 100 PERCENT

REJECT RATES OF 2.85, 4.5, AND 6.75, RESPECTIVELY, FOR EACH MODEL PLANT

	Number of Operations		Uncontrolled Emission Rate Per Plant,		Nationwide Uncontrolled Emissions,		Control Efficiency,	Nationwide Emission Rate,	Nationwide Emission Rate,	Nationwide Emission Rate,	Nationwide Emission Rate,
	Percent	Total	KG/YR	LB/YR	KG/YR	LB/YR	Percent	KG/YR	LB/YR	MG/YR	TONS/YR
Small Model Plant	A	B=(A*No. Operats)	C	D=(C*2.2)	E=(B*C)	F=(E*2.2)	G	H=(E*(1-G))	I=(H*2.2)	J=(H/1,000)	K=(I/2,000)
Level of Control:											
Trivalent chromium process	15	336	6.0	13.2	2,016	4,435	100	0	0	0.00	0.00
Trivalent chromium process	40	896	6 0	13.2	5,376	11,827	100	0	0	0.00	0.00
Trivalent chromium process	40	896	6.0	13 2	5,376	11,827	100	0	0	0.00	0.00
Trivalent chromium process	5	112	6 0	13.2	672	1,478	100	0	0	0.00	0.00
Total	100	2,240			13,440	29,568	100.0	0	0	0.00	0.00
Medium Model Plant											
Level of Control:											
Trivalent chromium process	15	63	24 0	52.8	1,512	3,326	100	0	0	0.00	0.00
Trivalent chromium process	40	168	24.0	52.8	4,032	8,870	100	0	0	0.00	0.00
Trivalent chromium process	40	168	24.0	52.8	4,032	8,870	100	0	0	0.00	0.00
Trivalent chromium process	5	21	24.0	52.8	504	1,109	100	0	0	0.00	0.00
Total	100	420			10,080	22,176	100.0	0	0	0.00	0.00
Large Model Plant											
Level of Control·											
Trivalent chromium process	15	21	240.0	528.0	5,040	11,088	100	0	0	0.00	0.00
Trivalent chromium process	40	56	240.0	528.0	13,440	29,568	100	0	0	0.00	0.00
Trivalent chromium process	40	56	240.0	528.0	13,440	29,568	100	0	0	0.00	0.00
Trivalent chromium process	5	7	240.0	528.0	1,680	3,696	100	0	0	0.00	0.00
Total	100	140			33,600	73,920	100.0	0	0	0.00	0.00
Total					57,120	125,664		0	0	0.00	0.00

TABLE H-3. REGULATORY IMPACT ANALYSES: JOB AND CAPTIVE SHOPS--CHROMIC ACID ANODIZING

MODEL PLANT

	Small	Large	Total
Total tank surface area, ft2	42	300	
Uncontrolled emission factor, lb/hr/ft2	0.000123	0.000123	
Operating time, h/yr	1400	2400	
Uncontrolled emission rate, kg/yr (surface area, ft2*lb/hr/ft2)*(hr/yr)*(2.2046)	3.3	40.2	
No. of operations nationwide	515	165	680

CONTROL OPTION I (BASELINE): HEXAVALENT CHROMIUM EMISSION ESTIMATES

	Number of Operations		Uncontrolled Emission Rate Per Plant,		Nationwide Uncontrolled Emissions,		Existing Control Efficiency,	Nationwide Emission Rate,	Nationwide Emission Rate,	Nationwide Emission Rate,	Nationwide Emission Rate,
	Percent	Total	KG/YR	LB/YR	KG/YR	LB/YR	Percent	KG/YR	LB/YR	MG/YR	TONS/YR
Small Model Plant	A	B=(A*No. Operats)	C	D=(C*2.2)	E=(B*C)	F=(E*2.2)	G	H=(E*(1-G))	I=(H*2.2)	J=(H/1,000)	K=(I/2,000)
Level of Control:											
Uncontrolled	40	206	3.3	7.2	676	1,487	0	676	1,487	0.68	0.74
Mist eliminator (single set of blades)	10	52	3.3	7.2	171	375	90	17	38	0.02	0.02
Fume Suppressant	30	155	3 3	7.2	508	1,119	97	15	34	0.02	0.02
Packed-bed scrubber	20	103	3.3	7.2	338	743	95	17	37	0.02	0.02
Total	100	516			1,693	3,724	57.17	725	1,595	0.74	0.80
Large Model Plant											
Level of Control·											
Uncontrolled	40	66	40.2	88 4	2,651	5,833	0	2,651	5,833	2.65	2.92
Mist eliminator (single set of blades)	10	17	40.2	88.4	683	1,502	90	68	150	0.07	0.08
Fume suppressant	30	50	40.2	88 4	2,009	4,419	97	60	133	0.06	0.07
Packed-bed scrubber	20	33	40 2	88.4	1,326	2,916	95	66	146	0.07	0.07
Total	100	166			6,668	14,670	57.32	2,846	6,261	2.85	3.14
Total					8,361	18,394		3,571	7,856	3.59	3.94

TABLE H-3. (Continued)

CONTROL OPTION IIa: BASED ON USE OF PACKED-BED SCRUBBERS THAT REDUCE UNCONTROLLED EMISSIONS BY 97 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant,		Nationwide Uncontrolled Emissions,		Control Efficiency,	Nationwide Emission Rate,	Nationwide Emission Rate,	Nationwide Emission Rate,	Nationwide Emission Rate,
Small Model Plant	Percent A	Total B=(A*No. Operats)	KG/YR C	LB/YR D=(C*2.2)	KG/YR E=(B*C)	LB/YR F=(E*2.2)	Percent G	KG/YR H=(E*(1-G))	LB/YR I=(H*2.2)	MG/YR J=(H/1,000)	TONS/YR K=(I/2,000)
Level of Control:											
Packed-bed scrubber	40	206	3.3	7.2	676	1,487	97	20	45	0.02	0.02
Packed-bed scrubber	10	52	3.3	7.2	171	375	97	5	11	0.01	0.01
Fume suppressant	30	155	3.3	7.2	508	1,119	97	15	34	0.02	0.02
Packed bed scrubber	20	103	3.3	7.2	338	743	97	10	22	0.01	0.01
Total	100	516			1,693	3,724	97.00	51	112	0.05	0.06
Large Model Plant											
Level of Control:											
Packed-bed scrubber	40	66	40.2	88.4	2,651	5,833	97	80	175	0.08	0.09
Packed-bed scrubber	10	17	40.2	88.4	683	1,502	97	20	45	0.02	0.02
Fume suppressant	30	50	40.2	88.4	2,009	4,419	97	60	133	0.06	0.07
Packed bed scrubber	20	33	40.2	88.4	1,326	2,916	97	40	87	0.04	0.04
Total	100	166			6,668	14,670	97.00	200	440	0.20	0.22
Total					8,361	18,394		251	552	0.25	0.28

TABLE H-3. (Continued)

CONTROL OPTION IIb: BASED ON USE OF MESH-PAD MIST ELIMINATORS THAT REDUCE UNCONTROLLED EMISSIONS BY 97 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant,		Nationwide Uncontrolled Emissions,		Control Efficiency, Percent	Nationwide Emission Rate, KG/YR	Nationwide Emission Rate, LB/YR	Nationwide Emission Rate, MG/YR	Nationwide Emission Rate, TONS/YR
	Percent	Total	KG/YR	LB/YR	KG/YR	LB/YR					
Small Model Plant	A	B=(A*No. Operats)	C	D=(C*2.2)	E=(B*C)	F=(E*2.2)	G	H=(E*(1-G))	I=(H*2.2)	J=(H/1,000)	K=(I/2,000)
Level of Control:											
Mesh-pad mist eliminator	40	206	3.3	7.2	676	1,487	97	20	45	0.02	0.02
Mesh-pad mist eliminator	10	52	3.3	7.2	171	375	97	5	11	0.01	0.01
Fume suppressant	30	155	3.3	7 2	508	1,119	97	15	34	0.02	0.02
Packed-bed scrubber	20	103	3.3	7.2	338	743	97	10	22	0.01	0.01
Total	100	516			1,693	3,724	97.00	51	112	0.05	0.06
Large Model Plant											
Level of Control:											
Mesh-pad mist eliminator	40	66	40 2	88 4	2,651	5,833	97	80	175	0 08	0.09
Mesh pad mist eliminator	10	17	40.2	88.4	683	1,502	97	20	45	0 02	0.02
Fume suppressant	30	50	40 2	88 4	2,009	4,419	97	60	133	0.06	0.07
Packed bed scrubber	20	33	40 2	88 4	1,326	2,916	97	40	87	0.04	0.04
Total	100	166			6,668	14,670	97.00	200	440	0.20	0.22
Total					8,361	18,394		251	552	0.25	0.28

TABLE H-3. (Continued)

CONTROL OPTION III: BASED ON USE OF CHEMICAL FUME SUPPRESSANTS THAT REDUCE UNCONTROLLED EMISSIONS BY 99.5 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant,		Nationwide Uncontrolled Emissions,		Control Efficiency, Percent	Nationwide Emission Rate, KG/YR	Nationwide Emission Rate, LB/YR	Nationwide Emission Rate, MG/YR	Nationwide Emission Rate, TONS/YR
	Percent	Total	KG/YR	LB/YR	KG/YR	LB/YR					
Small Model Plant	A	B=(A*No. Operats)	C	D=(C*2.2)	E=(B*C)	F=(E*2.2)	G	H=(E*(1-G))	I=(H*2.2)	J=(H/1,000)	K=(I/2,000)
Level of Control:											
Fume suppressant	40	206	3.3	7.2	676	1,487	99.5	3	7	0.00	0.00
Fume suppressant	10	52	3.3	7.2	171	375	99.5	1	2	0.00	0.00
Fume suppressant	30	155	3.3	7.2	508	1,119	99.5	3	6	0.00	0.00
Fume suppressant	20	103	3.3	7.2	338	743	99.5	2	4	0.00	0.00
Total	100	516			1,693	3,724	99.50	8	19	0.01	0.01
Large Model Plant											
Level of Control:											
Fume suppressant	40	66	40.2	88.4	2,651	5,833	99.5	13	29	0.01	0.01
Fume suppressant	10	17	40.2	88.4	683	1,502	99.5	3	8	0.00	0.00
Fume suppressant	30	50	40.2	88.4	2,009	4,419	99.5	10	22	0.01	0.01
Fume suppressant	20	33	40.2	88.4	1,326	2,916	99.5	7	15	0.01	0.01
Total	100	166			6,668	14,670	99.50	33	73	0.03	0.04
Total					8,361	18,394		42	92	0.04	0.05

TABLE H-4. COST IMPACT ANALYSES: JOB AND CAPTIVE SHOPS--HARD CHROMIUM PLATING

MODEL PLANT

	Small	Medium	Large	Total
Production rate, amp-h/yr	5,000,000	42,000,000	160,000,000	
Uncontrolled emission factor, mg/Ah	10	10	10	
Uncontrolled emission rate, kg/yr (amp-h/yr*mg/amp-h)/1,000,000 mg/kg	50	420	1,600	
No. of operations nationwide	1,080	310	150	1,540

CONTROL OPTION 1: BASELINE

	Number of Operations Percent A	Number of Operations Total B=(A*No. Operats)	Uncontrolled Emission Rate Per Plant, KG/YR C	Control Efficiency, Percent D	Controlled Emission Rate, KG/YR E=(C*(1-D))	Chromic Acid Recovery, KG/YR F=(C-E)* (1.923)	Chromic Acid Recovery $/YR G=(F)* ($3.28/KG)	Control Device Capital Cost, $ H	Control Device Annualized Cost, $ I	Control Device Net Annualized Cost, $ J=(I)-(G)	Nationwide Capital Cost, $ K=(H)*(B)	Nationwide Annualized Cost, $ L=(I)*(B)	Nationwide Annualized Cost, $ M=(J)*(B)
Small Model Plant													
Level of Control:													
Uncontrolled	30	324	50	0	50	0	0	0	0	0	0	0	0
Mist eliminator (single blade)	30	324	50	90	5	87	300	22,500	5,100	4,800	7,290,000	1,652,400	1,555,200
Packed bed scrubber(single bed)	40	432	50	97	2	93	300	36,700	10,100	9,800	15,854,400	4,363,200	4,233,600
Total	100	1,080									23,144,400	6,015,600	5,788,800
Medium Model Plant													
Level of Control:													
Uncontrolled	30	93	420	0	420	0	0	0	0	0	0	0	0
Mist eliminator (single blade)	30	93	420	90	42	727	2,400	45,400	10,900	8,500	4,222,200	1,013,700	790,500
Packed bed scrubber(single bed)	40	124	420	97	13	783	2,600	74,200	21,300	18,700	9,200,800	2,641,200	2,318,800
Total	100	310									13,423,000	3,654,900	3,109,300
Large Model Plant													
Level of Control:													
Uncontrolled	30	45	1,600	0	1,600	0	0	0	0	0	0	0	0
Mist eliminator (single blade)	30	45	1,600	90	160	2,769	9,100	91,000	24,200	15,100	4,095,000	1,089,000	679,500
Packed-bed scrubber(single bed)	40	60	1,600	97	48	2,984	9,800	148,400	49,000	39,200	8,904,000	2,940,000	2,352,000
Total	100	150									12,999,000	4,029,000	3,031,500
Total											49,566,400	13,699,500	11,929,600

TABLE H-4. (Continued)

CONTROL OPTION II: BASED ON USE OF CHEVRON-BLADE MIST ELIMINATORS (DOUBLE SET OF BLADES) THAT REDUCE UNCONTROLLED EMISSIONS BY 95 PERCENT.

	Number of Operations		Uncontrolled Emission Rate Per Plant, KG/YR	Control Efficiency, Percent	Controlled Emission Rate, KG/YR	Chromic Acid Recovery, KG/YR	Chromic Acid Recovery, $/YR	Control Device Capital Cost, $	Control Device Annualized Cost, $	Control Device Net Annualized Cost, $	Nationwide Capital Cost, $	Nationwide Annualized Cost, $	Nationwide Net Cost, $
	Percent	Total											
Small Model Plant	A	B=(A*No. Operats)	C	D	E=(C*(1-D))	F=(C-E)* (1.923)	G=(F)* ($3.28/KG)	H	I	J=(I)-(G)	K=(H)*(B)	L=(I)*(B)	M=(J)*(B)
Level of Control:													
Mist eliminator (double blade)	30	324	50	95	3	91	300	23,800	5,800	5,500	7,711,200	1,879,200	1,782,000
Mist eliminator (double blade)	30	324	50	95	3	91	300	29,800	6,700	6,400	9,655,200	2,170,800	2,073,600
Packed-bed scrubber	40	432	50	97	2	93	300	36,700	10,100	9,800	15,854,400	4,363,200	4,233,600
Total	100	1,080									33,220,800	8,413,200	8,089,200
Medium Model Plant													
Level of Control:													
Mist eliminator (double blade)	30	93	420	95	21	767	2,500	49,800	12,700	10,200	4,631,400	1,181,100	948,600
Mist eliminator (double blade)	30	93	420	95	21	767	2,500	62,400	14,700	12,200	5,803,200	1,367,100	1,134,600
Packed bed scrubber	40	124	420	97	13	783	2,600	74,200	21,300	18,700	9,200,800	2,641,200	2,318,800
Total	100	310									19,635,400	5,189,400	4,402,000
Large Model Plant													
Level of Control:													
Mist eliminator (double blade)	30	45	1,600	95	80	2,923	9,600	99,700	29,700	20,100	4,486,500	1,336,500	904,500
Mist eliminator (double blade)	30	45	1,600	95	80	2,923	9,600	124,800	33,600	24,000	5,616,000	1,512,000	1,080,000
Packed bed scrubber	40	60	1,600	97	48	2,984	9,800	148,400	49,000	39,200	8,904,000	2,940,000	2,352,000
Total	100	150									19,006,500	5,788,500	4,336,500
Total											71,862,700	19,391,100	16,827,700

TABLE H-4. (Continued)

CONTROL OPTION IIIA: BASED ON USE OF PACKED-BED SCRUBBERS THAT REDUCE UNCONTROLLED EMISSIONS BY 99 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant, KG/YR	Control Efficiency, Percent	Controlled Emission Rate, KG/YR	Chromic Acid Recovery, KG/YR	Chromic Acid Recovery, $/YR	Control Device Capital Cost, $	Control Device Annualized Cost, $	Control Device Net Annualized Cost, $	Nationwide Capital Cost, $	Nationwide Annualized Cost, $	Nationwide Net Cost, $
	Percent	Total				F=(C-E)*	G=(F)*						
Small Model Plant	A	B=(A*No. Operats)	C	D	E=(C*(1-D))	(1.923)	($3.28/KG)	H	I	J=(I)-(G)	K=(H)*(B)	L=(I)*(B)	M=(J)*(B)
Level of Control:													
Packed-bed scrubber	30	324	50	99	1	95	300	36,700	10,100	9,800	11,890,800	3,272,400	3,175,200
Packed-bed scrubber	30	324	50	99	1	95	300	45,900	11,500	11,200	14,871,600	3,726,000	3,628,800
Packed-bed scrubber	40	432	50	99	1	95	300	36,700	10,100	9,800	15,854,400	4,363,200	4,233,600
Total	100	1,080									42,616,800	11,361,600	11,037,600
Medium Model Plant													
Level of Control:													
Packed-bed scrubber	30	93	420	99	4	800	2,600	74,200	21,300	18,700	6,900,600	1,980,900	1,739,100
Packed-bed scrubber	30	93	420	99	4	800	2,600	92,800	24,200	21,600	8,630,400	2,250,600	2,008,800
Packed-bed scrubber	40	124	420	99	4	800	2,600	74,200	21,300	18,700	9,200,800	2,641,200	2,318,800
Total	100	310									24,731,800	6,872,700	6,066,700
Large Model Plant													
Level of Control:													
Packed-bed scrubber	30	45	1,600	99	16	3,046	10,000	148,400	49,000	39,000	6,678,000	2,205,000	1,755,000
Packed-bed scrubber	30	45	1,600	99	16	3,046	10,000	185,500	54,800	44,800	8,347,500	2,466,000	2,016,000
Packed-bed scrubber	40	60	1,600	99	16	3,046	10,000	148,400	49,000	39,000	8,904,000	2,940,000	2,340,000
Total	100	150									23,929,500	7,611,000	6,111,000
Total											91,278,100	25,845,300	23,215,300

TABLE H-4. (Continued)

CONTROL OPTION IIIB: BASED ON USE OF MESH-PAD MIST ELIMINATORS THAT REDUCE UNCONTROLLED EMISSIONS BY 99 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant, KG/YR	Control Efficiency, Percent	Controlled Emission Rate, KG/YR	Chromic Acid Recovery, KG/YR	Chromic Acid Recovery, $/YR	Control Device Capital Cost, $	Control Device Annualized Cost, $	Control Device Net Annualized Cost, $	Nationwide Capital Cost, $	Nationwide Annualized Cost, $	Nationwide Net Cost, $
	Percent	Total											
Small Model Plant	A	B=(A*No. Operats)	C	D	E=(C*(1-D))	F=(C-E)* (1.923)	G=(F)* ($3.28/KG)	H	I	J=(I)-(G)	K=(H)*(B)	L=(I)*(B)	M=(J)*(B)
Level of Control:													
Mesh-pad mist eliminator	30	324	50	99	1	95	300	23,000	8,300	8,000	7,452,000	2,689,200	2,592,000
Mesh-pad mist eliminator	30	324	50	99	1	95	300	28,900	9,500	9,200	9,363,600	3,078,000	2,980,800
Packed bed Scrubber	40	432	50	99	1	95	300	36,700	10,100	9,800	15,854,400	4,363,200	4,233,600
Total	100	1,080									32,670,000	10,130,400	9,806,400
Medium Model Plant													
Level of Control:													
Mesh-pad mist eliminator	30	93	420	99	4	800	2,600	66,000	26,700	24,100	6,138,000	2,483,100	2,241,300
Mesh-pad mist eliminator	30	93	420	99	4	800	2,600	82,500	29,900	27,300	7,672,500	2,780,700	2,538,900
Packed bed Scrubber	40	124	420	99	4	800	2,600	74,200	21,300	18,700	9,200,800	2,641,200	2,318,800
Total	100	310									23,011,300	7,905,000	7,099,000
Large Model Plant													
Level of Control:													
Mesh-pad mist eliminator	30	45	1,600	99	16	3,046	10,000	124,900	62,600	52,600	5,620,500	2,817,000	2,367,000
Mesh-pad mist eliminator	30	45	1,600	99	16	3,046	10,000	156,300	69,000	59,000	7,033,500	3,105,000	2,655,000
Packed bed Scrubber	40	60	1,600	99	16	3,046	10,000	148,400	49,000	39,000	8,904,000	2,940,000	2,340,000
Total	100	150									21,558,000	8,862,000	7,362,000
Total											77,239,300	26,897,400	24,267,400

TABLE H-5. COST IMPACT ANALYSES: JOB AND CAPTIVE SHOPS--DECORATIVE CHROMIUM PLATING

	MODEL PLANT Small	Medium	Large	Total
Production rate, amp-h/yr	3,000,000	12,000,000	120,000,000	
Uncontrolled emission factor, mg/Ah	2	2	2	
Uncontrolled emission rate, kg/yr (amp-h/yr*mg/amp-h)/1,000,000 mg/kg	6	24	240	
No. of operations nationwide	2,240	420	140	2,800

CONTROL OPTION I: BASELINE

	Number of Operations Percent A	Total B=(A*No. Operats)	Uncontrolled Emission Rate Per Plant, KG/YR C	Existing Control Efficiency, Percent D	Baseline Emission Rate, KG/YR E=(C*(1-D))	Chromic Acid Recovery, KG/YR F=(C-E)* (1.923)	Chromic Acid Recovery, $/YR G=(F)*($3.28/KG)	Control Device Capital Cost, $ H	Control Device Annualized Cost, $ I	Control Device Net Annualized Cost, $ J=(I)-(G)	Nationwide Capital Cost, $ K=(H)*(B)	Nationwide Annualized Cost, $ L=(I)*(B)	Nationwide Net Annualized Cost, $ M=(J)*(B)
Small Model Plant													
Level of Control:													
Uncontrolled	15	336	6 0	0	6.0	0	0	0	0	0	0	0	0
Fume suppressant (FS)	40	896	6 0	97	0.2	11	0	0	1,000	1,000	0	896,000	896,000
Packed-bed scrubber (PBS)	5	112	6.0	95	0.3	11	0	36,700	10,100	10,100	4,110,400	1,131,200	1,131,200
FS and PBS	40	896	6.0	97	0.2	11	0	36,700	11,100	11,100	32,883,200	9,945,600	9,945,600
Total	100	2,240									36,993,600	11,972,800	11,972,800
Medium Model Plant													
Level of Control:													
Uncontrolled	15	63	24.0	0	24.0	0	0	0	0	0	0	0	0
Fume suppressant (FS)	40	168	24.0	97	0.7	45	200	0	3,500	3,300	0	588,000	554,400
Packed-bed scrubber (PBS)	5	21	24 0	95	1 2	44	100	73,500	21,800	21,700	1,543,500	457,800	455,700
FS and PBS	40	168	24.0	97	0.7	45	200	73,500	25,300	25,100	12,348,000	4,250,400	4,216,800
Total	100	420									13,891,500	5,296,200	5,226,900
Large Model Plant													
Level of Control:													
Uncontrolled	15	21	240.0	0	240.0	0	0	0	0	0	0	0	0
Fume suppressant (FS)	40	56	240 0	97	7.2	448	1,500	0	18,700	17,200	0	1,047,200	963,200
Packed-bed scrubber (PBS)	5	7	240.0	95	12 0	438	1,400	124,600	41,900	40,500	872,200	293,300	283,500
FS and PBS	40	56	240.0	97	7.2	448	1,500	124,600	60,600	59,100	6,977,600	3,393,600	3,309,600
Total	100	140									7,849,800	4,734,100	4,556,300
Total											58,734,900	22,003,100	21,756,000

TABLE H-5. (Continued)

CONTROL OPTION IIa: BASED ON USE OF PACKED-BED SCRUBBERS THAT REDUCE UNCONTROLLED EMISSIONS BY 97 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant, KG/YR	Control Efficiency, Percent	Controlled Emission Rate, KG/YR	Chromic Acid Recovery, KG/YR	Chromic Acid Recovery, $/YR	Control Device Capital Cost, $	Control Device Annualized Cost, $	Control Device Net Annualized Cost, $	Nationwide Capital Cost, $	Nationwide Annualized Cost, $	Nationwide Net Annualized Cost, $
	Percent	Total											
Small Model Plant	A	B=(A*No. Operats)	C	D	E=(C*(1-D))	F=(C-E)* (1.923)	G=(F)*($3.28/KG)	H	I	J=(I)-(G)	K=(H)*(B)	L=(I)*(B)	M=(J)*(B)
Level of Control:													
Packed-bed scrubber (PBS)	15	336	6.0	97	0.2	11	0	36,700	10,100	10,100	12,331,200	3,393,600	3,393,600
Fume suppressant (FS)	40	896	6.0	97	0.2	11	0	0	1,000	1,000	0	896,000	896,000
Packed-bed scrubber (PBS)	5	112	6.0	97	0.2	11	0	36,700	10,100	10,100	4,110,400	1,131,200	1,131,200
FS and PBS	40	896	6 0	97	0.2	11	0	36,700	11,100	11,100	32,883,200	9,945,600	9,945,600
Total	100	2,240									49,324,800	15,366,400	15,366,400
Medium Model Plant													
Level of Control:													
Packed-bed scrubber (PBS)	15	63	24.0	97	0.7	45	200	73,500	21,800	21,600	4,630,500	1,373,400	1,360,800
Fume suppressant (FS)	40	168	24 0	97	0.7	45	200	0	3,500	3,300	0	588,000	554,400
Packed bed scrubber (PBS)	5	21	24.0	97	0 7	45	200	73,500	21,800	21,600	1,543,500	457,800	453,600
FS and PBS	40	168	24.0	97	0.7	45	200	73,500	25,300	25,100	12,348,000	4,250,400	4,216,800
Total	100	420									18,522,000	6,669,600	6,585,600
Large Model Plant													
Level of Control:													
Packed-bed scrubber (PBS)	15	21	240.0	97	7 2	448	1,500	124,600	41,900	40,400	2,616,600	879,900	848,400
Fume suppressant (FS)	40	56	240.0	97	7.2	448	1,500	0	18,700	17,200	0	1,047,200	963,200
Packed-bed scrubber (PBS)	5	7	240.0	97	7 2	448	1,500	124,600	41,900	40,400	872,200	293,300	282,800
FS and PBS	40	56	240.0	97	7.2	448	1,500	124,600	60,600	59,100	6,977,600	3,393,600	3,309,600
Total	60	140									10,466,400	5,614,000	5,404,000
Total											78,313,200	27,650,000	27,356,000

TABLE H-5. (Continued)

CONTROL OPTION IIb: BASED ON USE OF MESH-PAD MIST ELIMINATORS THAT REDUCE UNCONTROLLED EMISSIONS BY 97 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant, KG/YR	Control Efficiency, Percent	Controlled Emission Rate, KG/YR	Chromic Acid Recovery, KG/YR	Chromic Acid Recovery, $/YR	Control Device Capital Cost, $	Control Device Annualized Cost, $	Control Device Net Annualized Cost, $	Nationwide Capital Cost, $	Nationwide Annualized Cost, $	Nationwide Net Annualized Cost, $
	Percent	Total											
Small Model Plant	A	B=(A*No. Operats)	C	D	E=(C*(1-D))	F=(C-E)* (1.923)	G=(F)*($3.28/KG)	H	I	J=(I)-(G)	K=(H)*(B)	L=(I)*(B)	M=(J)*(B)
Level of Control:													
Mesh-pad mist eliminator	15	336	6.0	97	0.2	11	0	23,000	8,300	8,300	7,728,000	2,788,800	2,788,800
Fume suppressant (FS)	40	896	6.0	97	0.2	11	0	0	1,000	1,000	0	896,000	896,000
Packed-bed scrubber (PBS)	5	112	6.0	97	0.2	11	0	36,700	10,100	10,100	4,110,400	1,131,200	1,131,200
FS and PBS	40	896	6.0	97	0.2	11	0	36,700	11,100	11,100	32,883,200	9,945,600	9,945,600
Total	100	2,240									44,721,600	14,761,600	14,761,600
Medium Model Plant													
Level of Control:													
Mesh-pad mist eliminator	15	63	24.0	97	0.7	45	200	39,200	17,100	16,900	2,469,600	1,077,300	1,064,700
Fume suppressant (FS)	40	168	24.0	97	0.7	45	200	0	3,500	3,300	0	588,000	554,400
Packed-bed scrubber (PBS)	5	21	24.0	97	0.7	45	200	73,500	21,800	21,600	1,543,500	457,800	453,600
FS and PBS	40	168	24.0	97	0.7	45	200	73,500	25,300	25,100	12,348,000	4,250,400	4,216,800
Total	100	420									16,361,100	6,373,500	6,289,500
Large Model Plant													
Level of Control:													
Mesh-pad mist eliminator	15	21	240.0	97	7.2	448	1,500	87,200	44,300	42,800	1,831,200	930,300	898,800
Fume suppressant (FS)	40	56	240.0	97	7.2	448	1,500	0	18,700	17,200	0	1,047,200	963,200
Packed-bed scrubber (PBS)	5	7	240.0	97	7.2	448	1,500	124,600	41,900	40,400	872,200	293,300	282,800
FS and PBS	40	56	240.0	97	7.2	448	1,500	124,600	60,600	59,100	6,977,600	3,393,600	3,309,600
Total	100	140									9,681,000	5,664,400	5,454,400
Total											70,763,700	26,799,500	26,505,500

TABLE H-5. (Continued)

CONTROL OPTION III: BASED ON USE OF FUME SUPPRESSANTS THAT REDUCE UNCONTROLLED EMISSIONS BY 99.5 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant, KG/YR	Control Efficiency, Percent	Controlled Emission Rate, KG/YR	Chromic Acid Recovery, KG/YR	Chromic Acid Recovery, $/YR	Control Device Capital Cost, $	Control Device Annualized Cost, $	Control Device Net Annualized Cost, $	Nationwide Capital Cost, $	Nationwide Annualized Cost, $	Nationwide Net Annualized Cost, $
	Percent	Total											
Small Model Plant	A	B=(A*No. Operats)	C	D	E=(C*(1 D))	F=(C-E)* (1.923)	G=(F)*($3.28/KG)	H	I	J=(I)-(G)	K=(H)*(B)	L=(I)*(B)	M=(J)*(B)
Level of Control:													
Fume suppressant (FS)	15	336	6.0	99.5	0.0	11	0	0	1,000	1,000	0	336,000	336,000
Fume suppressant (FS)	40	896	6.0	99.5	0.0	11	0	0	1,000	1,000	0	896,000	896,000
Fume suppressant (FS)	2.5	56	6.0	99.5	0 0	11	0	0	1,000	1,000	0	56,000	56,000
FS and PBS	42.5	952	6.0	99.5	0.0	11	0	36,700	11,100	11,100	34,938,400	10,567,200	10,567,200
Total	100	2,240									34,938,400	11,855,200	11,855,200
Medium Model Plant													
Level of Control:													
Fume suppressant (FS)	15	63	24 0	99.5	0.1	46	200	0	3,500	3,300	0	220,500	207,900
Fume suppressant (FS)	40	168	24 0	99.5	0.1	46	200	0	3,500	3,300	0	588,000	554,400
Fume suppressant (FS)	2.5	11	24.0	99.5	0.1	46	200	0	3,500	3,300	0	36,750	34,650
FS and PBS	42.5	178	24 0	99.5	0.1	46	200	73,500	25,300	25,100	13,083,000	4,503,400	4,467,800
Total	100	420									13,083,000	5,348,650	5,264,750
Large Model Plant													
Level of Control:													
Fume suppressant (FS)	15	21	240.0	99.5	1.2	459	1,500	0	18,700	17,200	0	392,700	361,200
Fume suppressant (FS)	40	56	240.0	99.5	1.2	459	1,500	0	18,700	17,200	0	1,047,200	963,200
Fume suppressant (FS)	2.5	4	240.0	99.5	1.2	459	1,500	0	18,700	17,200	0	65,450	60,200
FS and PBS	42.5	59	240.0	99.5	1.2	459	1,500	124,600	60,600	59,100	7,351,400	3,575,400	3,486,900
Total	100	140									7,351,400	5,080,750	4,871,500
Total											55,372,800	22,284,600	21,991,450

TABLE H-5. (Continued)

CONTROL OPTION IVa: (SCENARIO 1) BASED ON USE OF THE TRIVALENT CHROMIUM PROCESS THAT REDUCES UNCONTROLLED EMISSIONS BY 100 PERCENT REJECT RATES OF 1, 3, AND 15 PERCENT, RESPECTIVELY FOR EACH MODEL PLANT

	Number of Operations		Uncontrolled Emission Rate Per Plant, KG/YR	Control Efficiency, Percent	Controlled Emission Rate, KG/YR	Chromic Acid Recovery, KG/YR	Chromic Acid Recovery, $/YR	Control Device Capital Cost, $	Control Device Annualized Cost, $	Control Device Net Annualized Cost, $	Nationwide Capital Cost, $	Nationwide Annualized Cost, $	Nationwide Net Annualized Cost, $
Small Model Plant	Percent A	Total B=(A*No. Operate)	C	D	E=(C*(1-D))	F=(C-E)* (1.923)	G=(F)*($3.28/KG)	H	I	J=(I)-(G)	K=(H)*(B)	L=(I)*(B)	M=(J)*(B)
Level of Control:													
Trivalent Chromium Process	15	336	6.0	100	0.0	12	0	66,900	23,500	23,500	22,478,400	7,896,000	7,896,000
Trivalent Chromium Process	40	896	6.0	100	0.0	12	0	66,900	23,500	23,500	59,942,400	21,056,000	21,056,000
Trivalent Chromium Process	5	112	6.0	100	0.0	12	0	66,900	23,500	23,500	7,492,800	2,632,000	2,632,000
Trivalent Chromium Process	40	896	6.0	100	0.0	12	0	66,900	23,500	23,500	59,942,400	21,056,000	21,056,000
Total	100	2,240									149,856,000	52,640,000	52,640,000
Medium Model Plant													
Level of Control:													
Trivalent Chromium Process	15	63	24.0	100	0.0	46	200	133,900	29,000	29,000	8,435,700	1,827,000	1,827,000
Trivalent Chromium Process	40	168	24.0	100	0.0	46	200	133,900	29,000	29,000	22,495,200	4,872,000	4,872,000
Trivalent Chromium Process	5	21	24.0	100	0.0	46	200	133,900	29,000	29,000	2,811,900	609,000	609,000
Trivalent Chromium Process	40	168	24.0	100	0.0	46	200	133,900	29,000	29,000	22,495,200	4,872,000	4,872,000
Total	100	420									56,238,000	12,180,000	12,180,000
Large Model Plant													
Level of Control:													
Trivalent Chromium Process	15	21	240.0	100	0.0	462	1,500	565,500	(2,280,200)	(2,280,200)	11,875,500	(47,884,200)	(47,884,200)
Trivalent Chromium Process	40	56	240.0	100	0.0	462	1,500	565,500	(2,280,200)	(2,280,200)	31,668,000	(127,691,200)	(127,691,200)
Trivalent Chromium Process	5	7	240.0	100	0.0	462	1,500	565,500	(2,280,200)	(2,280,200)	3,958,500	(15,961,400)	(15,961,400)
Trivalent Chromium Process	40	56	240.0	100	0.0	462	1,500	565,500	(2,280,200)	(2,280,200)	31,668,000	(127,691,200)	(127,691,200)
Total	100	140									79,170,000	(319,228,000)	(319,228,000)
Total											285,264,000	(254,408,000)	(254,408,000)

TABLE H-5. (Continued)

CONTROL OPTION IVb: (SCENARIO 2) BASED ON USE OF THE TRIVALENT CHROMIUM PROCESS THAT REDUCES UNCONTROLLED EMISSIONS BY 100 PERCENT
REJECT RATES OF 7 PERCENT FOR EACH MODEL PLANT

	Number of Operations		Uncontrolled Emission Rate Per Plant, KG/YR	Control Efficiency, Percent	Controlled Emission Rate, KG/YR	Chromic Acid Recovery KG/YR F=(C-E)*(1.923)	Chromic Acid Recovery, $/YR	Control Device Capital Cost, $	Control Device Annualized Cost, $	Control Device Net Annualized Cost, $	Nationwide Capital Cost, $	Nationwide Annualized Cost, $	Nationwide Net Annualized Cost, $
	Percent	Total											
Small Model Plant	A	B=(A*No. Operats)	C	D	E=(C*(1-D))		G=(F)*($3.28/KG)	H	I	J=(I)-(G)	K=(H)*(B)	L=(I)*(B)	M=(J)*(B)
Level of Control:													
Trivalent Chromium Process	15	336	6.0	100	0.0	12	0	66,900	(11,000)	(11,000)	22,478,400	(3,696,000)	(3,696,000)
Trivalent Chromium Process	40	896	6.0	100	0.0	12	0	66,900	(11,000)	(11,000)	59,942,400	(9,856,000)	(9,856,000)
Trivalent Chromium Process	5	112	6.0	100	0.0	12	0	66,900	(11,000)	(11,000)	7,492,800	(1,232,000)	(1,232,000)
Trivalent Chromium Process	40	896	6.0	100	0.0	12	0	66,900	(11,000)	(11,000)	59,942,400	(9,856,000)	(9,856,000)
Total	100	2,240									149,856,000	(24,640,000)	(24,640,000)
Medium Model Plant													
Level of Control:													
Trivalent Chromium Process	15	63	24.0	100	0.0	46	200	133,900	21,800	21,800	8,435,700	1,373,400	1,373,400
Trivalent Chromium Process	40	168	24.0	100	0.0	46	200	133,900	21,800	21,800	22,495,200	3,662,400	3,662,400
Trivalent Chromium Process	5	21	24.0	100	0.0	46	200	133,900	21,800	21,800	2,811,900	457,800	457,800
Trivalent Chromium Process	40	168	24.0	100	0.0	46	200	133,900	21,800	21,800	22,495,200	3,662,400	3,662,400
Total	100	420									56,238,000	9,156,000	9,156,000
Large Model Plant													
Level of Control:													
Trivalent Chromium Process	15	21	240.0	100	0.0	462	1,500	565,500	36,100	36,100	11,875,500	758,100	758,100
Trivalent Chromium Process	40	56	240.0	100	0.0	462	1,500	565,500	36,100	36,100	31,668,000	2,021,600	2,021,600
Trivalent Chromium Process	5	7	240.0	100	0.0	462	1,500	565,500	36,100	36,100	3,958,500	252,700	252,700
Trivalent Chromium Process	40	56	240.0	100	0.0	462	1,500	565,500	36,100	36,100	31,668,000	2,021,600	2,021,600
Total	100	140									79,170,000	5,054,000	5,054,000
Total											285,264,000	(10,430,000)	(10,430,000)

TABLE H-5. (Continued)

CONTROL OPTION IVc: (SCENARIO 3) BASED ON USE OF THE TRIVALENT CHROMIUM PROCESS THAT REDUCES UNCONTROLLED EMISSIONS BY 100 PERCENT
REJECT RATES OF 2.85, 4.5, AND 6.75, RESPECTIVELY, FOR EACH MODEL PLANT

	Number of Operations		Uncontrolled Emission Rate Per Plant, KG/YR	Control Efficiency, Percent	Controlled Emission Rate, KG/YR	Chromic Acid Recovery, KG/YR	Chromic Acid Recovery, $/YR	Control Device Capital Cost, $	Control Device Annualized Cost, $	Control Device Net Annualized Cost, $	Nationwide Capital Cost, $	Nationwide Annualized Cost, $	Nationwide Net Annualized Cost, $
	Percent	Total											
Small Model Plant	A	B=(A*No. Operats)	C	D	E=(C*(1-D))	F=(C-E)* (1.923)	G=(F)*($3.28/KG)	H	I	J=(I)-(G)	K=(H)*(B)	L=(I)*(B)	M=(J)*(B)
Level of Control:													
Trivalent Chromium Process	15	336	6.0	100	0.0	12	0	66,900	13,200	13,200	22,478,400	4,435,200	4,435,200
Trivalent Chromium Process	40	896	6.0	100	0.0	12	0	66,900	13,200	13,200	59,942,400	11,827,200	11,827,200
Trivalent Chromium Process	5	112	6.0	100	0.0	12	0	66,900	13,200	13,200	7,492,800	1,478,400	1,478,400
Trivalent Chromium Process	40	896	6.0	100	0.0	12	0	66,900	13,200	13,200	59,942,400	11,827,200	11,827,200
Total	100	2,240									149,856,000	29,568,000	29,568,000
Medium Model Plant													
Level of Control:													
Trivalent Chromium Process	15	63	24.0	100	0.0	46	200	133,900	26,300	26,300	8,435,700	1,656,900	1,656,900
Trivalent Chromium Process	40	168	24.0	100	0.0	46	200	133,900	26,300	26,300	22,495,200	4,418,400	4,418,400
Trivalent Chromium Process	5	21	24.0	100	0.0	46	200	133,900	26,300	26,300	2,811,900	552,300	552,300
Trivalent Chromium Process	40	168	24.0	100	0.0	46	200	133,900	26,300	26,300	22,495,200	4,418,400	4,418,400
Total	100	420									56,238,000	11,046,000	11,046,000
Large Model Plant													
Level of Control:													
Trivalent Chromium Process	15	21	240.0	100	0.0	462	1,500	565,500	108,900	108,900	11,875,500	2,286,900	2,286,900
Trivalent Chromium Process	40	56	240.0	100	0.0	462	1,500	565,500	108,900	108,900	31,668,000	6,098,400	6,098,400
Trivalent Chromium Process	5	7	240.0	100	0.0	462	1,500	565,500	108,900	108,900	3,958,500	762,300	762,300
Trivalent Chromium Process	40	56	240.0	100	0.0	462	1,500	565,500	108,900	108,900	31,668,000	6,098,400	6,098,400
Total	100	140									79,170,000	15,246,000	15,246,000
Total											285,264,000	55,860,000	55,860,000

TABLE H-6. COST IMPACT ANALYSES: JOB AND CAPTIVE SHOPS--CHROMIC ACID ANODIZING

MODEL PLANT

	Small	Large	Total
Total tanks surface area, ft2	42	300	
Operating time, h/yr	1400	2400	
Uncontrolled emission factor, lb/h/ft2	0.00012	0.000123	
Uncontrolled emission rate, kg/yr	3.3	40.2	
(ft2)*(lb/h/ft2)*(h/yr)/2.2046			
No. of operations nationwide	515	165	680

CONTROL OPTION I: BASELINE

	Number of Operations		Uncontrolled Emission Rate Per Plant, KG/YR	Existing Control Efficiency, Percent	Baseline Emission Rate, KG/YR	Chromic Acid Recovery, KG/YR F=(C-E)*(1.923)	Chromic Acid Recovery, $/YR G=(F)*($3.28/KG)	Control Device Capital Cost, $	Control Device Annualized Cost, $	Control Device Net Annualized Cost, $	Nationwide Capital Cost, $	Nationwide Annualized Cost, $	Nationwide Net Annualized Cost, $
	Percent	Total											
Small Model Plant	A	B=(A*No. Operate)	C	D	E=(C*(1-D))			H	I	J=(I)-(G)	K=(H)*(B)	L=(I)*(B)	M=(J)*(B)
Level of Control:													
Uncontrolled	40	206	3.3	0	3.3	0	0	0	0	0	0	0	0
Mist eliminator (single set of blades)	10	51	3.3	90	0.3	6	0	22,500	5,100	5,100	1,147,500	260,100	260,100
Fume suppressant	30	155	3.3	97	0.1	6	0	0	1,600	1,600	0	247,200	247,200
Single packed-bed scrubber	20	103	3.3	95	0.2	6	0	36,700	10,100	10,100	3,780,100	1,040,300	1,040,300
Total	100	515									4,927,600	1,548,400	1,548,400
Large Model Plant													
Level of Control:													
Uncontrolled	40	66	40.2	0	40.2	0	0	0	0	0	0	0	0
Mist eliminator (single set of blades)	10	16	40.2	90	4.0	70	200	48,600	11,200	11,000	777,600	179,200	176,000
Fume suppressant	30	50	40.2	97	1.2	75	300	0	4,600	4,300	0	227,700	212,850
Single packed-bed scrubber	20	33	40.2	95	2.0	73	200	78,700	25,800	25,600	2,597,100	851,400	844,800
Total	100	165									3,374,700	1,260,600	1,235,800
Total											8,302,300	2,809,000	2,784,200

TABLE H-6. (Continued)

CONTROL OPTION IIa: BASED ON USE OF PACKED-BED SCRUBBERS THAT REDUCE UNCONTROLLED EMISSIONS BY 97 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant, KG/YR	Control Efficiency, Percent	Controlled Emission Rate, KG/YR	Chromic Acid Recovery, KG/YR	Chromic Acid Recovery, $/YR	Control Device Capital Cost, $	Control Device Annualized Cost, $	Control Device Net Annualized Cost, $	Nationwide Capital Cost, $	Nationwide Annualized Cost, $	Nationwide Net Annualized Cost, $
Small Model Plant	Percent A	Total B=(A*No. Operats)	C	D	E=(C*(1-D))	F=(C-E)* (1.923)	G=(F)* ($3.28/KG)	H	I	J=(I)-(G)	K=(H)*(B)	L=(I)*(B)	M=(J)*(B)
Level of Control:													
Packed-bed scrubber	40	206	3.3	97	0.1	6	0	36,700	10,100	10,100	7,560,200	2,080,600	2,080,600
Packed-bed scrubber	10	51	3.3	97	0.1	6	0	45,900	11,500	11,500	2,340,900	586,500	586,500
Fume suppressant	30	155	3.3	97	0.1	6	0	0	1,600	1,600	0	248,000	248,000
Packed-bed scrubber	20	103	3.3	97	0.1	6	0	36,700	10,100	10,100	3,780,100	1,040,300	1,040,300
Total	100	515									13,681,200	3,955,400	3,955,400
Large Model Plant													
Level of Control:													
Packed-bed scrubber	40	66	40.2	97	1.2	75	300	78,700	25,800	25,500	5,194,200	1,702,800	1,683,000
Packed-bed scrubber	10	16	40.2	97	1.2	75	300	98,400	28,900	28,600	1,574,400	462,400	457,600
Fume suppressant	30	50	40.2	97	1.2	75	300	0	4,600	4,300	0	230,000	215,000
Packed-bed scrubber	20	33	40.2	97	1.2	75	300	78,700	25,800	25,500	2,597,100	851,400	841,500
Total	100	165									9,365,700	3,246,600	3,197,100
Total											23,046,900	7,202,000	7,152,500

TABLE H-6. (Continued)

CONTROL OPTION IIb: BASED ON USE OF MESH-PAD MIST ELIMINATORS THAT REDUCE UNCONTROLLED EMISSIONS BY 97 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant, KG/YR	Control Efficiency, Percent	Controlled Emission Rate, KG/YR	Chromic Acid Recovery, KG/YR	Chromic Acid Recovery, $/YR	Control Device Capital Cost, $	Control Device Annualized Cost, $	Control Device Net Annualized Cost, $	Nationwide Capital Cost, $	Nationwide Annualized Cost, $	Nationwide Net Annualized Cost, $
	Percent	Total											
Small Model Plant	A	B=(A*No. Operats)	C	D	E=(C*(1-D))	F=(C-E)* (1.923)	G=(F)* ($3.28/KG)	H	I	J=(I)-(G)	K=(H)*(B)	L=(I)*(B)	M=(J)*(B)
Level of Control:													
Mesh-pad mist eliminator	40	206	3.3	97	0.1	6	0	23,000	8,300	8,300	4,738,000	1,709,800	1,709,800
Mesh-pad mist eliminator	10	51	3.3	97	0.1	6	0	28,900	9,500	9,500	1,473,900	484,500	484,500
Fume suppressant	30	155	3.3	97	0.1	6	0	0	1,600	1,600	0	248,000	248,000
Packed-bed scrubber	20	103	3.3	97	0.1	6	0	36,700	10,100	10,100	3,780,100	1,040,300	1,040,300
Total	100	515									9,992,000	3,482,600	3,482,600
Large Model Plant													
Level of Control:													
Mesh-pad mist eliminator	40	66	40 2	97	1.2	75	300	91,700	40,100	39,800	6,052,200	2,646,600	2,626,800
Mesh-pad mist eliminator	10	16	40.2	97	1.2	75	300	114,900	44,700	44,400	1,838,400	715,200	710,400
Fume suppressant	30	50	40.2	97	1.2	75	300	0	4,600	4,300	0	230,000	215,000
Packed-bed scrubber	20	33	40.2	97	1.2	75	300	78,700	25,800	25,500	2,597,100	851,400	841,500
Total	100	165									10,487,700	4,443,200	4,393,700
Total											20,479,700	7,925,800	7,876,300

TABLE H-6. (Continued)

CONTROL OPTION III: BASED ON USE OF FUME SUPPRESSANTS THAT REDUCE UNCONTROLLED EMISSIONS BY 99.5 PERCENT

	Number of Operations		Uncontrolled Emission Rate Per Plant, KG/YR	Existing Control Efficiency, Percent	Baseline Emission Rate, KG/YR	Chromic Acid Recovery, KG/YR	Chromic Acid Recovery, $/YR	Control Device Capital Cost, $	Control Device Annualized Cost, $	Control Device Net Annualized Cost, $	Nationwide Capital Cost, $	Nationwide Annualized Cost, $	Nationwide Net Annualized Cost, $
	Percent	Total											
Small Model Plant	A	B=(A*No. Operats)	C	D	E=(C*(1-D))	F=(C-E)* (1.923)	G=(F)* ($3.28/KG)	H	I	J=(I)-(G)	K=(H)*(B)	L=(I)*(B)	M=(J)*(B)
Level of Control:													
Fume suppressant	40	206	3.3	99.5	0.0	6	0	0	1,600	1,600	0	329,600	329,600
Fume suppressant	10	51	3 3	99.5	0.0	6	0	0	1,600	1,600	0	81,600	81,600
Fume suppressant	30	155	3.3	99.5	0.0	6	0	0	1,600	1,600	0	247,200	247,200
Fume suppressant	20	103	3.3	99.5	0.0	6	0	0	1,600	1,600	0	164,800	164,800
Total	100	515									0	824,000	824,000
Large Model Plant													
Level of Control:													
Fume suppressant	40	66	40.2	99.5	0.2	77	300	0	4,600	4,300	0	303,600	283,800
Fume suppressant	10	16	40.2	99.5	0 2	77	300	0	4,600	4,300	0	73,600	68,800
Fume suppressant	30	50	40 2	99.5	0.2	77	300	0	4,600	4,300	0	230,000	215,000
Fume suppressant	20	33	40.2	99.5	0.2	77	300	0	4,600	4,300	0	151,800	141,900
Total	100	165									0	759,000	709,500
Total											0	1,583,000	1,533,500

TABLE H-7. COST EFFECTIVENESS ANALYSES: JOB AND CAPTIVE SHOPS--HARD CHROMIUM PLATING

	Nationwide Net Annualized Control Costs ($ Millions per year)				Nationwide Emission Estimates, Mg/yr				Cost Effectiveness, $/Mg			
Control Options	Small Plants	Medium Plants	Large Plants	Total	Small Plants	Medium Plants	Large Plants	Total	Small Plants	Medium Plants	Large Plants	Total
Option I vs. Option II												
Option I (Baseline)	5.79	3.11	3.03	11.93	18.47	44.53	82.08	145.08				
Option II	8.09	4.40	4.34	16.83	2.27	5.47	10.08	17.82				
Difference	2.30	1.29	1.31	4.90	16.20	39.06	72.00	127.26	140,000	30,000	20,000	40,000
Option I vs. Option IIIa												
Option I (Baseline)	5.79	3.11	3.03	11.93	18.47	44.53	82.08	145.08				
Option IIIa	11.04	6.07	6.11	23.22	0.54	1.30	2.40	4.24				
Difference	5.25	2.96	3.08	11.29	17.93	43.23	79.68	140.84	290,000	70,000	40,000	80,000
Option I vs. Option IIIb												
Option I (Baseline)	5.79	3.11	3.03	11.93	18.47	44.53	82.08	145.08				
Option IIIb	9.81	7.10	7.36	24.27	0.54	1.30	2.40	4.24				
Difference	4.02	3.99	4.33	12.34	17.93	43.23	79.68	140.84	220,000	90,000	50,000	90,000
Option II vs. Option IIIa												
Option II	8.09	4.40	4.34	16.83	2.27	5.47	10.08	17.82				
Option IIIa	11.04	6.07	6.11	23.22	0.54	1.30	2.40	4.24				
Difference	2.95	1.67	1.77	6.39	1.73	4.17	7.68	13.58	1,710,000	400,000	230,000	470,000
Option II vs. Option IIIb												
Option II	8.09	4.40	4.34	16.83	2.27	5.47	10.08	17.82				
Option IIIb	9.81	7.10	7.36	24.27	0.54	1.30	2.40	4.24				
Difference	1.72	2.70	3.02	7.44	1.73	4.17	7.68	13.58	990,000	650,000	390,000	550,000

Option I: Baseline.
Option II: Based on the use of chevron-blade mist eliminators (double set of blades) that reduce uncontrolled emissions by 95 percent
Option IIIa: Based on the use of packed-bed scrubbers that reduce uncontrolled emissions by 99 percent.
Option IIIb: Based on the use of mesh-pad mist eliminators that reduce uncontrolled emissions by 99 percent.

TABLE H-8. COST EFFECTIVENESS ANALYSES: JOB AND CAPTIVE SHOPS--DECORATIVE CHROMIUM PLATING

Control Options	Nationwide Net Annualized Control Costs ($ Millions per year) Small Plants	Medium Plants	Large Plants	Total	Nationwide Emission Estimates, Mg/yr Small Plants	Medium Plants	Large Plants	Total	Cost Effectiveness, $/Mg Small Plants	Medium Plants	Large Plants	Total
Option I vs. Option IIa												
Option I (Baseline)	11.97	5.23	4.56	21.76	2.37	1.78	5.93	10.08				
Option IIa	15.37	6.59	5.40	27.36	0.40	0.30	1.01	1.71				
Difference	3.40	1.36	0.84	5.60	1.97	1.48	4.92	8.37	1,730,000	920,000	170,000	670,000
Option I vs. Option IIb												
Option I (Baseline)	11.97	5.23	4.56	21.76	2.37	1.78	5.93	10.08				
Option IIb	14.76	6.29	5.45	26.51	0.40	0.30	1.01	1.71				
Difference	2.79	1.06	0.89	4.75	1.97	1.48	4.92	8.37	1,420,000	720,000	180,000	570,000
Option I vs. Option III												
Option I (Baseline)	11.97	5.23	4.56	21.76	2.37	1.78	5.93	10.08				
Option III	11.86	5.26	4.87	21.99	0.07	0.05	0.17	0.29				
Difference	-0.11	0.03	0.31	0.23	2.30	1.73	5.76	9.79	(50,000)	20,000	50,000	20,000
Option I vs. Option IVa												
Option I (Baseline)	11.97	5.23	4.56	21.76	2.37	1.78	5.93	10.08				
Option IVa	52.64	12.18	-319.23	-254.41	0.00	0.00	0.00	0.00				
Difference	40.67	6.95	-323.79	-276.17	2.37	1.78	5.93	10.08	17,160,000	3,900,000	(54,600,000)	(27,400,000)
Option I vs. Option IVb												
Option I (Baseline)	11.97	5.23	4.56	21.76	2.37	1.78	5.93	10.08				
Option IVb	-24.64	9.16	5.05	-10.43	0.00	0.00	0.00	0.00				
Difference	-36.61	3.93	0.49	-32.19	2.37	1.78	5.93	10.08	(15,450,000)	2,210,000	80,000	(3,190,000)

Option I: Baseline.

Option IIa: Based on the use of packed-bed scrubbers that reduce uncontrolled emission by 97 percent.

Option IIb: Based on the use of mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent.

Option III: Based on the use of fume suppressants that reduce uncontrolled emissions by 99.5 percent.

Option IVa: (Scenario 1) Based on the use of the trivalent chromium process that reduces hexavalent chromium emissions by 100 percent.

Option IVb: (Scenario 2) Based on the use of the trivalent chromium process that reduces hexavalent chromium emissions by 100 percent.

Option IVc. (Scenario 3) Based on the use of the trivalent chromium process that reduces hexavalent chromium emissions by 100 percent.

TABLE H-8. (Continued)

Control Options	Nationwide Net Annualized Control Costs ($ Millions per year) Small Plants	Medium Plants	Large Plants	Total	Nationwide Emission Estimates, Mg/yr Small Plants	Medium Plants	Large Plants	Total	Cost Effectiveness, $/Mg Small Plants	Medium Plants	Large Plants	Total
Option I vs. Option IVc												
Option I (Baseline)	11.97	5.23	4.56	21.76	2.37	1.78	5.93	10.08				
Option IVc	29 57	11.05	15.25	55 86	0.00	0.00	0.00	0.00				
Difference	17.60	5.82	10.69	34.10	2.37	1.78	5.93	10.08	7,430,000	3,270,000	1,800,000	3,380,000
Option IIa vs. Option III												
Option IIa	15.37	6.59	5.40	27.36	0.40	0.30	1.01	1.71				
Option III	11.86	5.26	4.87	21.99	0.07	0.05	0.17	0.29				
Difference	-3.51	-1.33	-0 53	-5.37	0.33	0.25	0.84	1.42	(10,640,000)	(5,320,000)	(630,000)	(3,780,000)
Option IIa vs. Option IVa												
Option IIa	15.37	6.59	5.40	27.36	0 40	0 30	1.01	1.71				
Option IVa	52 64	12 18	-319.23	-254 41	0 00	0 00	0.00	0.00				
Difference	37 27	5.59	-324.63	-281.77	0 40	0.30	1.01	1.71	93,180,000	18,630,000	(321,420,000)	(164,780,000)
Option IIa vs. Option IVb												
Option IIa	15.37	6.59	5.40	27.36	0.40	0.30	1.01	1.71				
Option IVb	-24.64	9.16	5.05	-10.43	0.00	0.00	0.00	0.00				
Difference	-40.01	2.57	-0 35	-37 79	0.40	0.30	1.01	1.71	(100,020,000)	8,570,000	(350,000)	(22,100,000)
Option IIa vs. Option IVc												
Option IIa	15.37	6.59	5.40	27 36	0.40	0.30	1.01	1.71				
Option IVc	29.57	11.05	15.25	55 86	0.00	0.00	0.00	0.00				
Difference	14.20	4.46	9 85	28.50	0.40	0.30	1.01	1.71	35,500,000	14,870,000	9,750,000	16,670,000

Option I: Baseline.

Option IIa: Based on the use of packed-bed scrubbers that reduce uncontrolled emission by 97 percent.

Option IIb: Based on the use of mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent.

Option III: Based on the use of fume suppressants that reduce uncontrolled emissions by 99.5 percent.

Option IVa: (Scenario 1) Based on the use of the trivalent chromium process that reduces hexavalent chromium emissions by 100 percent.

Option IVb: (Scenario 2) Based on the use of the trivalent chromium process that reduces hexavalent chromium emissions by 100 percent.

Option IVc: (Scenario 3) Based on the use of the trivalent chromium process that reduces hexavalent chromium emissions by 100 percent.

TABLE H-8. (Continued)

Control Options	Nationwide Net Annualized Control Costs ($ Millions per year) Small Plants	Medium Plants	Large Plants	Total	Nationwide Emission Estimates, Mg/yr Small Plants	Medium Plants	Large Plants	Total	Cost Effectiveness, $/Mg Small Plants	Medium Plants	Large Plants	Total
Option IIb vs. Option III												
Option IIb	14 76	6.29	5.45	26.51	0 4	0 3	1.01	1.71				
Option III	11.86	5.26	4.87	21.99	0.07	0.05	0.17	0.29				
Difference	-2.9	-1.03	-0.58	-4 52	0 33	0.25	0.84	1.42	(8,790,000)	(4,120,000)	(690,000)	(3,180,000)
Option IIb vs. Option IVa												
Option IIb	14.76	6.29	5 45	26 51	0.4	0.3	1.01	1.71				
Option IVa	52.64	12.18	-319.23	-254 41	0	0	0	0				
Difference	37.88	5.89	-324.68	-280 92	0.4	0 3	1.01	1.71	94,700,000	19,630,000	(321,470,000)	(164,280,000)
Option IIb vs. Option IVb												
Option IIb	14.76	6.29	5.45	26 51	0.40	0.30	1 01	1.71				
Option IVb	-24 64	9.16	5.05	-10 43	0 00	0.00	0.00	0 00				
Difference	-39.40	2.87	-0 40	-36 94	0.40	0 30	1.01	1.71	(98,500,000)	9,570,000	(400,000)	(21,600,000)
Option IIb vs. Option IVc												
Option IIb	14 76	6.29	5.45	26 51	0.40	0.30	1.01	1.71				
Option IVc	29.57	11 05	15.25	55 86	0 00	0 00	0.00	0.00				
Difference	14 81	4.76	9.80	29.35	0 40	0 30	1 01	1.71	37,030,000	15,870,000	9,700,000	17,160,000
Option III vs. Option IVa												
Option III	11.86	5.26	4.87	21.99	0.07	0.05	0.17	0.29				
Option IVa	52 64	12.18	-319.23	-254 41	0.00	0 00	0 00	0.00				
Difference	40 78	6 92	-324.10	-276.40	0 07	0 05	0.17	0.29	582,570,000	138,400,000	(1,906,470,000)	(953,100,000)

Option I: Baseline.
Option IIa: Based on the use of packed-bed scrubbers that reduce uncontrolled emission by 97 percent.
Option IIb: Based on the use of mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent.
Option III: Based on the use of fume suppressants that reduce uncontrolled emissions by 99.5 percent.
Option IVa: (Scenario 1) Based on the use of the trivalent chromium process that reduces hexavalent chromium emissions by 100 percent.
Option IVb: (Scenario 2) Based on the use of the trivalent chromium process that reduces hexavalent chromium emissions by 100 percent.
Option IVc: (Scenario 3) Based on the use of the trivalent chromium process that reduces hexavalent chromium emissions by 100 percent.

TABLE H-8. (Continued)

Control Options	Nationwide Net Annualized Control Costs ($ Millions per year)				Nationwide Emission Estimates, Mg/yr				Cost Effectiveness, $/Mg			
	Small Plants	Medium Plants	Large Plants	Total	Small Plants	Medium Plants	Large Plants	Total	Small Plants	Medium Plants	Large Plants	Total
Option III vs. Option IVb												
Option III	11.86	5.26	4.87	21.99	0.07	0.05	0.17	0.29				
Option IVb	-24.64	9.16	5.05	-10.43	0.00	0.00	0.00	0.00				
Difference	-36.50	3.90	0.18	-32.42	0.07	0.05	0.17	0.29	(521,430,000)	78,000,000	1,060,000	(111,790,000)
Option III vs. Option IVc												
Option III	11.86	5.26	4.87	21.99	0.07	0.05	0.17	0.29				
Option IVc	29.57	11.05	15.25	55.86	0.00	0.00	0.00	0.00				
Difference	17.71	5.79	10.38	33.87	0.07	0.05	0.17	0.29	253,000,000	115,800,000	61,060,000	116,790,000

Option I: Baseline.
Option IIa: Based on the use of packed-bed scrubbers that reduce uncontrolled emission by 97 percent.
Option IIb: Based on the use of mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent.
Option III: Based on the use of fume suppressants that reduce uncontrolled emissions by 99.5 percent.
Option IVa: (Scenario 1) Based on the use of the trivalent chromium process that reduces hexavalent chromium emissions by 100 percent.
Option IVb: (Scenario 2) Based on the use of the trivalent chromium process that reduces hexavalent chromium emissions by 100 percent.
Option IVc: (Scenario 3) Based on the use of the trivalent chromium process that reduces hexavalent chromium emissions by 100 percent.

TABLE H-9. COST EFFECTIVENESS ANALYSES: JOB AND CAPTIVE SHOPS--CHROMIC ACID ANODIZING

	Nationwide Net Annualized Control Costs ($ Millions per year)			Nationwide Emission Estimates, Mg/yr			Cost Effectiveness, $/Mg		
Control Options	Small Plants	Large Plants	Total	Small Plants	Large Plants	Total	Small Plants	Large Plants	Total
Option I vs. Option IIa									
Option I (Baseline)	1.55	1.24	2.78	0.74	2.84	3.58			
Option IIa	3.96	3.20	7.15	0.05	0.20	0.25			
Difference	2.41	1.96	4.37	0.69	2.64	3.33	3,490,000	740,000	1,310,000
Option I vs. Option IIb									
Option I (Baseline)	1.55	1.24	2.78	0.74	2.84	3.58			
Option IIb	3.48	4.39	7.88	0.05	0.20	0.25			
Difference	1.93	3.15	5.10	0.69	2.64	3.33	2,800,000	1,190,000	1,530,000
Option I vs. Option III									
Option I (Baseline)	1.55	1.24	2.78	0.74	2.84	3.58			
Option III	0.82	0.71	1.53	0.01	0.03	0.04			
Difference	-0.73	-0.53	-1.25	0.73	2.81	3.54	(1,000,000)	(190,000)	(350,000)
Option IIa vs. Option III									
Option IIa	3.96	3.20	7.15	0.05	0.20	0.25			
Option III	0.82	0.71	1.53	0.01	0.03	0.04			
Difference	-3.14	-2.49	-5.62	0.04	0.17	0.21	(78,500,000)	(14,650,000)	(26,760,000)
Option IIb vs. Option III									
Option IIb	3.48	4.39	7.88	0.05	0.20	0.25			
Option III	0.82	0.71	1.53	0.01	0.03	0.04			
Difference	-2.66	-3.68	-6.35	0.04	0.17	0.21	(66,500,000)	(21,650,000)	(30,240,000)

Option I: Baseline.
Option IIa: Based on the use of single packed-bed scrubbers that reduce uncontrolled emissions by 97 percent.
Option IIb: Based on the use of mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent.
Option III: Based on the use of chemical fume suppressants that reduce uncontrolled emissions by 99.5 percent.