

**Assessment of Management Options and
Economic Impacts of Reducing
Air Emissions of Hexavalent Chromium
From Electroplating Operations
in Canada**

12
692
150
64
101

(Final Report)



For: Environment Canada
Economic Analysis Branch
Hull, Quebec

Submitted By: CHEMinfo Services Inc.
1706 Avenue Rd., Suite 4
Toronto, Ontario M5M 3Y6
Phone: (416) 785-9051
Fax: (416) 785-9876
e-mail: cheminfo@netcom.ca
March 1997

**Assessment of Management Options and
Economic Impacts of Reducing
Air Emissions of Hexavalent Chromium
From Electroplating Operations
in Canada**

Final Report

Prepared for:

**Environment Canada
Economics Analysis Branch
Hull, Quebec**

Prepared by:

**CHEMinfo Services Inc.
1706 Avenue Rd., Suite 4
Toronto, ON M5M 3Y6
Phone: (416) 785-9051
Fax: (416) 785-9876
e-mail: cheminfo@netcom.ca**

In association with:

**Apogee Research Inc.
144 Front St. W., Suite 500
Toronto, Ontario
M5J 2L7**

March 1997

Table of Contents

1. EXECUTIVE SUMMARY	1
1.1 Industry Structure	1
1.2 Hexavalent Chromium Emissions in Canada	4
1.3 Technical Assessment of Control Options	6
1.4 Direct Emissions Reduction Costs	6
1.5 Reduction in HVC Emissions	7
1.6 Comparison of Costs and Benefits	8
1.7 Management Options Assessment	10
1.8 Regulatory Environment	11
2. INTRODUCTION	14
2.1 Background	14
2.2 Objectives of This Report	15
2.3 Methodology	15
3. CHROMIUM ELECTROPLATING INDUSTRY	19
3.1 Electroplating Processes	19
3.2 Structure Of Canadian Industry	20
3.3 Supply of Chromium Plating Bath Chemicals	25
4. HEXAVALENT CHROMIUM EMISSIONS	28
4.1 Generation of Emissions	28
4.2 Electroplating Emissions in Canada	28

5. TECHNICAL ASSESSMENT OF EMISSION REDUCTION OPTIONS	34
5.1 Introduction	34
5.2 Summary of Technical Assessment	34
5.3 Sources of Literature Information	37
5.4 Evaluation Criteria	37
5.5 HVC Emission Sources	37
5.6 Prevention Of Chromium Mist In Exhaust Air	38
5.7 Capture and Control Technologies	41
6. EMISSIONS REDUCTION COSTS	49
6.1 Summary of Emissions Reduction Costs	49
6.2 Direct Cost Model Applied to Industry	49
6.3 Reduction in HVC Emissions	57
6.4 Direct Economic Impacts	58
7. SOCIO-ECONOMIC ANALYSIS	61
8. BENEFITS OF HVC EMISSIONS REDUCTION	67
8.1 Summary	67
8.2 Scenario Descriptions and Simplifying Assumptions	68
8.3 Identification of Benefits	69
8.4 Valuation Methodology	69
8.5 Baseline Level of Emissions	70
8.6 Emission Reductions	71
8.7 Mortality and Morbidity Incidences Avoided	72
8.8 Values of Mortality and Morbidity Incidences Avoided	73
8.9 Estimates of Total Annualized Benefits	77

9. COMPARISON OF DIRECT COSTS AND BENEFITS	81
9.1 Introduction	81
9.2 Base Case Comparison	81
9.3 Alternative Case Comparison	82
10. ASSESSMENT OF MANAGEMENT OPTIONS	84
10.1 Introduction	84
10.2 Summary of Management Options Assessment	84
10.3 Approach and General Considerations to Assessment	85
10.4 Preliminary Screening	89
10.5 Assessment of Applicable Management Options	93
10.6 Ranking of Management Options and Conclusions	104
11. OVERVIEW OF REGULATORY ENVIRONMENT	109
11.1 Summary	109
11.2 Final US EPA Air Toxics Rule for Chromium Emissions	111
12. BIBLIOGRAPHY	117

1. Executive Summary

1.1 Industry Structure

There are approximately 210 facilities in Canada which undertake hexavalent chromium plating¹. Approximately 56% of these facilities are dedicated to hard (or functional) plating while nearly all the rest carry out decorative plating. Only 2 to 3% of facilities are involved in both decorative and functional plating, or anodizing operations.

There are a total of approximately 495 tanks dedicated to chromium plating in Canada, with a total rectifier capacity estimated at 2.5 million amps (or 21,900 million amp-hr based on 8760 hours per year). Hard chrome plating facilities generally have a greater number of tanks than decorative plating facilities. Decorative tanks are idle for most of the time so that multiple tanks in a facility are not necessary. The average daily tank operating time rate for hard chrome platers is 11.5 hours, while decorative platers energize their tanks 2.6 hours per day, on average.

Typically platers set their rectifiers at 40% to 70% of the capacity. Actual settings vary with each batch of products to be plated. Surface area of parts, plating time and other parameters can affect the current applied. Taking into consideration the applied current versus the capacity of the rectifiers, the average operating rate of the tanks is 32% for hard plating tanks and 8% for decorative plating tanks.

Tank Number, Capacity and Operating Rates

	Functional	Decorative	Total/Overall
Number of facilities	118	92	210
Number of tanks	375	120	495
Average # tanks per facility	3.2	1.3	2.4
Average time of tank operation (hr/day)	11.5	2.6	8.9
Capacity utilization	32%	8%	26%

¹ Personal conversation - Patrick Billinge, Sales Manager, Atotech Canada Ltd., Jan. 24, 1997.

Decorative plating activity is concentrated in Ontario and Quebec where much of the metal manufacturing and metal working industry is located. By contrast, there is a greater proportion of functional electroplaters in Western Canada. Functional chrome platers in the Prairies and BC are more dependent on business from customers involved in the oil and gas, pulp and paper, and mining sectors. Functional platers have a greater number of tanks per facility, such that the weight of electroplating is shifted to Western Canada.

The distribution of electroplating tanks across Canada is similar to the distribution of facilities. There is a concentration of hard chrome tanks located in Alberta. While the regional market demand may play a major role in attracting electroplaters to Alberta, the low cost of electric power relative to other provinces may also be a factor.

Regional Location of Tanks

	Total	
Alberta	147	30%
Ontario	126	25%
Quebec	84	17%
BC	84	17%
MB, SK	33	7%
Atlantic	21	4%
Total	495	100%

1.1.1 Size of the Industry

The Canadian chromium related electroplating industry is estimated to generate approximately \$490 million in annual revenues which is divided between merchant operators (i.e., job shops) and captive markets (i.e. internal facilities). Electroplaters surveyed for this project had average annual sales of \$2.3 million, while profit levels in 1996 were in the range of 5 to 15% of revenues.

Electroplating job shops in Canada are, for the most part, made up of small and medium sized companies. Nearly 70% of job shops that conduct chromium electroplating have annual revenues of less than \$2 million and approximately 35% have annual revenues of less than \$500,000. Chromium electroplating often makes up only a portion of electroplating activity at these facilities. For instance, those electroplating job shops surveyed rely on chromium for only 10 to 30% of annual revenues. Other plating activity, albeit some of it in preparation for chromium plating, usually represents the majority of manufacturing activity.

Size of Canadian Electroplating Industry

Type of Electroplating	Total Annual "Revenues"	Number of Facilities	Revenues Per Facility	Revenues Attributed to Chromium Electroplating	Chromium Electroplating Revenues per Facility
	(\$ million)		(\$ million)	(\$ million)	(\$ million)
Functional	\$307	118	2.6	47	0.4
Decorative	\$184	92	2.0	55	0.6
Total	\$491	210	2.3	102	0.49

1.1.2 Regional Concentration and Importance of the Sector

Overall, there is a concentration of electroplating facilities in the Ontario and Prairie regions (primarily Alberta). Ontario and the Prairies, combined, are home to 2/3 of Canadian chromium electroplaters. Quebec is the next most popular location for chromium electroplaters with 18% of the facilities.

1.1.3 Trends in Electroplating Industry

Hexavalent chromium electroplating activity has been in general decline over the last 20 years, according to Canadian electroplating chemicals suppliers. Many electroplating operations have closed or moved out of Canada. At the same time there has been a consolidation among the industry such that the number of shops has declined over the last decade. Whereas there may have been 300 to 350, or so, chromium electroplaters in Canada in the late 1980s, the number dropped by 15 to 30% by 1996. Electroplating chemical suppliers claim demand for chromic acid has declined by a slightly greater amount as facilities have become more efficient.

Estimated Number of Chromium Electroplaters

1970	1980	1990	1996
600	400	250	210

Source: Chemical suppliers', CHEMinfo Services estimates

There have been several factors negatively influencing demand for chromium plating in Canada. One has been a shift toward electroless nickel plating for some functional hard

chromium applications. At the same time, decorative plating has declined in Canada as a result of the penetration of plastics in such applications as automobiles, other transportation vehicles and appliances.

Although the growth of HVC electroplating activity in Canada is expected to increase at very slow rates, new tanks and facilities will be installed as older operations are retired. Overall the industry is expected to grow at 1-2% per year.

1.2 Hexavalent Chromium Emissions in Canada

Canadian electroplaters had a potential (based on actual operating rates - not full rectifier capacity) to emit approximately 42 tonnes of HVC, during 1996. However, most firms employed control technologies such that actual estimated emissions were only 3.2 tonnes. Hard chromium plating tanks accounted for nearly 97.5% of these emissions, while decorative and anodizing operations only represented 2.5%.

Summary of HVC Emissions From Electroplating, 1996

	Functional	Decorative (tonne)	Total
Total potential emissions (based on actual operating conditions)	40.5	1.1	41.6
Overall control level	92%	93%	92%
Actual emissions	3.1	0.1	3.2

The regional pattern of emissions estimated from the survey sample does not follow the location pattern of electroplating facilities. A few large emitters which operate without any control technologies in-place contribute heavily to emissions in their regions. One large identified electroplater based in BC, operating without emission controls, contributes an estimated 15% of all estimated emissions in Canada (and 45% of emissions from surveyed sample). This plater skews the pattern of emissions identified in the survey.

Functional chrome platers account for the majority of emissions and dominate the regional emissions pattern. Emissions from decorative plating operations are concentrated in Ontario and Quebec. Low amounts of HVC are emitted from operations in the Atlantic provinces, Manitoba and Saskatchewan.

Functional and Decorative Regional Emissions

(Regional Emissions Based on Pattern of Electroplating Tanks)

	Functional	Decorative	Total	
		(kg)		
Ontario	781	20	801	25%
Quebec	531	13	545	17%
Alberta	937	24	961	30%
BC	531	13	545	17%
MB, SK	219	6	224	7%
Atlantic	125	3	128	4%
Total	3125	79	3203	100%

1.2.1 Level of Emissions Control

It is estimated that 93% of the electroplaters have some controls in place to reduce HVC emissions to air. Approximately 15 electroplating facilities across Canada, operating a total of 36 tanks had no emission controls during 1996. In the survey of 70 plating facilities, only 5 did not possess any form of controls. At facilities where controls are in place they are applied to all tanks in the facility. In operations where controls are not in place, none of the tanks were found to have controls.

Emissions From Facilities With & Without Controls

	Without Controls	With Controls	Total/Overall
Total emissions (tonne/yr)	2.2 68%	1.0 32%	3.2 100%
Total number of electroplating facilities	15 7%	195 93%	210 100%
Average emission per facility (kg/yr)	145#	5	15
Number of tanks	36	459	495
Average emission per tank (kg/yr)	61	2	6

rounded

The most popular type of control applied by electroplaters is inclusion of fume suppressants in tank baths. This technology requires no capital cost and is easy to operate. Packed bed scrubbers and various types of mist eliminators including: mesh pad; chevron blade and baffles are employed at slightly more than half of the tanks in Canada. Polypropylene balls and condensing coils are less popular devices with only 10 to 15% of

the tanks equipped with these technologies. Use of trivalent chrome baths may also be considered a control measure with 100% efficiency (since no HVC is emitted). Less than 3% of the platers use trivalent chromium.

1.3 Technical Assessment of Control Options

Mist pad eliminators, packed bed scrubbers, surface tension modifiers and other types of mist suppressants present technically favourable options to plastic balls, condensing coils and many other possible control technologies. Properly maintained mist pad eliminators and scrubbers can achieve high levels of HVC emissions reduction with no adverse impact on product quality. At some facilities surface tension modifiers and other forms of mist suppressants (i.e., foam blankets) can pose pitting problems, or other quality issues for some electroplaters.

Technical Ranking of Control Options

Control Technology	Rank
Mist pad eliminator	1
Packed bed scrubber	2
Surface tension modifiers (wetting agents)	3
Foam mist suppressants	4
Plastic balls	5
Condensing coil	6

Plastic balls and condensing coils do not provide a high level of HVC emissions reduction efficiency. However, these technologies are often used in combination with other controls to increase the overall control efficiency.

The assessment of HVC emissions control technologies was conducted using the following evaluation criteria (listed in order of descending weight of importance):

Criteria	Weight of Importance
A. efficiency in reducing emissions;	5
B. ease of process parameter monitoring;	4
C. ease of maintenance;	3
D. negative impacts on quality of finished products; and	2
E. availability, ease of installation or application.	1

1.4 Direct Emissions Reduction Costs

The estimated annualized direct cost to Canadian electroplaters of achieving rates of emission less than the ultimate proposed limits of (0.2 mg/m³ for existing facilities after 2000, and for all new facilities) is \$0.4 million. This estimate includes capital expenditures, operating and equipment maintenance costs. Cost impacts of monitoring for regulatory compliance are not included. These may be determined after the specific details of the management option to be implemented have been defined.

**Summary of Costs to Achieve Ultimate Limit (0.2 mg/m³)
(Capital Plus Operating)**

	Number of Facilities	Average Annualized Total Costs (\$ million/yr)
Existing facilities with no controls	15	\$0.2
Existing facilities with controls	13	\$0.1
New facilities (1 new facility per year)	15	\$0.1*
Total	43	\$0.4

* includes capital for one new facility per year plus additive operating costs for increasing number of new facilities

** costs relate to 15 facilities installed over 15 years

**Summary of Installation and Operating Costs
(For Average Size Plant: 2 to 3 tanks per facility)**

Technology	Annualized Capital Costs	Annual Operating (\$/facility)	Total Annualized
Wet scrubber with mesh pad eliminator	\$4,608	\$8,952	\$13,560
Mist suppressants		\$4,000	\$4,000
Polypropylene balls	\$200	\$2,080	\$2,160

Note: Capital costs annualized over 15 years at 5% interest

1.5 Reduction in HVC Emissions

Applying control technologies such that all facilities and tanks are in compliance with the proposed emission limits (0.2 mg/m³ for existing facilities after 2000, and for all new facilities) would result in 70 to 75% reduction in annual HVC emissions in Canada, or approximately 2.4 tonnes per year. The proposed reduction options would achieve 98% to 99% reduction efficiency at each facility (or tank) applied. A low level of emissions

would still occur from facilities in compliance with the proposed emissions limit (since 100% control efficiency is not achieved). Total 1996 HVC emissions in Canada would be reduced to approximately 800 kilograms annually if all firms were in compliance with the 0.2 mg/m³ emission limit.

Ultimate HVC Emission Reductions

	Year 1	Year 15
	(kg)	
Existing facilities	2218	2218
New facilities	145	2175
Total emissions reduction	2363	4393
Percent of potential emissions	74%	

The ratio of these direct (and ultimate) control costs to revenues varies with the size of the facility and the types of other business activities engaged by the company. For companies with annual revenues of less than \$500,000 the cost of applying a wet scrubbers/mesh pad eliminator system can represent a major burden and eliminate annual profits. Mist suppressants present a lower cost and effective option for those facilities which do not already use them.

1.6 Comparison of Costs and Benefits

The analysis of costs and benefits associated with reduced emissions of HVC heavily favour the benefits side. Due to resource constraints for this study, only one benefit accruing from reduced HVC emissions is quantified. This benefit is the lung cancer incidences avoided due to reduced HVC emissions. There are two aspects of reduced lung cancer incidences that are quantified in order to calculate this health benefit: (i) cancer mortality and (ii) cancer morbidity (other morbidities are not included in analysis).

A five step process was utilized to calculate the economic valuation of the human health benefits identified:

1. develop baseline HVC emission estimates that are expected to occur without the introduction of the proposed emission limits.
2. determine HVC emission reductions that are expected to occur due to the introduction of the proposed emission limits.
3. calculate the number of statistical lives saved and morbidity effects avoided due to the introduction of the proposed emissions limits.

4. identify economic values to attach to the lung cancer incidences avoided.
5. calculate the annualized economic value of the total benefits that accrue from the introduction of the proposed emission limits and undertake sensitivity analysis on key variables.

The net benefit (cost) is provided for two scenarios, namely:

1. where electroplaters achieve an emission limit of 1.0 mg/m³ in 1997 and beyond (**base case**); and
2. where electroplaters achieve an emission limit of 0.2 mg/m³ in 1997 and beyond (**alternative case**).

1.6.1 Base Case Comparison

1. where electroplaters achieve an emission limit of 1.0 mg/m³ in 1997 and beyond (**base case**); and

There is a positive net benefit across all combinations of (i) social discount rate and (ii) weighted average dollars for all cancer cases. The net present value (NPV) of these net benefits ranges from a high of \$99 million to a low of \$28 million. The medium case net benefit has a NPV of approximately \$48 million. These benefits are those that accrue over the next fifteen years, only.

Net Present Value of Stream of Benefits (Costs)

(millions of 1996 Can. \$)

Social Discount Rate	Weighted Average Dollars for All Cancer Cases Avoided		
	Low (\$1.9)#	Medium (\$3.1)#	High (\$6.2)#
5%	27.7	47.7	99.4

Value of avoided cancer incident (includes mortality and morbidity related to cancer)

As the present value of the net benefits is positive, the annualized net benefits will be positive as well. A social discount rate of 5% is used to determine the annualized net benefits over the next fifteen years. Annualized net benefits range from \$2.1 million to \$12.4 million with a medium value of \$4.6 million.

Annualized Stream of Net Benefits (Costs) Over Next 15 Years

(millions of 1996 Can. \$)

Social Discount Rate	Weighted Average Dollars for All Cancer Cases Avoided
----------------------	---

	Low (\$1.9)	Medium (\$3.1)	High (\$6.2)
High (9%)	3.5	6.0	12.4
Medium (5%)	2.7	4.6	9.6
Low (2%)	2.1	3.7	7.7

1.6.2 Alternative Case Comparison

- where electroplaters achieve an emission limit of 0.2 mg/m³ in 1997 and beyond (**alternative case**).

For the alternative case (reflecting a higher level of control for all platers starting in 1997), there is a positive net benefit across all combinations of (i) social discount rate and (ii) weighted average dollars for all cancer cases. These net benefits range from a high of \$139 million to a low of \$39 million and only include benefits calculated over the next fifteen years.

Net Present Value of Stream of Benefits (Costs)

(millions of 1996 Can. \$)

Discount Rate	Weighted Average Dollars for All Cancer Cases Avoided		
	Low (\$1.9)	Medium (\$3.1)	High (\$6.2)
5%	39.3	67.1	138.8

As the present value of the net benefits, of this case, is positive, the annualized net benefits will be positive as well. Annualized net benefits range from \$3 million to \$17 million with a medium value of approximately \$6 million. A social discount rate of 5% has been used to determine the annualized net benefits over the next fifteen years.

Annualized Stream of Benefits (Costs) Over Next 15 Years

(millions of 1996 Can. \$)

Social Discount Rate	Weighted Average Dollars for All Cancer Cases Avoided		
	Low (\$1.9)	Medium (\$3.1)	High (\$6.2)
High (9%)	5.0	8.4	17.3
Medium (5%)	3.8	6.5	13.4
Low (2%)	3.0	5.1	10.7

1.7 Management Options Assessment

Mandatory technology standards (i.e., regulations that mandate control technologies with actual operating conditions, possibly monitored through key operational parameters)

are assessed to be the most environmentally effective and recommended management option for the electroplaters. This option establishes a level playing field between the majority of electroplaters that have already installed control technologies and the minority that have not.

Jurisdictional issues of enforcement, enforcement costs and potential resistance from that section of the industry that have not already applied control measures or represent minor contributions to total emissions, are potential drawbacks. These may be overcome with preparation of technology standards that consider the unique characteristics of segments of the electroplating industry (i.e., differences between functional and decorative platers, large and small platers, etc.)

Other less attractive options include the following:

- **Structured agreements** with the largest sources could be effective in achieving fairly large and rapid reductions (e.g., one electroplater without controls in place was responsible for nearly half of the emissions identified in a survey of 70 electroplating facilities). Environment Canada should explore the willingness of the largest HVC emitters to enter into structured agreements. This should be considered a step to reduce emissions in the short term. In the longer term, it would not necessarily control emissions from new sources or smaller sources currently in operation.
- **Mandatory pollution prevention plans** could be considered, particularly for electroplaters that do not currently meet some specified emission standard. (For example, all companies could be required to report amp-hours and their control technologies to allow estimation of actual emissions. Companies with estimated emissions above a minimum standard would be required to submit a full plan). The plans could also be required for all new electroplating operations.
- **Voluntary measures and information provision** are potentially applicable, but not likely to be very environmentally effective. Control technologies are well understood and have been adopted by most electroplaters. Electroplaters that continue to operate without control technologies have little incentive to comply given the difficulties in detecting their operations, the difficulties in measuring their emissions and the lack of an industry association encompassing all electroplaters that could create significant pressure to comply.
- Management options that are even less attractive include: quantity controls; performance standards; trading programs; environmental charges and taxes; financial incentives; and environmental liability.

1.8 Regulatory Environment

There are no Canadian federal regulations or guidelines directly relating to hexavalent chromium air emissions from electroplating facilities². However, certain provinces and municipalities have regulations or by-laws relating to potential emissions of HVC. Under these regulations, electroplaters operate with provincially administered permits or Certificates of Approvals. Typically these regulations stipulate stack concentrations or point of impingement concentrations³.

Identified Canadian Provincial and Municipal Regulations

Provincial	Limits
Quebec	Stack: 2 mg/m ³
Ontario	Point of impingement 5 µ/m ³
Municipal	
Montreal Urban Community (MUC)	Stack: 2 mg/m ³
Greater Vancouver Regional District (GVRD)	Stack 0.5 mg/m ³
Toronto	Point of impingement 5 µ/m ³

The Ministère de l'Environnement et de la Faune du Québec (MEF) is reviewing its regulation stipulating air emission concentration limits in order to establish an "air quality by-law" which should be in application by the fall of 1997. The MEF will maintain the same air emissions concentration limit for HVC (2 mg/m³) as its actual guideline.

1.8.1 US EPA Air Toxics Rule

The US EPA has proposed the industry apply stringent Maximum Available Control Technology (MACT) to reduce air emissions of HVC. These would apply to both decorative and functional (hard) chrome plating facilities⁴.

² Environment Canada: Peter Paine, Chemical Industries Division

³ Environment Canada: Peter Paine, Chemical Industries Division

⁴ Environment Canada: Peter Paine, Chemical Industries Division

Summary of US EPA MACT Standards for Chromium Electroplating and Anodizing Facilities

Process	Emission Limit
Existing small hard chromium plating	0.03 mg/m ³
Existing large & all new hard chromium plating	0.015 mg/m ³
New and existing decorative chromium plating and chromic acid anodizing	0.01 mg/m ³
Alternate for decorative chromium plating and chromic acid anodizing	No emission limit. Maintain surface tension below 45 dynes/cm
All new and existing decorative chromium plating using trivalent chromium	No emission limit. No surface tension monitoring. Notification of presence of process.

2. Introduction

2.1 Background

Environment Canada, industry representatives and other stakeholders have been working collaboratively in a Strategic Options Process (SOP) to develop a program to reduce releases to the environment of toxic substances generated from the metal finishing industry (MFI). The SOP is addressing compounds of cadmium, chromium and nickel which were assessed to be toxic under CEPA. This report only considers air emissions of hexavalent chromium (HVC) from electroplating facilities in Canada. Through the collaborative SOP process, HVC emission limits for existing and new electroplating facilities have been proposed, as follows:⁵

Testing Period	Required HVC Stack Concentration Limit After Testing
Before January 1997	2.0 mg/m ³
After January 1997 Before January 1999	1.0 mg/m ³
After January 1999 Before January 2000	0.5 mg/m ³
After January 2000	0.2 mg/m ³

- All new (after 1996?) operations at the time of start-up are required to meet an emission limit for HVC of 0.2 mg/m³.

One reference point used in this analysis is the stack concentration limit of 0.2 mg/m³. This reference point is useful since it reflects the results of a very high level of emissions reduction (generally over 90% of potential uncontrolled emissions), and the most stringent limit for existing facilities from the option listed in the above schedule. However, it is recognized that this limit may not be applicable to all electroplating facilities and will depend on time of testing (given the base case schedule proposed above). For the purposes of the cost/benefit analysis provided in this report, a set of assumptions vis-à-vis the above schedule of limits is established. In general, the cost/benefit analysis uses 1.0 mg/m³ as the concentration limit reference point required for electroplating facilities.

⁵ Memorandum from Peter Paine to SOP Issue Table Members; MFIT Meeting No. 7, November 12, 1996, Montreal Quebec.

2.2 Objectives of This Report

This report provides a background document to assist Environment Canada and stakeholders in addressing reductions in air emissions of HVC, and in particular assessing the impacts of adopting the proposed emission limits. It should not be used for any other purpose.

Objectives of the Study

1. Provide air emissions estimates for HVC from electroplating facilities in Canada.
2. Define control technologies most applicable in meeting the proposed emission limits established through the SOP.
3. Estimate direct cost impacts on electroplaters of applying best available control technology to meet the proposed emission limits.
4. Conduct assessment of management options for regulatory authorities.
5. Provide costs and benefits analysis as a result of applying most reasonable recommended management option(s).
6. Make recommendation to Environment Canada of management option (or combination of options) best suited to achieving the proposed emission limits.

2.3 Methodology

There were relevant constraints on time and resources available to gather and analyze information for this study. Only 8 weeks were available between initiation and completion of this report, and allocated resources totaled 33 days of professional effort. Therefore, CHEMinfo's research and analysis relied heavily on existing information sources (i.e., many US EPA documents). Care was taken not to "reinvent the wheel". The methodology for this study included the following three components:

- literature search;
- random survey of 70 electroplating facilities; and
- interviews of chemical bath suppliers, control equipment vendors.

2.3.1 Literature Search

Literature information provided background on chromium electroplating processes, equipment, HVC emission control technologies, emission factors and cost models relevant to controlling emissions. Descriptions of various control technologies is largely derived from US EPA documents and other literature cited.

2.3.2 Survey of Chromium Electroplaters

A random telephone survey of 70 chromium electroplaters across Canada was conducted. The objective was to survey enough electroplaters to provide a basis for characterizing the industry as a whole, as well as some of its components (i.e., regional distribution). It is estimated the 70 facilities surveyed represent approximately one third of all chromium electroplating facilities in Canada.

The proposal for this study recommended a random survey of 100 electroplaters across Canada. The number proposed of 100 was based on preliminary information suggesting there were 500 to 600 chromium electroplaters in Canada. With only approximately 210 electroplaters, and many internal shops (which were difficult to locate), there was a lack of time to complete 100 interviews. It became increasingly difficult to identify platers to contact as the field research progressed. However, the 70 electroplaters contacted represent nearly 30% of all HVC platers in Canada. This coverage which was higher than had been originally expected (17%), provides a reasonable representation of the industry on many, but not all, dimensions.

In undertaking the survey, the aim was to conduct random sampling across Canada. Lists of electroplating facilities were collected from various sources including: Canadian Trade Index; Environment Canada; and web sites on the internet. Potential survey respondents were contacted on a random basis. The survey sample is believed to be reasonably representative of the total population of electroplating activity in Canada along the following dimensions:

- regional location for all plating activity;
- average level of emissions per facility;
- average level of potential emissions per tank;
- level of in-place controls among the industry;
- size of the businesses; and
- employment activity in chromium plating per facility.

The survey sample is not likely to be representative of the total population for the following dimensions;

- regional or provincial HVC emissions;
- regional location of decorative and hard chrome (i.e., no decorative identified in Atlantic provinces); and
- number of internal (captive) facilities versus job shops (i.e., internal shops were more difficult to identify).

In total, approximately 300 firms were contacted. For some companies telephone numbers were “no longer in service”, implying the company was no longer in operation.

Many companies contacted were involved in electroplating, but did not plate with chromium. Some companies were not willing to participate in the study, citing lack of interest and time to respond. However, the overall co-operation among the electroplating facilities was good, with 80% of facilities contacted providing the requested information. Among the chromium electroplaters, the survey participation rate was lower at 72%, with many operations personnel (especially at small facilities) citing a lack of time to answer questions.

Responses to Survey Requests

	Approximate Number
Total companies telephoned	303
Firms with telephone number out of service	69
Firms providing responses	185
Firms not involved with chromium electroplating	80
Firms involved with chromium electroplating	105
Chromium electroplaters not wishing, or no time, to respond to survey	29
Firms providing information	76
Firms with insufficient information to include in survey sample	6
Firms included in survey sample	70

2.3.3 Interviews of Industry Suppliers

Interviews of chemical bath suppliers, electroplating equipment vendors, and control technology vendors were valuable in cross-checking the validity of the survey results and industry structure information. An important source of information was Atotech Canada Ltd. of Burlington, ON, which is the largest supplier of chromic acid in Canada and is therefore familiar with most electroplating accounts. This company provided some of the following key information:

- total number of facilities electroplating with HVC in Canada;
- regional distribution of firms;
- distribution of hard and decorative platers; and
- technical information on its products.

2.3.4 Application of Emission Factors

US EPA's emission factor data documented in AP-42 publications were applied in estimating potential HVC air emissions from Canadian electroplating facilities.

Emission Factor for Potential HVC Emissions (no emission controls)

	grains/amp-hr	mg/amp-hr
Functional hard plating	0.12	7.776
Decorative plating	0.033	2.384

Source: US EPA, AP-42, Metallurgical Industry, 12.20-15, July 1996

Several sources of information are available on the efficiency of emission control technologies, including the US EPA AP-42 documents. Vendors of technology and electroplaters themselves agree that the differences in control efficiency between published information and actual facility experience can vary significantly. The actual performance of emission control technologies depends on proper maintenance and monitoring. Chromic acid presents an aggressive chemical agent which can degrade the efficiency of control technologies over time.

Control Efficiencies of Various Technologies

Source of Information	Technology Vendors & Platers	US EPA AP-42	University of Northern Iowa	Assumed Efficiencies
Technology				
Floating polypropylene balls	65-75%	65%	70%	70%
Fume suppressants (foam)		87%	95%	95%
Wetting agents (liquid surface tension modifiers)	99.8%		95%	98%
Mesh pad mist eliminator	99%+	99%	99%	99%
Chevron blade mist eliminator		92.3%	95-98%	95%
Packed bed scrubber (alone)	99%	97.8%	95%	95%
Venturi scrubber			95%	95%
Baffle system			76%+	76%
Condensing coil			23%	23%
Fume suppressants, PP balls		97.5%		98%
Fume suppressants, PP balls, packed bed scrubber		99.8%		99.8%

3. Chromium Electroplating Industry

3.1 Electroplating Processes

Chromium plating is carried out with chromic acid (CrO_3) solutions which contain one or more catalytic anions, and minor amounts of other chemical agents. The electrodeposited chromium metal is extremely hard, corrosion resistant and shiny. It has a low coefficient of friction, imparts exceptional wear characteristics and can serve as a decorative coating to parts on which it is plated. This process is generally used to give a deposit thickness of greater than 0.001 mil and up to 20 mils (1 mil equals 0.00254 cm) or more.

3.1.1 Functional (Hard) Chromium Plating

Hard chromium deposits are thick and used to rebuild or salvage worn parts such as drilling parts, rolls and roll journals, molding dies and other tools, cylinder heads, crankshafts and other machined items.

3.1.2 Decorative Chromium Plating

In decorative chromium plating, a thin coat of chromium is added to protect the already bright finish from tarnishing. For example, a car bumper has between 5 and 15 millionths of an inch of chrome over a nickel finish. The nickel gives the bright finish and the chromium imparts a bluish hue to the metal and protects it from oxidation.

It is sometimes difficult to determine whether a finish is decorative or hard since both finishes share the advantages of a chrome surface. For example, the characteristics of hard chrome partially enhance a decorative finish and add to its quality and types of applications; while the bright finish of decorative chrome adds to the appearance (and hence acceptability) of hard chrome deposits.

Anodizing is an electrochemical treatment whereby stable oxide films or coatings are formed on a metallic surface. Both chromic acid and sulfuric acid processes are used to form the oxide film. Chromic acid processes generate film thickness between 0.02 and 0.04 mil. The advantages of using chromic acid over sulfuric acid include increased corrosion protection, excellent base for paint or other organic coatings, and little or no effect on fatigue strength. For these reasons, chromic acid anodizing is used for threaded parts and aircraft parts.

Functions and Process Parameters

Type of operation	Functions	Process Parameters
Hard ("functional" or "industrial") chromium electroplating	Provides a surface with functional properties such as: <ul style="list-style-type: none"> • Wear resistance • A low coefficient of friction • Hardness • Corrosion resistance. 	<u>Specified in regulation:</u> Plate thickness of 1.3 to 760 microns Current density of 150 to 600 A/ft ² Plating time of 20 minutes to 36 hours <u>Others:</u> Chromic acid concentration of 30 to 50 oz/gal Sulfuric acid concentration of 0.3 to 0.5 oz/gal Solution temperature of 120° to 150°F
Decorative chromium electroplating	Provides a bright surface with wear-and-tarnish resistance.	<u>Specified in regulation:</u> Plate thickness of 0.003 to 2.5 microns (chromic acid bath) or 0.13 to 25 microns (trivalent chromium bath) Current density of 50 to 220 A/ft ² Plating time of 0.5 to 5 minutes <u>Others:</u> Chromic acid concentration of 30 to 50 oz/gal Sulfuric acid concentration of 0.3 to 0.5 oz/gal Solution temperature of 100° to 115°F
Chromium anodizing	Provides corrosion resistance or electrical insulation.	<u>Specified in regulation:</u> Chromic acid concentration of 6.67 to 13.3 oz/gal <u>Others:</u> Film thickness of 0.02 to 0.05 microns Current density of 144 to 720 A/ft ² Anodizing time of 30 to 60 minutes Solution temperature of 90° to 95°F pH of 0.5 to 0.85 Voltage of 20 or 40 volts

Source: U.S. EPA

3.2 Structure Of Canadian Industry

There are approximately 210 facilities in Canada which undertake hexavalent chromium plating⁶. Approximately 56% of these facilities are dedicated to hard (or functional) plating while nearly all the rest carry out decorative plating. Only 2 to 3% of facilities are involved in both decorative and functional plating. In most of those cases, facilities are generally dedicated to functional plating and have one decorative tank. Rarely do platers use the same tanks for decorative and functional plating.

One chemical supplier estimates there are fewer than half a dozen chromium anodizers in Canada, representing less than 3% of chromium plating activity. In addition, there are a few platers which use trivalent chromium and consequently do not have the potential to emit hexavalent chromium from those plating baths. For the purposes of this study,

⁶

Personal conversation - Atotech Canada Ltd., Jan. 24, 1997.

anodizing operations are not distinguished numerically, and are included with the decorative platers.

Chromium Plating Facilities in Canada

	Type of Plating Facilities	Number of Chromium Tanks
	(plants)	(tanks)
Functional hard chromium platers	56%	74%
Decorative plating facilities *	44%	26%
Total number in Canada	210	495

* includes chromium anodizing platers

Three quarters (~75%) of the plating activity is carried out at job shops which service a wide variety of customers. Products that are chromium plated for decorative reasons include automotive parts, plumbing fixtures, furniture components, appliance and electronic parts, crafts (i.e., framing) and a great number of other metal items, largely for consumer application. Some industrial products require hard chromium plating for functional purposes. A thick metallic chrome layer provides a protective metal surface that is resistant to wear. Examples of products that are hard chrome plated include oil and gas drilling equipment, plastics molds, aircraft components, and machinery wear parts, to mention some. Manufacturers which have regular requirements may chose to undertake chrome plating internally. There are also examples of internal chrome plating activity which involve products for maintenance rather than for sale. One example is the printing industry, where some of the larger printers plate press rollers (i.e., rotogravure rollers). Overall, approximately 25% of the plating is carried out internally. In most of these cases, internal electroplating is usually a small part of manufacturing activity and a low portion of total operating costs.

There is no distinction to be made between job shops and internal plating, in regards to the type of plating (decorative or hard) that is carried out by each. Overall 75% of all types of HVC plating activity is carried out by job shops. Some shops undertake both decorative and hard plating, although for the most part the commercial job shops specialize in one or the other.

Types of Chromium Electroplating Facilities

	Job Shops	Internal	Number of facilities
Functional	88	30	118
Decorative	69	23	92
Number of facilities	157	53	210

Source: Chemical suppliers', CHEMinfo Services estimates

For most job shops chromium plating represents only a portion of their operations. Typically these firms have equipment to undertake zinc, tin, copper, cadmium and other types of electroplating.

3.2.1 Chromium Electroplating Tank Population

There are a total of approximately 495 tanks dedicated to chromium plating in Canada, with a total rectifier capacity estimated at 2.5 million amps (or 21,900 million amp-hr using 8760 hours per year). Hard chrome plating facilities generally have a greater number of tanks than decorative plating facilities. Decorative tanks are idle for most of the time so that multiple tanks in a facility are not necessary. The average daily tank operating time rate for hard chrome platers is 11.5 hours, while decorative platers energize their tanks on average for 2.6 hours each day.

Tank Number, Capacity and Operating Rates

	Functional	Decorative	Total/ Overall
Number of facilities	118	92	210
Number of tanks	375	120	495
Average # tanks per facility	3.2	1.3	2.4
Average time of operation (hr/day)	11.5	2.6	8.9
Capacity (million amps)	1.9	0.60	2.50
Actual operating rate (million amps)	0.6	0.05	0.65
Capacity utilization	32%	8%	26%

Typically platers set their rectifiers at 40% to 70% of the rectifier capacity. Actual settings vary with each batch of products to be plated. Surface area of parts, plating time and other parameters can affect the current applied. Taking into consideration the applied current versus the capacity of the rectifiers, the average operating rate of the tanks is 32% for hard plating tanks and 8% for decorative plating tanks.

3.2.2 Regional Distribution of Plating Activity

Decorative plating activity is centered in Ontario and Quebec where much of the metal manufacturing and metal working industry is located. By contrast, there is a greater proportion of functional electroplaters in Western Canada. Functional chrome platers in the Prairies and BC are more dependent on business from customers involved in the oil and gas, pulp and paper, and mining sectors.

Regional Distribution of Chrome Electroplaters

Region	Industry Estimates*			Survey Results
	Decorative	Functional	Overall	
AB, SK, MB	5%	55%	30%	33%
Ontario	50%	20%	35%	30%
BC	15%	7%	11%	17%
Quebec	25%	13%	19%	16%
Atlantic	5%	5%	5%	4%
Total	100%	100%	100%	100%

* Chemical suppliers, electroplaters.

The distribution of electroplating tanks across Canada is similar to the distribution of facilities. There is a high concentration of hard chrome tanks located in Alberta. While the regional market demand may play a major role in attracting electroplaters to Alberta, the low cost of electric power relative to other provinces may also be a factor.

Regional Location of Tanks

	Total	
Alberta	147	30%
Ontario	126	25%
Quebec.....	84	17%
BC	84	17%
MB, SK	33	7%
Atlantic	21	4%
Total	495	100%

The distribution of hard chrome plating capacity is similarly weighed toward Western Canada. Decorative platers servicing the furniture, appliance, auto and other manufacturing sectors are mostly located in Ontario and Quebec. Although our survey did not cover any decorative platers in the Atlantic provinces, competitors indicate some exist in the region.

Distribution of Hard and Decorative Plating Tanks in Canada (Extrapolated From Survey Results)

	Hard		Decorative	
Alberta	120	32%	27	23%
Ontario	90	24%	36	30%
BC	66	18%	18	15%
Quebec	63	17%	21	18%
MB, SK	15	4%	18	14%
Atlantic	21	6%	0	0%
Total	375	100%	120	100%

3.2.3 Trends in Chromium Electroplating Industry

Hexavalent chromium electroplating activity has been in general decline over the last 20 years, according to Canadian electroplating chemicals suppliers. Many electroplating operations have closed or moved out of Canada. At the same time there has been a consolidation among the industry, such that the number of shops has declined over the last decade. Whereas there may have been 300 to 350, or so, chromium electroplaters in Canada in the late 1980s, the number declined by 15 to 30% by 1996. Electroplating

chemical suppliers claim demand for chromic acid has declined by a slightly greater amount as facilities have become more efficient.

Trend in Number of Chromium Electroplaters in Canada

1970	1980	1990	1996
600	400	250	210

Source: Chemical suppliers', CHEMinfo Services estimates

There have been several factors negatively influencing demand for chromium plating in Canada. One has been a shift toward electroless nickel plating (not based on using HVC) for some functional hard chromium applications. At the same time decorative plating has declined in Canada as a result of the penetration of plastics in such application area as automobiles, other transportation vehicles and appliances.

3.3 Supply of Chromium Plating Bath Chemicals

Atotech Canada Ltd. with operations in Burlington, ON claims to supply over 90% of the chromium electroplating shops in Canada. Minor chromium bath chemical suppliers include: Enthone-OMI (a division of ASARCO), in Concord, ON; and MacDermid Chemicals Ltd. of Mississauga, ON. Brudac Canada Inc. of Dorval, PQ distributes chromic acid bath chemicals. Several other small chemical suppliers and distributors participate in the business.

Major Suppliers of Chromium Bath Chemicals

Company	Location
Atotech Canada Ltd.	Burlington ON
Enthone-OMI (a division of ASARCO)	Concord ON
MacDermid Chemicals Ltd.	Mississauga ON
Brudac Canada Inc.	Dorval PQ

There is no production of chromic acid in Canada. Most imports come from the United States, Germany and Italy. Foreign producers include Occidental Chemicals and American Chrome in the United States and Bayer in Germany.

North American Producers of Chromic Acid

Company	Location	Capacity (kT/yr)
Occidental Chemicals	Castle Hayne NC	40
American Chrome	Corpus Christi TX	32
Total North American capacity (100% chromic acid, anhydride basis)		72

Source: Chemical Marketing Reporter

Chromic acid has many other uses apart from electroplating. A major application in North America is the production of chromated copper arsenate - a wood preservative which has gained in popularity as a substitute for pentachlorophenol and creosote. Examples of other chromic acid applications include preparation of catalysts and magnetic particles.

Although the number of decorative and functional chrome plating facilities are approximately equal in Canada, the quantity of chromic acid used by the decorative platers represents 70% of the total, according to chemical suppliers. Decorative plating facilities tend to lose a greater amount of their chromic acid through drag out. They generally have a greater number of drag-outs per day than hard chrome platers which will plate the same batch of pieces over a greater length of time.

Chromic Acid Requirement at Canadian Electroplaters

Plating Type	Chromic Acid Demand
Decorative plating facilities	70%
Functional hard chromium platers	30%
Chromium anodizers	neg.
Total	100%

Source: Chemical suppliers' estimates

3.3.1 Prices for Chromic Acid

Chromic acid is available to electroplaters in different forms, although most is sold as “flake” contained in 50 kg metal drums. Electroplaters may chose to purchase: a ready-made chromium bath solution which includes sulphuric acid, catalyst and other ingredients; or a liquid chromic acid solution (often supplied in 1,100 liter totes). Other solid forms of the acid are available (i.e., granular, powder). Prices for chromic acid vary depending on the size of the order, the suppliers; annual amounts purchased, freight and the form in which it is purchased.

Price Range for Chromic Acid

<u>50 kg drums (flake)</u>	<u>\$/kg</u>
1 drum order	4-6
40 drum order	3-4

4. Hexavalent Chromium Emissions

4.1 Generation of Emissions

Plating and anodizing operations involve use of electricity and hot, corrosive solutions. Operating parameters in plating and anodizing include:

- bath temperature;
- anode surface area;
- cathode surface area;
- amperage;
- voltage; and
- current density.

To a large extent, these parameters are not variable, but must be set within a narrow range to achieve desired results. Other factors that remain constant and are not adjustable are:

- bath surface area;
- part geometry; and
- anode/cathode geometry.

While each of these factors plays a key role in producing the desired finish, each also contributes to the amount of mist (or aerosol) generated during bath operation. The mist is produced from oxygen and hydrogen gases formed at the anode and cathode, respectively. Approximately 80-90 percent of the electrical charge applied to a chrome plating solution goes into the formation of hydrogen and oxygen gases. The generation of these gases results in the formation of tiny gas bubbles, which eventually rise to the surface of the solution. These bubbles burst and generate fine aerosol droplets. The aerosols that arise vary in size and are comprised of the plating bath solution components. The droplets are then carried away from the chrome plating tank by the exhaust ventilation system.

4.2 Electroplating Emissions in Canada

Canadian electroplaters had a potential (based on actual operating rates - not at full rectifier capacity) to emit approximately 42 tonnes of HVC, during 1996. However, most firms employed control technologies such that actual estimated emissions were only 3.2 tonnes. Hard chromium plating tanks accounted for nearly 97.5% of these emissions, while decorative and anodizing operations only represented 2.5%.

Summary of HVC Emissions From Electroplating, 1996

	Functional	Decorative (tonne)	Total
Total potential emissions (based on actual operating conditions)	40.5	1.1	41.6
Overall control level	92%	93%	92%
Actual emissions	3.1	0.1	3.2

The regional pattern of emissions estimated from the survey sample does not follow the location pattern of electroplaters. A few large emitters which operate without any control technologies in-place contribute heavily to emissions in their regions. One large electroplater based in BC, operating without emission controls contributes an estimated 15% of all emissions in Canada (and 45% of emissions from surveyed sample). This plater skews the pattern of emissions identified in the survey.

It is proposed that a more representative pattern of HVC emissions from electroplaters may be estimated by applying the regional distribution of plating tanks (rather than facilities) across Canada. The assumption used for this estimate, is that several large platers (not covered in our random survey) operate in Canada without control technologies in-place.

Estimated HVC Emissions From Electroplating in Canada

Region	Based on Survey Results		Based on Regional Pattern of Electroplating Tanks	
		Emissions (kg)		Emissions (kg)
BC	49%	1569	17%	545
Ontario	25%	791	25%	800
Alberta	16%	498	30%	961
Quebec	9%	283	17%	545
Atlantic	2%	53	4%	128
MB, SK	<1%	9	7%	224
Total	100%	3203	100%	3203

Functional chrome platers account for the majority of emissions and dominate the regional emissions pattern. Emissions from decorative plating operations are centered in Ontario and Quebec, low amounts emitted from operations in the Atlantic provinces, Manitoba and Saskatchewan.

Functional and Decorative Regional Emissions
(Regional Emissions Based on Pattern of Electroplating Tanks)

	Functional	Decorative	Total	
		(kg)		
Ontario	781	20	801	25%
Quebec	531	13	545	17%
Alberta	937	24	961	30%
BC	531	13	545	17%
MB, SK	219	6	224	7%
Atlantic	125	3	128	4%
Total	3125	79	3203	100%

4.2.1 Level of Emission Control

In the survey sample of 70 plating facilities, only 5 did not possess any form of controls. Extrapolating this incidence rate to 210 electroplaters, it is estimated that 15 electroplating operations across Canada, with a total of 36 tanks had with no emission controls during 1996. Approximately 93% of the electroplaters have some controls in place to reduce HVC emissions to air. At facilities where controls are in place they are applied to all tanks in the facility. In operations where controls are not in place, none of the tanks were found to have controls.

Emissions From Facilities With & Without Controls

	Without Controls	With Controls	Total/ Overall
Total emissions (tonne/yr)	2.2 68%	1.0 32%	3.2 100%
Total number of electroplating facilities	15 7%	195 93%	210 100%
Average emission per facility (kg/yr)	145	5	15
Number of tanks	36	459	495
Average emission per tank (kg/yr)	61	2	6

Among the 70 electroplaters surveyed, only 3 hard chrome platers operating 9 tanks, and 2 decorative chrome platers operating 2 tanks had no emission controls in place. Using this data to extrapolate for the total population of electroplating facilities, it is estimated, there may be 10, or so facilities, operating nearly 30 hard chrome plating tanks in Canada without any controls. Similarly, there may be on the order of half a dozen decorative platers (with 5 to 6 tanks) operating without emission controls of any kind.

4.2.2 Types of Controls Employed

Among the 70 firms surveyed, 93% of the electroplating tanks employed at least one type of control technology to reduce HVC emissions to air. Many facilities employ multiple control technologies on each tank. Only 7% of the facilities (and tanks) had no controls in place. Facilities without controls contributed to 68% of total HVC emissions.

Level of Emission Controls Among Surveyed Sample, Only

	# of Tanks Using	% of Tanks Among Surveyed Facilities
Number of tanks employing at least one control technology	154	93%
Tanks with no controls	11	7%
Number of tanks employing multiple control technologies	59	36%

The most popular type of control applied by electroplaters is inclusion of fume suppressants in tank baths. This technology requires no capital cost and is easy to operate. Packed bed scrubbers and various types of mist eliminators including: mesh pad; chevron blade and baffles are employed at slightly more than half of the tanks in Canada. Polypropylene balls and condensing coils are less popular devices with only 10 to 15% of the tanks equipped. Use of trivalent chrome may also be considered a control measure with 100% efficiency (since no HVC is emitted). Less than 3% of the platers use trivalent chromium.

Level of Controls Among Surveyed Electroplaters

	# of Tanks Using	% of Tanks Among Surveyed Facilities
Fume suppressants	89	54%
Scrubbers, mist eliminators	85	52%
Polypropylene balls	21	13%
Condensing coils	17	10%
Trivalent chromium	2	3%
Total number of tanks among surveyed facilities	165	Many tanks have multiple control equipment

4.2.3 Compliance With Possible Emissions Limits

It is estimated less than 5% of facilities and tanks in Canada do not meet the emission limit of 2.0 mg/scm, while less than 10% do not meet the 1.0 mg/scm limit. Approximately 20% of the facilities operating 16% of the tanks surveyed had calculated HVC concentration emission levels that were in excess of the limit for existing facilities of 0.2 mg/scm (milligrams per standard cubic meter of exhaust air) to take effect for those testing after the year 2000. Less than 10, or so, facilities (7%) using 11 tanks which employ no controls of any kind, contribute 68% of total estimated HVC emission in Canada.

Facilities Not in Compliance With Proposed Limits

(Extrapolated From Survey Results)

	Number of Facilities	Number of Tanks	% of Tanks
Facilities not meeting 2 mg/scm	6	18	4%
Facilities not meeting 1 mg/scm	14	41	8%
Facilities not meeting 0.5 mg/scm	15	44	9%
Facilities not meeting 0.2 mg/scm	28	80	16%

Facilities and Tanks Not Meeting Proposed Emission Limit

(Emission Concentration Limit Reference: 0.2 mg/scm)

Tanks	Functional	Decorative	Total Overall
Estimated total number of tanks in Canada	375	120	495
Estimated portion not meeting proposed limit (0.2 mg/scm)	18%	10%	16%
Estimated number of tanks not meeting limit	68	12	80

(Emission Concentration Limit Reference: 1.0 mg/scm)

Tanks	Functional	Decorative	Total Overall
Estimated total number of tanks in Canada	375	120	495
Estimated portion not meeting proposed limit (1.0 mg/scm)	10%	3%	8%
Estimated number of tanks not meeting limit	38	3	41

At facilities where no controls were in place, emissions levels greatly exceeded a 0.2 mg/scm limit. At facilities where some controls were in place, calculated emission concentrations were usually only slightly higher than this limit. In some cases, at facilities where fume suppressants were used, low speed ventilation fans were employed, such that the concentration of HVC in the discharge air was higher.

Degree of Non-Compliance With 2.0 mg/scm, Contribution to Total Emissions

	Average HVC emission (mg/m ³)	Contribution to Total Annual Emissions
Facilities without controls	2.8	68%
Facilities with controls	0.8	6%
Facilities in compliance	<0.2	26%

5. Technical Assessment Of Emission Reduction Options

5.1 Introduction

Many technology options are available to electroplaters aiming to reduce air emissions of HVC. Six stand-alone technologies have been selected for technical assessment. These technologies are readily available in the market place, and have been applied at many chromium electroplating facilities in Canada. Each technology was evaluated using literature information and experiences related by electroplaters surveyed in this study. Although technologies were assessed on a stand-alone basis, pollution prevention techniques and emission control equipment are often combined in actual practice.

The technical assessment of options ranked each of the technologies for five criteria. A ranking of 6 was used as the best score, while a ranking of 1 was the least desirable. A ranking of the importance of each of the criteria was applied in the context on achieving environmental objectives resulting from voluntary initiatives or regulatory requirements, and using the consultant's best judgment. Differences in ranking of the importance of criteria are defined by a linear ranking from 5 (high importance) to 1 (low importance). This simplified weighting scale may exaggerate the importance (or lack thereof) of some criteria. Therefore the evaluation should be used for indicative (not absolute) purposes only, and not be considered as an promotional endorsement of any technology. It should be noted that the relative weight of importance of any of the criteria may be unique to facilities in which the technology is actually applied. In addition, electroplaters have a variety of options, including combinations of controls, to achieve HVC emission reductions. The effectiveness of applying multiple technologies enhances environmental performance and qualifies the value of any single control technology used in isolation. A technical assessment of combinations of controls is not carried out, although a description of some combinations is provided.

5.2 Summary of Technical Assessment

Mist pad eliminators, packed bed scrubbers, surface tension modifiers represent and other types of mist suppressants present technically favourable options to plastic balls, condensing coils and many other possible control technologies, in most cases. Properly maintained mist pad eliminators and scrubbers can achieve high levels of control with no adverse impact on product quality. At some facilities surface tension modifiers and other

forms of mist suppressants (i.e., foam blankets) can pose pitting problems, or other quality issues for some electroplaters.

Technical Ranking of Control Options

Control Technology	Rank	Weighted Score
Mist pad eliminator	1	66
Packed bed scrubber	2	65
Surface tension modifiers (wetting agents)	3	64
Foam mist suppressants	4	49
Plastic balls	5	46
Condensing coil	6	37

Plastic balls and condensing coils do not provide a high level of HVC emissions reduction efficiency. However, these technologies are often used in combination with other controls.

Evaluation of Technical Control Options

Technology	Emission Reduction Efficiency	Ease of Installation	Negative Impacts On Quality	Ease of Maintenance	Ease of Process Parameter Monitoring	
	A	B	C	D	E	
Surface tension modifiers (wetting agents)	4	6	3	6	4	
Foam mist suppressants	3	5	1	5	5	
Plastic balls	2	4	2	4	6	
Mist pad eliminator	6	2	6	2	2	
Packed bed scrubber	5	1	6	3	3	
Condensing coil	1	3	6	1	1	
Ranking of criteria importance	5	1	4	3	2	
Weighted Score (Ranking X Importance)						Overall Score
Surface tension modifiers (wetting agents)	20	6	12	18	8	64
Foam mist suppressants	15	5	4	15	10	49
Plastic balls	10	4	8	12	12	46
Mist pad eliminator	30	2	24	6	4	66
Packed bed scrubber	25	1	24	9	6	65
Condensing coil	5	3	24	3	2	37

5.3 Sources of Literature Information

The technical assessment of emission reduction options was carried out using information derived from the literature. No field testing of control equipment was conducted or possible in the scope of this project. A heavy weighting was placed on information developed by the US EPA. Much of the information contained in this section is largely taken from two sources, namely:

1. Technical Assessment Of New Emission Control Technologies Used In The Hard Chromium Electroplating Industry, Industries Studies Branch (Prepared by Midwest Research Institute), Office of Air Quality and Standards, US EPA, Research Triangle Park, NC, 27711, July 1993, EPA No. 453-R-93-031; and
2. Practical Pollution Prevention Guide Chromium Emission Reduction For Electroplaters And Anodizers, Program for Toxic Air Pollutant Studies, University of Northern Iowa, Copyright 1993, Iowa Waste Reduction Center, University of Northern Iowa.

5.4 Evaluation Criteria

The assessment HVC emissions control technologies was conducted using the following evaluation criteria (listed in order of descending importance):

- A. efficiency in reducing emissions;
- B. ease of process parameter monitoring;
- C. ease of maintenance;
- D. negative impacts on quality of finished products; and
- E. availability, ease of installation or application.

5.5 HVC Emission Sources

Formation of hydrogen and oxygen gas are responsible for generating chromium mist over the electroplating tanks. Bubbles of hydrogen and oxygen burst through the surface carrying bath solution into the air. Major factors affecting chromium mist generation include:

- current (amps) applied;
- time of plating;
- parts surface area and tank geometry, including freeboard;
- viscosity of the chrome plating solution; and

- surface tension of the plating solution.

The HVC concentration of the aerosol mist is the same as the solution. However, the HVC concentration in air depends on the ventilation flow rate over the tank. Higher flows of air result in lower HVC concentration.

Although some plating solution containing HVC may be atomized and become airborne during rinsing of parts after they are removed from the plating bath, the amount of emissions from this source are assumed negligible.

5.6 Prevention Of Chromium Mist In Exhaust Air

The goal of pollution prevention is to minimize or prevent the creation of pollution that will require control or treatment. In the case of chrome plating or anodizing, pollution prevention can be implemented to inhibit the release of chromium mist into the air. This can be accomplished by forming a physical barrier atop the plating bath, using such plastic balls or mist suppressants, or by altering the chemistry of the bath with the addition of wetting agents. The following pollution prevention technologies are discussed:

- mist suppressants (wetting agents, foam blankets); and
- floating plastic balls.

5.6.1 Mist Suppressants

Reducing the surface tension of the chrome plating bath using surfactant wetting agents is a common method mist suppression employed by Canadian electroplaters. Specialized surfactants reduce surface tension and therefore reduce the rate of mist generation by causing the gas bubbles to burst with less intensity through the surface. Surface tension reduction can be achieved by the addition of stable wetting agents. For chrome finishing, decreasing the surface tension to 40 - 45 dynes/cm, or lower (i.e. 20 to 30 dynes/cm) will achieve excellent chromium emission reduction. Suppliers of these specialized surfactants claim 99%- 99.9% reduction in mist generation and emissions, if the surface tension is maintained at proper levels. Lower levels of efficiency have been reported, and the conservative assumption for this assessment is that only 95% efficiency is achieved. These lower levels may relate the efficiencies achieved when the surfactant is partially degraded. In addition to reducing the amount of chrome emitted, wetting agents causes less bath solution to adhere to the plated part, producing less chromium-laden wastewater from rinsing.

Because wetting agents are chemicals (i.e., fluorinated surfactants) added to the bath, they may affect the quality of the deposit. Too much may cause burning, pitting, cloudiness, or poor adhesion resulting in a high reject rate. Insufficient amounts may result in little or no effect on reducing chromium emissions. Some hard chrome electroplaters in Canada claim serious potential quality problems associated with previous use of surface tension modifying chemicals. However, some electroplaters surveyed for this study point out that newer products and proper metal preparation (cleaning) minimize potential quality issues.

Surface tension can be measured by using a “tensiometer”, an instrument that measures the force necessary to lift a metal wire ring off of the surface of a liquid. A second method for measuring surface tension is the use of a “stalagmometer”. While stalagmometers are much less expensive, they can be difficult to use. One major problem is that the plating solution tends to dissolve the ink marks used to make the calculations for surface tension.

A direct benefit of using wetting agents would be reduced plating or anodizing solution carry over into subsequent tanks. This would result in a savings of chemical resources within the process and reduced chromium loading in process wastewaters.

Many commercially available wetting agents also form foams. These double-action wetting agents/mist suppressants are slightly more efficient in reducing emissions, and not as much product is required.

5.6.2 Foam Blankets

A mist (or fume, aerosol) suppressant is a chemical which forms a barrier on the surface of the bath solution to prevent the mist from escaping. Typically surface tension modifiers create foam on top of the plating solution and serve to suppress escape of mist from the plating bath. Specialized surfactants may be employed for foam creation on top of the plating solution (although surface tension has not been significantly lowered).

During operation of the plating or anodizing process, the mist suppressant generates a foam blanket and traps the process gases either between the bath surface and the blanket or within the foam blanket itself. Mist suppressants can be over 99 percent efficient in reducing emissions from decorative chrome plating and anodizing. However, lower levels of efficiency have been reported, and the assumption for this assessment has been conservative that only 95% efficiency is achieved.

Mist suppressants are chemical additives which may affect the chemical balance of the plating solution. Because of this, a generic suppressant is not available for wide spread use. Within a facility, depending on various types of baths available (i.e., hard, decorative, proprietary) a different mist suppressant may be required for each bath; or a different concentration of mist suppressant may be required to achieve the desired result.

A second factor when using mist suppressants is the amount of foam generated during bath use. Too much mist suppressant will cause a large foam blanket that may result in excessive carry-over into subsequent rinse tanks. This will lead to increased need to replenish the suppressant in the operating tank. The foam blanket may also be drawn into the exhaust system, allowing a more concentrated chromium exhaust to be released from the stack. Finally, too much mist suppressant can lead to spill over onto the facility floor or into other tanks, thereby generating large amounts of waste requiring clean-up, treatment and disposal. In any case, the thickness of the layer of foam has to be monitored for optimum efficiency.

Because hydrogen is the primary gas formed during the plating process, dissipation of the gas is important. Build up of hydrogen within the foam, or under the foam, will pose a serious explosion risk. This is especially true when parts are removed "hot" (electric current still on). When "hot" parts are removed the hydrogen gas is spontaneously ignited and may result in equipment damage and serious personal injury, as well as causing an increased fire risk.

Some mist suppressants have to be replaced due to the degradation of the active ingredient. These are known as "temporary". Other mist suppressants only have to be replaced when they are diminished through carry-over.

5.6.3 Floating Plastic Balls

Solid polypropylene balls, $\frac{3}{4}$ " to 2" in diameter, placed on top of the plating bath will retard mist generation and evaporation of the plating solution. They may prevent up to 70 percent of the mist from escaping the plating solution. These balls can be effectively used in both decorative and hard chrome plating processes.

Polypropylene is resistant to chromic acid solutions at temperatures up to 60°C (140°F). Higher temperatures may cause swelling and breakage of the balls. Solid balls are used rather than hollow balls because hollow balls may develop seam leaks and allow the solution to be trapped within the ball. Exposed to chromic acid over long periods of time, there have been reports of polypropylene balls partially degrading at the surface. This can result in minute particles of polypropylene floating on the solution surface which lead to quality control problems during plating.

When using balls in a plating solution, pre-cleaning of parts is essential. Small amounts of oil and grease from dirty parts may float on the bath surface and adhere to the balls. As parts are raised and lowered in the bath, the oil-covered balls may drag across the part surface and prevent effective plating and rinsing, resulting in a flawed chrome surface. This is not usually a problem in captive shops where incoming parts are fairly clean. However, in some job shops, parts are received completely covered with oils and/or

greases. Improved cleaning to prevent carry over of unwanted oils and greases into the plating solution is critical for effective emission reduction when using the plastic balls.

A common problem with plastic balls is that they become trapped in recessed areas of parts and prevent plating or cause burning or dulling of the part plated. The size of the balls is an important factor in whether or not the balls will become entrapped. If possible, balls that are larger than the recessed area of the parts should be chosen. To help prevent entrapment of balls, plastic mesh bags can be used. The bag will keep the balls together on the surface, and reduce the likelihood of balls being carried over into subsequent tanks.

5.7 Capture and Control Technologies

Chromium presents a potential health hazard, such that much of the mist generated from the plating baths needs to be captured by ventilation systems and removed from the workplace. The efficiency of capture ventilation systems depends on such factors as: type of enclosure (hood installed), rate of air flowing through the system; and other factors. The air stream may be sent to a pollution control device. There are a number of commercially available pollution control devices, including:

- mesh-pad mist eliminators;
- packed bed scrubbers;
- blade-type mist eliminators;
- venturi scrubbers;
- cyclone scrubbers;
- fan-separator packed bed scrubbers;
- spray towers;
- dry scrubbers;
- baffle systems;
- condensing coil systems; and
- combined systems.

5.7.1 Capture Devices - Tank Covers

Thin plastic sheets can be placed over the plating bath to reduce emissions by trapping and condensing vapors at the tank. The tank cover can be constructed of plexiglass, or other suitable plastic, and cut to fit the size of the tank. When buying or fabricating the cover, a facility needs to determine how the cover will be removed to allow transfer of parts and equipment during plating or anodizing operations. For rigid plastic covers, it is easiest to use anchors and hinges for allowing tank access. The cover operates similar to a door or window. Flexible plastic sheeting may be anchored on one side and rolled back

and forth across the tank by inserting a rigid pole in the end of the sheeting on the other side. This type of cover would operate similar to a window shade.

Tank covers may not be practical when parts need to be frequently lowered into and removed from the plating bath since this would require that the cover be continually removed and replaced. Also, the chromium environment can dry out or corrode plastics, requiring them to be replaced. Replacement will depend on the care provided to the cover and the amount of chromium mist generated and trapped by the cover.

5.7.2 Mesh Pad Mist Eliminators

The principal control mechanisms for mesh-pad mist eliminators are droplet impaction and interception. Inertial impaction occurs when larger particles, traveling with sufficient velocity, collide with the pad filaments and adhere to their surface. Other particles, because of their size and relative velocity, are intercepted by the fluid layer surrounding the surface of the filament.

In the composite mesh-pad system, the material layers in the center of the pad are composed of extremely small-diameter (0.01 to 0.02 cm [4 to 8 mil]) fibers. The material layers on either side of the center are composed of progressively larger (0.04 to 0.09 cm [16 to 37 mil]) diameter fibers. As the gas stream flows through the composite mesh pad, the small particles that escape the collection device upstream of the mesh pad (e.g., packed-bed scrubber or other mesh pads) impinge on the composite pad and coalesce into larger droplets. This process is accomplished by using a pad comprised of layers of material with various fiber diameters and operating the pad at its flood point. The flood point is the condition in which the liquid flow in the pad is hampered causing liquid to build up in the pad. The enlarged particles are then removed in the back side of the composite mesh pad or in the backup mesh pad downstream of the composite pad. When composite mesh pads are used in series, the pressure drop across the system typically ranges from 1.2 to 1.7 kPa (5 to 7 in. w.c.).

The performance of mesh-pad mist eliminators is dependent upon the fiber diameter, void fraction (amount of free volume), and the air velocity passing through the pad. One of the major factors that affects mesh-pad mist eliminator performance is the tendency of the unit to plug, with the tendency being inversely proportional to the size of the fiber. Regular cleaning of the pads or replacement is critical to optimizing performance. The void fraction influences performance because the higher the void fraction, the greater the resistance to plugging. Mesh pads with higher void fractions can handle heavier contaminant loadings.

Gas stream velocity affects performance because the entrained particles must have adequate velocity to collide with the fibers. However, gas velocities that are too high can cause collected particles to be reentrained in the gas stream. Therefore, gas velocities

should be maintained high enough to optimize collection through inertial impaction yet not cause reentrainment.

Composite mesh pads are used in various configurations and are available through many chromium electroplating equipment suppliers.

5.7.2.1 Composite Mesh Pads Used in Series

When mesh pads are used in series, the first stages of the unit generally serve to reduce the loading on the pads. The first stage is sometimes a single or double set of chevron blades. These parallel, chevron-shaped baffles are used to remove the large particles, which constitute the majority of chromium emissions. The use of chevron blades reduces the tendency for the pads to plug. The chevron-blade section may be followed by a coarse mesh pad that is used to further reduce the loading on the composite pad. This first mesh pad is sometimes irrigated with water to promote the coalescing (enlargement) of the mist droplets, which makes the droplets easier to remove. The primary purpose of the second pad (composite pad) is to increase the size of the particles that penetrated the first pad. The larger particles are then collected or reentrained in the back side of the second pad. The last pad is used to capture the reentrained material that was not collected by the previous pads. In some mesh-pad systems, all the pads are operated dry with periodic washing to clean the pads.

5.7.3 Packed Bed Scrubbers

Packed bed scrubbers can achieve a high level emission reduction efficiency and are usually the most appropriate type of scrubber for chrome plating and anodizing emissions. Some types of scrubbers are not effective in controlling chromium mist, while others, like the venturi scrubber which may provide greater effectiveness (at higher cost) than necessary.

In a packed bed scrubber, the air stream travels through a spraying area and layer of packing material saturated with the scrubbing liquid, usually water. Much of the mist or gas is captured and removed. There are a variety of packing materials commonly used in scrubbers, including plastic and ceramic materials.

The efficiency of a packed bed scrubber is affected by the velocity of the incoming gas and the proportion of incoming gas to scrubbing liquid. If the velocity of the gas passing through the packing media is too high or too low, efficiency will decrease. Similarly, too much scrubbing liquid or too little would result in lowered efficiency. Additional layers of saturated or non-saturated packing media or liquid spray areas may increase the removal efficiency.

5.7.4 Venturi Scrubber

A Venturi scrubber is a wet scrubber which has a "figure 8" structure. Mist enters at the top. Water is introduced just above the narrowest part of the throat; the fumes and water interact just below this point. The pressure change causes the gas and/or particles to be absorbed by the water. The heavier, pollutant-laden droplets fall to the bottom of the throat. The lighter droplets continue on to a separator that removes the remainder of the now-contaminated water from the air stream. The water generated from this process may be recirculated within the scrubber or treated as wastewater.

Although Venturi scrubbers can remove chromium mist from an air stream, they are not often used for this purpose because packed bed scrubbers provide an equivalent level of efficiency at a lower cost.

5.7.5 Spray Tower

Spray towers are the simplest type of scrubber. They consist of a series of nozzles to spray water droplets that trap particulate matter, and a water removal system. Spray towers are used primarily to control large particulate matter, and are thus may not achieve a high level of control for chrome plating or anodizing emissions.

5.7.6 Dry Scrubbers

Dry scrubbers are mainly used for acid gas control. They are not designed to handle high temperature mists and are not recommended for chrome plating or anodizing emissions.

5.7.7 Condensing Coil Systems

Condensing is the process of cooling hot vapor back into the liquid state, thereby reducing the effects of evaporation. To apply this concept to chromium electroplating, a condensing coil is placed in the entry area of an exhaust duct from the chrome plating bath. The hot chromium-bearing vapor rising from the plating tank will collect and return to the liquid phase on the condenser. At this point it can be routed back into the tank via a drain board, thus reducing the amount of chromium escaping into the atmosphere.

Condensers are relatively easy to construct. A simple condenser consists of a piece of sheet metal with an attached cooling coil. The cooling coil has both an intake and outlet through which cold water can pass.

Installation of condensing units is simple and cost effective. Once measurements are taken of the existing ventilation unit, the fabrication of the necessary equipment can be

done at nearly any sheet metal shop. Installation requirements are minimal, since the condenser can be placed within existing exhaust duct work.

5.7.8 Baffle Systems

The principle behind baffling is to create an obstruction or an interruption in the air flow from the chrome plating bath. This interruption causes the air carrying the chromium mist to change its directional flow. In this manner, some of the chromium condenses on the baffle surface. When the air leaves the tank, after passing through the baffle, less chromium remains entrained.

Few baffle systems are in place among Canadian electroplaters. The emissions reduction performance defined in this study is based on bench scale laboratory testing.

Baffles must be constructed of a material that can withstand the corrosive property of the chrome bath. The best suited materials for construction appear to be Schedule 80 PVC and polypropylene. Other plastics have known to become brittle during prolonged exposure to chromic acid. Following prolonged exposure, baffles may fracture into pieces from stress caused by the force of the exhaust air moving through the system.

With a very limited market, manufacturers of pre-fabricated baffles are not likely to exist. Consequently these systems would likely need to be individually fabricated (by arrangement of the electroplater). Individual fabrication will allow the chrome plater to specify the exact size and number of baffles needed for each tank. Installation of the baffle system will cause little disturbance to the plating process, since the baffle is installed within the existing exhaust duct work.

5.7.9 Combined Technology Systems

Various control technologies can be combined to reduce emissions. Several of these are described.

5.7.9.1 Composite Mesh Pads With Packed-Bed Scrubbers

Treatment of chromic acid mist is accomplished by impingement of the droplets on the packing material in the upgraded scrubber systems. The velocity of the gas stream is reduced at the scrubber inlet to maximize impingement efficiency. Water is sprayed countercurrent to the flow of the gas stream, thereby enlarging the mist droplets contained in the gas stream and causing some droplets to drop to the bottom of the scrubber. The gas stream then passes through the packed bed where chromic acid droplets impinge on the packing material and are washed to the bottom of the scrubber. The packing material used in the newer scrubbers has a high surface area-to-volume ratio (presenting more impaction opportunities) and the capacity to distribute, collect, and redisperse the scrubbing liquid quickly. Composite mesh pads, which are located behind the packed bed, are used to remove any reentrained droplets that are carried over from the packed-bed section, as well as particles that are too small to be captured by the packed bed. One or two coarse mesh pads follow the composite pad and are used to remove any enlarged droplets that are reentrained from the composite pad.

5.7.9.2 Fiber-Bed Mist Eliminators

Fiber-bed mist eliminators remove contaminants from a gas stream using the mechanisms of inertial impaction and Brownian diffusion. When inertial impaction is the principal control mechanism, fiber-bed mist eliminators are more efficient than other control devices using this mechanism (e.g., typical mesh-pad mist eliminators and packed-bed scrubbers) because of the higher surface area-to-volume ratios. These higher ratios result in greater obstruction of the gas flow, permitting additional opportunities for impaction of the mist droplets onto the bed fibers. Fiber beds designed for contaminant removal by Brownian diffusion as well as inertial impaction are the most efficient mist eliminators currently available.

Fiber-bed units are designed for horizontal, concurrent gas-liquid flow through the bed. The contaminated gas stream flows toward the downstream face of the bed. The acid mist in the gas stream impacts on the surface of the fibers and drains down the outer face of the bed to the sump while the cleaned gas flows up and out the top of the unit. Fiber-bed units are equipped with a water spray system to wash down any large particulates that may clog the unit. The spray is activated in response to an increase in pressure drop over that specified in the design of the unit. Pressure drops for impaction units range from 0.15 to 2.0 kPa (0.5 to 8 in. w.c.), and pressure drops for Brownian diffusion units range from 1.2 to 3.7 kPa (5 to 15 in. w.c.).

The major factors affecting the performance of fiber-bed mist eliminators are the velocity of the inlet gas stream, pressure drop across the fiber bed, and the water recirculation rate.

With impaction-type units, the velocity of the gas flowing to the unit must be maintained above a certain lower limit because of the decrease in efficiency of inertial impaction at low flow rates. This lower limit varies, depending on the specific design of the impaction bed, but typically ranges from 30 m/min (100 ft/min) for some fiber beds to 110 m/min (350 ft/min) for other beds. The Brownian-diffusion type units have no lower limit on gas flow rate because mist collection increases as the gas flow rate approaches zero. The maximum gas flow rate in fiber-bed mist eliminators is defined by the point at which: (1) collection efficiency begins to drop below acceptable levels, or (2) the gas-phase pressure drop becomes excessive. Performance may be affected as a result of plugging of the bed if the water spray system is not activated in response to an increase in the pressure drop.

Most vendors do not recommend fiber-bed mist eliminators as the first stage of the control system because of their tendency to plug. It is recommended that a coarse filtering device be provided upstream of the fiber beds to prevent plugging and operational problems that may arise from plugging of the fiber-bed media. Packed-bed scrubbers or serially positioned mesh pads are commonly used to reduce the inlet loading to the fiber beds. To obtain representative cost estimates for this control systems approach, costs for typical packed-bed scrubbers or mesh-pad systems should be combined with costs for fiber-bed mist eliminators.

5.7.9.3 Baffle System and Floating Plastic Balls

To implement this combination, the balls are used in the bath to cover the surface of the tank, while the baffle is placed in the front of existing exhaust duct work. The balls could be confined to a "mesh type" bag to keep them from being trapped in recessed areas.

Combining these two technologies significantly reduces emissions from chromium electroplating. The amount of evaporation of chromium-laden mist is reduced via the floating balls. This reduced amount of mist generated is sent through the directional changes of the baffles, where still more of the mist is trapped and returned to the bath. In other words, the chromium mist which is not trapped by the balls, escapes to the exhaust, and is trapped in the baffle system and directed back towards the plating bath. Combining these technologies does not require much additional effort, while the chrome removal rate increases significantly.

5.7.9.4 Condensing Coil System and Floating Plastic Balls

The addition of condensing coils to the plastic balls will further reduce chromium emissions. Although this combination of emission reduction strategies was not tested, the condenser can be expected to trap about 20 to 25 percent of what passes through the balls.

5.7.9.5 Baffle and Condensing Coil System

Installing the system requires placing the baffle within the existing exhaust duct work, while placing the condenser in front of the baffle. The order of air flow would be through the condenser, through the baffle and out the stack. Therefore, any chromium which does not condense on the condenser is trapped in the baffle system. The exhaust fan speed may need to be increased, since there have been two air flow restrictions added to the system.

6. Emissions Reduction Costs

6.1 Summary of Emissions Reduction Costs

The estimated annual direct cost to Canadian electroplaters for applying Best Available Control Technologies (BACT) and achieving rates of emission less than the ultimate proposed limits of (0.2 mg/m³ for existing and new facilities) is \$0.4 million. This estimate includes capital expenditures and various operating and equipment maintenance costs. Cost impacts of monitoring for regulatory compliance are not included.

Summary of Costs to Achieve Ultimate Limit (0.2 mg/m³) (Capital Plus Operating)

	Number of Facilities	Average Annualized Total Costs (\$ million/yr)
Existing facilities with no controls	15	\$0.2
Existing facilities with controls	13	\$0.1
New facilities (1 new facility per year)	15	\$0.1*
Total	43	\$0.4

* includes capital for one new facility per year plus additive operating costs for increasing number of new facilities

** costs relate to 15 facilities installed over 15 years

6.2 Direct Cost Model Applied to Industry

This costing analysis is based on the profile of Canadian chromium electroplating industry emissions as defined in previous sections, and as they relate to achieving the ultimate proposed emission limits for existing plants (0.2 mg/m³), by applying BACT. Total industry costs also incorporate the cost of meeting the proposed emissions limits (0.2 mg/m³) for new electroplating facilities.

For 1996, it is estimated there were 80 tanks located at existing electroplating facilities in Canada not meeting the emission limit of 0.2 mg/m³. However, not all of these facilities were the same in terms of controls in place and amount of potential HVC emissions to be treated. Most hard chrome plating tanks not meeting this limit already possess some form

of control technology. In many cases facilities operate wet scrubbers. For this cost analysis the assumption has been made that hard chrome plating tanks not meeting the proposed limit, would need to apply mist suppressants (surface tension modifiers) to increase the overall efficiency of emissions control. Tanks without any controls would need to install units with wet scrubbers in combination with mesh pad mist eliminators.

Existing facilities are segmented into two groups for the purposes of defining what types of controls are best applicable: 1) For existing facilities in Canada, with no controls in place, the selected control is the installation of a wet scrubber in combination with a mesh pad eliminator. These systems are commercially available as a combined unit and can reduce HVC emissions by greater than 99.5%. The abatement equipment would be operated during plating process; 2) For the group of facilities with controls already in place (nearly all of these operate with scrubbers, condensers, polypropylene balls, etc.) the selected control technology is the continual application of mist suppressants, which can reduce HVC emissions by up to 98% (in addition to other control measures already in place). Decorative and hard chrome facilities have been treated as being similar in their requirements for controls technologies.

Control Technologies Used in Cost Analysis

Type of Facility	Control Option
Hard chrome facilities not meeting proposed limit - with no controls in place	Scrubber with mesh pad mist eliminator
New facility installed each year	Scrubber with mesh pad mist eliminator
Decorative chrome tanks not meeting proposed limit	Scrubber with mesh pad mist eliminator
Facilities not meeting proposed limit - with controls already in place	Mist suppressants

Nearly half of the few decorative plating tanks not in compliance with the proposed emission limit already employ mist suppressants. The other half identified in the survey had no controls in place. For both these types of operations, the assumption is the installation and operation of mesh pad mist eliminators in conjunction with wet scrubbing is necessary to comply with the proposed emission limits. The above assumption establishes a conservative (high) estimate for the total cost to industry in achieving the proposed limits for existing plants.

The Canadian industry is expected to attract new entrants, while older and unprofitable facilities (or tanks) close down. The number of new facilities assumed to be installed in Canada each year is 3, with a total of 10 average sized tanks. Three facilities equal 1.4% of existing facilities in 1996. However, the additional assumption is that only 1 of the 3 facilities would be installed without HVC emission control technologies. This situation may occur if the plant did not require any controls to meet local HVC emission regulation limits. Assuming that 33% of new facilities would not install controls is a conservative estimate (i.e., overstates costs) taking into consideration that 93% of existing facilities have controls in place. For new tanks installed, the assumption is that mesh pad mist eliminators in conjunction with wet scrubbing is installed for each new facility or tanks.

Summary of Installation and Operating Costs Summary
(For Average Size Plant: 2 - 3 Tanks per Facility)

Technology	Annualized Capital Costs	Annual Operating	Total Annualized
Wet scrubber with mesh pad eliminator	\$4,608	\$8,952	\$13,560
Mist suppressants		\$4,000	\$4,000
Polypropylene balls	\$200	\$2,080	\$2,280

6.2.1 Costs for Wet Scrubbers With Mist Eliminators

The total annualized costs for installing and operating a wet scrubber and mesh pad mist eliminator in Canada is estimated at nearly \$15,000 for a 10,000 SCFM sized unit. This size is selected since it matches the requirement for a typical existing or new plant in Canada. On average a 10,000 SCFM unit can accommodate treatment for 3.2 average sized tanks. The air flow rate is related to the top surface area of the tank. Equipment suppliers estimate between 100 to 150 SCFM of flow capacity are required per square foot of surface area. The average surface area of tanks identified from the survey of electroplaters was 33 square feet.

**Capital and Operating Cost Summary
for Wet Scrubber/Mesh Pad Eliminator
(Existing and New Facilities)**

Air stream Flow rate (SCFM)	2000	3000	5000	10000*	20000
Capital & installation	\$2,360	\$2,657	\$3,396	\$4,608	\$6,648
Maintenance & operating	\$2,357	\$3,536	\$5,394	\$8,952	\$15,904
Total annualized costs	\$4,717	\$6,193	\$8,790	\$13,560	\$22,552

* 10,000 SCFM should be able to handle 3.2 average sized electroplating tanks.

Information on capital, operating and maintenance costs for wet scrubbers with mesh pad eliminators system were provided by Canadian equipment suppliers, namely: - Chemical Equipment of Markham, ON and Kontek Ecological Systems, based in Burlington, ON. Canadian suppliers are competitively priced with variations resulting from optional equipment and controls. Canadian companies compete with U.S. firms for the limited domestic market.

The amount of air containing the HVC emissions being processed strongly influences the size of the scrubber and therefore the capital costs. Other factors influencing the price of facilities may pay for equipment include: the extent and types of automatic (computer) controls; materials used; the ease of installation; and location of the facility.

**Capital Costs for Scrubber/Mesh Pad Eliminator, By Size
(Source: Canadian equipment suppliers)**

Air stream Flow rate (SCFM)	2000	3000	5000	10000	20000
Capital	\$19,500	\$22,075	\$29,250	\$40,830	\$60,000
Installation	\$4,000	\$4,500	\$5,000	\$6,000	\$8,000
Transportation	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000
Total capital	\$24,500	\$27,575	\$35,250	\$47,830	\$69,000
Annualized capital cost*	\$2,360	\$2,657	\$3,396	\$4,608	\$6,648

Annualized: 5% interest, 15 year term.

Average annual maintenance and operating costs can total \$2,000 to \$15,000, or more. Incremental operating costs include water supply, wastewater treatment and maintenance. Incremental electricity costs for ventilation, and heating costs are assumed to be zero.

Assumptions, Calculations for Water Treatment, Supply Costs

Air stream Flow rate (SCFM)	2000	3000	5000	10000	20000
Volume of scrubbing water (gallons/minute)	1.3	2.0	3.3	6.6	13.2
Average operating rate	48%	48%	48%	48%	48%
Total volume of water litre/year)	332069	498103	830172	1660344	3320688
Water cost (\$/litre)	0.00063	0.00063	0.00063	0.00063	0.00063
Treatment cost (\$/litre)	0.003	0.003	0.003	0.003	0.003
Total water cost (\$/year)	\$209	\$313	\$522	\$1,044	\$2,087
Water treatment cost (\$/year)	\$1,097	\$1,646	\$2,743	\$5,486	\$10,971

One time capital costs have been annualized so that they may be combined with annual operating costs. It is assumed operating costs are constant are current levels. Capital costs (including installation and delivery charges) were annualized at an interest rate of 5% over a 15 year period. Annual operating costs are added to annualized capital costs to define the total costs for existing facilities.

Capital costs for the one new electroplating facility (or tanks) assumed to be installed are incurred by the industry each year. This capital cost is nearly \$48,000 annually. The total operating costs for all new facilities (installed after the current year) entering the chromium electroplating industry continue to increase. These operating costs increase since one facility is added to the population of “new” facilities each year. The capital and operating costs of all “new” facilities can be added to establish the time series on annual costs.

Since these total annualized costs change with time (due to changes in operating costs), it was necessary to establish the net present value (NPV) of the stream of costs incurred. The discount rate assumed in this analysis was 5% for time series of 15 years. The NPV of the total costs was annualized to arrive at an average total cost for “new” facilities. Again, the interest rate was assumed to be 5% over a term of 15 years.

6.2.2 Costs of Mist Suppressants

The cost of mist suppressants (surface tension modifiers) typically range from C\$10 to 60 per kilogram⁷, but can be as low as \$5. The more expensive products tend to last longer. Mist suppressants are carried out of the bath on parts or degraded over time, thus requiring constant replacement. Typically, they are used up more rapidly than foam mist

⁷ Atotech Inc.

suppressants. Utility costs are negligible or non-existent, since wetting agents would also be considered a “stand alone” control technology.

Improper use of wetting agents can result in defective plating or anodizing and may even ruin the solution. Replacement of the solution can be expensive in terms of new bath purchase, old bath disposal and down time while the situation is corrected. These costs are not addressed in this study.

The major cost of using mist suppressants is the purchase of the chemical. Cost of monitoring and dispensing systems are not included in this analysis, since these are considered to be minor when annualized over a long period. Mist suppressants can reduce the amount of chromic acid losses through mist generation. These savings are estimated using the assumptions provided below.

Assumptions Used in Costing Mist Suppressants

Assumptions	
Mist suppressant consumption (litre/10,000 ampere-hours)	0.075
Price of mist suppressant (\$/litre)	\$25
Reduction in chromic acid losses (kg/yr)	276
Price of chromic acid (\$/kg)	\$4.00
Annual operating rate per facility (ampere-hour/yr)	27,448,000

Notes:

Mist suppressant consumption rate is average of 0.05 and 0.1 provided by chemical supplier.

Price of mist suppressant provided by chemical supplier.

Estimation of reduction in chromic acid losses is based on potential emissions of HVC converted to chromic acid basis.

Annual operating rate per facility is average of all facilities in survey

Calculation of Net Costs of Mist Suppressants⁸

Cost Component	\$/facility
Total cost of purchased mist suppressant	\$5,000
Total value of chromic acid savings	(\$1,000)
Net annual cost of mist suppressants	\$4,000

⁸ Mist suppressant consumption is proportion to amp-hour of operation. Consumption of mist suppressant based on average facility operating 27 million amp-hour per year.

6.2.2.1 Foam Mist Suppressants

Foam mist suppressants come in liquid or powder form, and may range in cost from C\$10 to \$60 per litre or kilogram. The amount of mist suppressant chemical necessary to form a sufficient foam barrier will vary depending on the type of chemical mist suppressant used, tank size and frequency of plating. Trial and error additions will determine the amount of mist suppressant necessary to form an adequate but not excessive foam for an individual plating bath.

According to manufacturers' instructions for different mist suppressants, the recommended amount of chemical to add ranges from 0.01 to 0.1 percent of the total volume of the plating bath to approximately one ounce per 500 gallons initially with frequent additions thereafter. When used in the appropriate amount there is minimal carry over, thus replenishment is not required very often and maintenance costs are minimal.

Since mist suppressants are also "stand alone" emission controls, utility requirements are nonexistent, except perhaps for make-up water in the case of powders. Improper use of mist suppressants can generate serious waste management problems due to spills into other tanks or on the floor; or ruin the plating or anodizing solution itself.

6.2.3 Costs of Polypropylene Balls

The cost of polypropylene balls ranges from approximately \$50 to \$400 per 1,000 balls, depending on the ball size and total quantity purchased. One supplier quotes a price of C\$130 per box. There are 1,000 one inch diameter balls in a box. From the survey sample, the average tank requires nearly 5,000. The cost to cover a tank is estimated at \$650, while the cost for an average facility is \$2,080.

Assumptions and Cost Calculations for Polypropylene Balls

<u>Assumption / Cost Element</u>	
Average area of one tank (sq ft)	33.2
Number of 1 inch balls required (rounded to nearest thousand)	5,000
Price per box of 1,000 one inch balls	\$130
Number of boxes required for one tank	5
Number of tanks (per facility)	3.2
Initial capital costs to load 3.2 tanks	\$2,080
Annualized capital costs	\$200
Annual replacement cost of balls	\$2,080

Since the balls operate on a “stand alone” basis, there are no additional operating costs for utilities or process related waste treatment. There may be an occasional need to replace some of the balls on an annual basis depending on the operating conditions of the tank and balls that may get lost during carry out. The conservative assumption used in this analysis is that the balls will need to be replaced every year.

6.3 Reduction in HVC Emissions

Applying control technologies such that all facilities and tanks are in compliance with the proposed emission limits would result in 70 to 75% reduction in annual HVC emissions in Canada, or 2.4 tonnes per year. The proposed reduction options would achieve 98% to 99% reduction efficiency at each facility (or tank) applied. A low level of emissions would still occur from facilities in compliance with the proposed emissions limit. Total 1996 HVC emissions in Canada would be reduced to approximately 800 kilograms annually if all firms were in compliance with the proposed emission limits.

Ultimate HVC Emission Reductions

	Year 1	Year 15
	(kg/yr)	
Existing facilities	2218	2218
New facilities	145	2175
Total emissions reduction	2363	4393
Percent of potential emissions	74%	

Emissions Impact of Applying Control Technologies

Type of Facility	Estimated Portion of Total Annual Emissions	Control Option	Control Efficiency
Hard chrome tanks not meeting proposed limit			
- with no controls in place	65%	Scrubber with mesh pad mist eliminator	99%
- with controls already in place	5%	Wetting agents	98%
Decorative chrome tanks not meeting proposed limit	2%	Scrubber with mesh pad mist eliminator	99%
New tanks to be installed each year	2%	Scrubber with mesh pad mist eliminator	99%
Total contribution to emissions at facilities requiring technologies	74%		
Contribution to annual emissions (tonnes)	2.4		
Emission reduction after application of control technologies (98-99% reduction)	2.4		
Facilities in compliance (% of emissions)	26%		
Annual emissions from facilities in compliance (tonnes)	0.8		

6.4 Direct Economic Impacts

The merchant (job shop) chromium electroplating business industry in Canada is mostly made up of small and medium sized companies. Nearly 70% of the companies have annual sales of less than \$2 million, and roughly 35% have annual total revenues of less than \$500,000. Chromium electroplating often makes up only a portion of the electroplating activity at most facilities. Most electroplating job shops surveyed rely on chromium for only 10 to 30% of revenues. Other plating activity, albeit some of it in preparation for chromium plating is usually the majority of the business activity. Chromium electroplating activity that is carried out internally as a part of large, integrated manufacturing companies represents a low portion of total costs.

The average annual sales of electroplating operations surveyed was \$2.3 million. This average includes the sales of companies which are involved in other businesses and electroplate internally as well as the job shops. Job shops had lower company sales than internal shops integrated with other manufacturing activity. Companies involved in the auto and aerospace parts production which undertake their own electroplating have annual sales ranging from tens to hundreds of millions of dollars.

Sales Distribution of Surveyed Electroplaters
(data biased toward job shops - few internal facilities surveyed)

Annual sales range	Portion of Companies Responding
Less than \$100,000	7%
\$100,000 to \$499,999	30%
\$500,000 to \$2 million	32%
\$2 to 5 million	27%
\$5+ million	5%
	100%

Some companies surveyed volunteered profit information. Most providing such information state profit levels in 1996 were in the range of 5 to 15% of sales. Many very small companies with sales of less than \$500,000, "profit" and owners' salaries are not distinguishable.

The ratio of control cost to revenues varies with the size of the facility and the types of other business activities engaged by the company. For companies with annual revenues of less than \$500,000 the cost of applying a wet scrubbers/mesh pad eliminator system can represent a major burden and eliminate annual profits for some operations. Mist suppressants present a lower cost and effective option for those facilities which do not already use them.

Impact Analysis of Applying Controls
(Ratio of Average Annualized Costs to Annual Sales*)

Annual sales range	Mist Suppressants	Mesh Pad Eliminator
Less than \$100,000	8%	30%
\$100,000 to \$499,999	1%	5%
\$500,000 to \$2 million	0.3%	1%
\$2 to 5 million	0.1%	0.4%
\$5+ million	0.05%	0.2%
\$10+ million	0.04%	0.1%

* mid-point in sales range used for calculation.

7. Socio-Economic Analysis

7.1.1 Size of the Industry

The Canadian electroplating industry is estimated to generate approximately \$490 million in annual revenues which is divided between merchant markets (i.e. job shops) and captive markets (i.e. internal facilities). Overall, electroplaters surveyed for this project had average annual sales of \$2.3 million. Most respondents to our survey who provided sufficient information suggested that profit levels in 1996 were in the range of 5 to 15% of revenues.

Electroplating job shops in Canada are, for the most part, made up of small and medium sized companies. Nearly 70% of job shops that conduct chromium electroplating have annual revenues of less than \$2 million, and approximately 35% have annual revenues of less than \$500,000. Chromium electroplating often makes up only a portion of electroplating activity at these facilities. For instance, those electroplating job shops surveyed rely on chromium for only 10 to 30% of annual revenues. Other plating activity, albeit some of it in preparation for chromium plating, usually represents the majority of business activity.

Size of Canadian Electroplating Industry

Type of Electroplating	Total Annual "Revenues"	Number of Facilities	Revenues Per Facility	Revenues Attributed to Chromium Electroplating	Chromium Electroplating Revenues per Facility
	(\$ million)		(\$ million)	(\$ million)	(\$ million)
Functional	\$307	118	2.6	47	0.4
Decorative*	\$184	92	2.0	55	0.6
Total	\$491	210	2.3	102	0.49

Source: CHEMinfo Services survey. Industry sources. * includes trivalent chromium plating.

Chromium electroplating activity carried out internally as a part of large, integrated manufacturing companies represents a low proportion of the companies' total costs. Companies involved in auto and aerospace parts production which undertake their own electroplating have annual revenues ranging from a few million to hundreds of millions of dollars. It is quite difficult to distinguish revenues generated by these companies that should be attributed to electroplating activities as electroplating is just one step (albeit

critical) in a chain of value added exercises that are undertaken. Therefore, we have estimated costs of electroplating activities at these companies to proxy revenues that may be generated.

7.1.2 Regional Concentration and Importance of the Sector

Overall, there is a concentration of electroplating facilities in the Ontario and Prairie regions (primarily Alberta) with the rest of the facilities scattered throughout the remaining regions in Canada. Ontario and the Prairies, combined, are home to 2/3 of Canadian chromium electroplaters. Quebec is the next most popular location for chromium electroplaters with 18% of the facilities.

Regional Distribution of Chrome Electroplaters

Region	Number of Facilities			Overall Percentage		
	Decorative	Hard Chrome	Overall	Decorative	Hard Chrome	Overall
Atlantic	5	6	11	5%	5%	5%
BC	14	8	22	15%	7%	11%
Ontario	45	24	69	49%	20%	33%
Prairies	5	65	70	5%	55%	33%
Quebec	23	15	38	26%	13%	18%
Total	92	118	210	100%	100%	100%

While Ontario and the Prairies are home to roughly the same number of electroplating facilities, there is a substantial difference in the type of electroplating that is undertaken within these provinces. Decorative plating activity is centered in Ontario and Quebec (75% of decorative facilities) where much of the metal manufacturing and metal working industry is located. Decorative platers in Ontario and Quebec service the furniture, appliance and auto manufacturing sectors.

By contrast, there is a greater proportion of hard chrome (i.e. functional) electroplaters located in the Prairies region. Functional chrome platers in the Prairies are more dependent on business from customers involved in the oil and gas, pulp and paper, and mining sectors. In addition, the low cost of electric power in Alberta relative to other provinces may also be a factor for locating functional electroplating facilities in that province.

It should be noted that electroplating operations, whether they be decorative or hard chrome, are important value adding components to the various industrial sectors

mentioned above. Electroplating operations provide a relatively low cost service which has a significant impact on the revenues of these other industrial sectors.

7.1.3 Employment

Electroplaters surveyed had an average of 21 total employees. Of this amount, approximately 4.5 of these workers were employed directly to work on chromium electroplating. In total, the electroplating industry in Canada employs approximately 4,400 people with around 930 of these dedicated to working on chromium electroplating. Due to the presence of more establishments, there are more hard chrome employees than decorative.

Regional Distribution of Electroplating Employment

Region	Total Electroplating Employment			Chromium Related Employment			
	Decorative	Hard Chrome	Overall	Decorative	Hard Chrome	Overall	% of employment
Atlantic	105	126	231	22	26	48	5%
BC	294	168	462	62	35	97	11%
Ontario	945	504	1449	198	106	304	33%
Prairies	105	1365	1470	22	287	309	33%
Quebec	483	315	798	101	66	167	18%
Total	1,932	2,478	4,410	405	520	925	100%

Employment is evenly split between Ontario and the Prairies which combined, represent 66% of total employment in the sector. Quebec has 18% of total employment in the sector.

7.1.4 Growth

The chromium electroplating industry has been in general decline over the last two decades. As a result of this negative growth, there have been many electroplating operations that have closed or relocated outside of Canada. In addition, there has been a consolidation among industry participants. Industry estimates suggest that in the late 1980's there were between 300 to 350 chromium electroplaters in Canada while by 1996, this number has declined by 15 to 30%.

Several factors have contributed to this negative growth rate in demand for both functional and decorative chromium electroplating in Canada. In functional hard chrome electroplating, there has been a general shift towards electroless nickel plating. Concurrently, there has been an increasing penetration of plastics into the automotive

(e.g. on bumpers), general transportation and appliance manufacturing sectors which has reduced demand for decorative chromium electroplating.

Growth in chromium electroplating is dependent on the health of a few end use sectors such as the aerospace, auto, and upstream oil and gas sectors. Factors outside the control of electroplaters such as growth or decline in passenger travel or international oil and gas prices can have a significant impact on the volume of business that is directed to chromium electroplaters from these sectors.

Several of the electroplaters contacted during the course of the project indicated that they expect a moderate increase in activity. Overall, the Canadian electroplating industry is expected to experience very slow growth over the next five years. This slow growth is attributed to moderate expansion in the end use sectors for chromium electroplating services (e.g. auto, oil & gas exploration, etc.).

7.1.5 Suppliers to the Industry

All chromic acid (i.e. chromium) used by Canadian electroplaters is imported as there are no domestic producers. There are only two producers of chromic acid in the U.S.: Occidental Chemicals, located in Castle Hayne, North Carolina and American Chrome located in Corpus Christi, Texas. Other countries which export chromic acid to Canada are Germany (Bayer) and Italy.

There are few chromium bath chemical suppliers that service Canadian electroplaters. Atotech Canada Ltd. located in Burlington, ON suggests that they supply over 90% of chromium electroplating shops in Canada. Minor chromium bath chemical suppliers include: Enthone-OMI (a division of ASARCO), in Concord, ON; MacDermid Chemicals Ltd. of Mississauga, ON; Brudac Canada Inc. of Dorval, PQ; and Empire Buff of Montreal, PQ. There may be several other very small chemical suppliers and distributors participating in this business. Chromium bath chemical suppliers have an extensive product line (i.e., many chemicals and sometimes equipment) and service more than just the chromium requirements of Canadian electroplaters. The overall competitiveness and profitability of these diversified chemical and equipment suppliers should not be significantly impacted given the proposed emission limits developed through the Strategic Options Process. However, lower emission standards or less onerous monitoring requirements in Canada versus the U.S., may favour Canadian electroplaters.

Suppliers of Chromium Bath Chemicals

<u>Company</u>	<u>Location</u>
Atotech Canada Ltd.	Burlington ON

Enthone-OMI (a division of ASARCO)	Concord	ON
MacDermid Chemicals Ltd.	Mississauga	ON
Empire Buff	Montreal	PQ
Brudac Canada Inc.	Dorval	PQ

There are around 1-2 dozen or so major suppliers of equipment (process, pollution abatement) to Canadian electroplaters. Some of these firms service a wide range of equipment requirements of Canadian electroplaters while others focus on specific pollution abatement equipment. For instance, Chemical Equipment Fabricators service a very broad range of equipment requirements of Canadian electroplaters while other suppliers such as Eco-Tec concentrate on supplying ion exchange equipment to electroplaters.

Major Suppliers of Electroplating Equipment in Canada

Company	Location		Equipment Specialty
Chemical Equipment Fabricators	Markham	ON	full line of equipment
Kontek	Burlington	ON	scrubbers atmospheric evaporative products
Empire Buff	Montreal	PQ	full line of equipment
Eco-Tec Inc.	Pickering	ON	ion exchange equipment
Atotech Canada Ltd.	Burlington	ON	full line of equipment
Poly-Products	Markham	ON	atmospheric evaporative products
Turbo Tak	London	ON	scrubbers tanks, filters and hoods
Thora Industrial Plastics Company	Scarborough	ON	scrubbers
Miller Plastics Ltd.	Mississauga	ON	scrubbers chemical pumps
Plating Performance Products	Brampton	ON	full line of equipment
AC Plastics	Montreal	PQ	full line of equipment
Plasticair	Mississauga	ON	scrubbers fan and exhaust systems

7.1.6 International Trade

Electroplating is generally a regional service business. There is not a significant level of international trade in electroplated chromium parts by themselves. Plated parts are often components in other products which are traded internationally. Service factors and transportation cost constraints international trade chromium parts by themselves. These

factors contribute to the development of niche markets/regions for chromium electroplating services. In addition, the relative ease in which one could start an electroplating business precludes much international trade as local demand will be served by entry of new facilities in a high demand region.

While the international flow of parts to be electroplated is low, the end products which contain chromium electroplated parts are imported and exported in large volumes. For instance, two of the largest demand sectors for chromium electroplating services are the automotive and appliance manufacturing industries which are quite active in exporting and importing products. In addition, component parts may be exported or imported after chromium electroplating but prior to use in the manufacture of finished products. There is no known tracking of the international trade of chromium electroplated component parts prior to use in the manufacturing process or when they are located on finished products.

8. Benefits of HVC Emissions Reduction

8.1 Summary

The estimated annualized health benefits to Canadian society of reducing HVC emissions to achieve the proposed emissions limits range from \$2.5 million to \$17.8 million with a medium value of \$5-7 million. These benefits vary due to changes in: (i) the weighted average dollar value for all cancer cases avoided; (ii) the social discount rate; and (iii) the proposed emission limit that is adhered to. There are two scenarios with regards to the quantification of benefits outlined in this section. These scenarios vary according to the HVC emission limit adhered to, either 1.0 mg/m³ or 0.2 mg/m³.

Benefits quantified only represent incidences of lung cancer avoided. No other mortality/morbidity effects or environmental impacts are included in these economic estimates.

Annualized Stream of Health Benefits Over the Next Fifteen Years - Base Case (1.0 mg/m³ Emission Limit)

(millions of dollars)

Social Discount Rate	Weighted Average Dollars for All Cancer Cases Avoided		
	Low (\$1.9)	Medium (\$3.1)	High (\$6.2)
High (9%)	3.9	6.4	12.8
Medium (5%)	3.1	5.0	10.0
Low (2%)	2.5	4.0	8.0

Annualized Stream of Health Benefits Over the Next Fifteen Years - Alternative Case (0.2 mg/m³ Emission Limit)

(millions of dollars)

Social Discount Rate	Weighted Average Dollars for All Cancer Cases Avoided		
	Low (\$1.9)	Medium (\$3.1)	High (\$6.2)
High (9%)	5.5	8.9	17.8
Medium (5%)	4.2	6.9	13.8
Low (2%)	3.4	5.6	11.2

8.2 Scenario Descriptions and Simplifying Assumptions

Human health benefits accruing from reduced HVC emissions are calculated for two scenarios in this chapter. These two scenarios vary according to the proposed HVC emission limit that electroplaters must adhere to and consequently the level of HVC emissions that are reduced.

Current HVC Emission Limits Proposed by Environment Canada

Testing Period	Required HVC Stack Concentration Limit After Testing
Before January 1997	2.0 mg/m ³
After January 1997	1.0 mg/m ³
Before January 1999	
After January 1999	0.5 mg/m ³
Before January 2000	
After January 2000	0.2 mg/m ³

All new operations at the time of start-up are required to meet an emission limit for HVC of 0.2 mg/m³.

According to the proposed Environment Canada emission limits, electroplaters who within one of the above periods meet the corresponding emission level will not be required to make further emission reductions in later years.⁹ Therefore, if all electroplaters are tested and eventually reduce their emission levels to adhere to the 1.0 mg/m³ level in 1997, then they will not have to make any further HVC emission reductions in later years.

The first scenario which we will refer to as the base case has the following dimensions:

1. all electroplaters conduct emission testing in 1997;
2. all electroplaters have to meet the 1.0 mg/m³ level in 1997 and beyond;
3. no further emission reductions beyond meeting the above limit are attributed to the introduction of the emission limit (i.e. no requirement to reduce emissions below 1.0 mg/m³ level); and
4. human health benefits from HVC emission reductions are realized in 1997 and for the next fifteen years.

⁹ Minutes from Metal Finishing Issue Table meeting number 7, November 12, 1996.

The second scenario which we will refer to as the alternative case has the following dimensions:

1. all electroplaters conduct emission testing in 1997;
2. all electroplaters have to meet the 0.2 mg/m³ level in 1997 and beyond;
3. no further emission reductions beyond meeting the above limit are attributed to the introduction of the emission limit (i.e. no requirement to reduce emissions below 0.2 mg/m³ level); and
4. human health benefits from HVC emission reductions are realized in 1997 and for the next fifteen years.

The alternative case is a reflection on the ultimate control of HVC emissions from chromium electroplaters as they will reduce emissions by approximately 98% in this scenario.

8.3 Identification of Benefits

Due to resource constraints for this study, only one benefit accruing from reduced HVC emissions is quantified. This benefit is the lung cancer incidences avoided due to reduced HVC emissions. There are two aspects of reduced lung cancer incidences that are quantified in order to calculate this health benefit: (i) cancer mortality and (ii) cancer morbidity.

Limited discussions with the U.S. EPA and Health Canada did not reveal any completed work on qualitatively identifying or physically quantifying morbidity impacts of exposure to HVC emissions from electroplating facilities. It should be noted that this does not preclude their existence. It is merely a reflection on limited project resources.

8.4 Valuation Methodology

A five step process was utilized to calculate the economic valuation of the human health benefits identified above:

1. develop baseline HVC emission estimates that are expected to occur without the introduction of the proposed emission limits.
2. determine HVC emission reductions that are expected to occur due to the introduction of the proposed emission limits.
3. calculate the number of statistical lives saved and morbidity effects avoided due to the introduction of the proposed emissions limits.
4. identify economic values to attach to the lung cancer incidences avoided.

5. calculate the annualized economic value of the total benefits that accrue from the introduction of the proposed emission limits and undertake sensitivity analysis on key variables.

A more detailed description of the various components of our methodology are presented in the following sections.

8.5 Baseline Level of Emissions

To provide the context of the benefits analysis, it is necessary to determine the baseline level of emissions that would occur in the future without the introduction of the proposed HVC emission limits. There are two components required to calculate the baseline level of HVC emissions:

1. determine HVC emissions from existing electroplating facilities; and
2. determine HVC emissions from electroplating facilities that are expected to enter the industry.

This analysis is conducted over a fifteen year time span from the date that the emission limits are introduced. A simplifying assumption is that all existing facilities (as well as new facilities that enter the industry) will remain in the industry over the next fifteen years.

Interviews with suppliers of chromium bath chemicals to Canadian electroplaters indicated that the total population of chromium electroplaters in Canada is approximately 210 facilities. A survey of 1/3 of the Canadian population of chromium electroplaters revealed an annual total of 1,068 kg of HVC emissions in 1996. It is assumed that this sample of 70 chromium electroplaters is representative of the industry in general. Therefore, the identified emissions were extrapolated to calculate an overall HVC emission estimate for existing Canadian electroplaters of 3.2 tonnes annually. This emission estimate represents the baseline level of HVC emissions which would be emitted from existing electroplating facilities if the current operating environment of Canadian electroplaters remained constant.

The Canadian chromium electroplating industry is expected to attract new entrants over the next fifteen years in which our analysis is based. It is assumed that one chromium electroplating facility per year (annually over the next fifteen years) would have entered the Canadian market and not installed any control technologies. The project team has used the average level of HVC emissions from hard chrome facilities which do not have any control technologies installed as a reference to determine the total HVC emissions from new facilities. The project team has used a hard chrome facility as the model

operation since existing decorative facilities are operating well below full capacity and therefore additional capacity in the industry is not required. Hard chrome electroplating will more than likely be the form of chromium electroplating that is expanded in the future.

Other facilities that enter the market annually are assumed to install control technologies such that there are only negligible HVC emissions from these facilities. These facilities are assumed to control to at least 99% efficiency.

Therefore, HVC emissions from new facilities equals the 0.145 tonnes of emissions that are currently emitted from an average hard chrome electroplating facility without any control technologies installed.

It should be noted that emissions from new facilities are additive. The 0.145 tonnes of emissions that occur in the first year of new entrants is added to the 0.145 tonnes of emissions from new entrants in the second year to determine the total level of emissions from new facilities entering the industry after two years.

Baseline Level of Hexavalent Chromium Emissions from Canadian Electroplaters

Year	Baseline Level of Emissions (tonnes)		
	Existing Facilities	New Facilities	Total
1997	3.2	0.145	3.345
2000	3.2	0.580	3.780
2005	3.2	1.305	4.505
2010	3.2	2.030	5.230
2011	3.2	2.175	5.375

8.6 Emission Reductions

In order to determine human health benefits realized from reducing HVC emissions, it is necessary to first calculate the level of emissions that would be reduced from introducing the new emission limits. Again, this discussion must be framed around both existing and new facilities.

The survey of existing Canadian chromium electroplaters revealed that applying control technologies such that all facilities and tanks are in compliance with the proposed emission limit of 1.0 mg/m³ (base case) would result in a 41% reduction in HVC emissions. Similarly, achieving the emission limit of 0.2 mg/m³ (alternative case) would result in a 70% reduction in annual HVC emissions.

Applying a 41% emission reduction to the baseline level of emissions of 3.2 tonnes for existing facilities yields approximately a 1.3 tonne emission reduction per year. Meanwhile, applying a 70% emission reduction to baseline emissions yields approximately a 2.2 tonne emission reduction per year.

Therefore, total HVC emissions from existing electroplating facilities in Canada would be reduced to approximately 1.9 tonnes annually if the base case was introduced or 1.0 tonnes annually if the alternative case was introduced. This assumes that all firms will be in compliance with the proposed emission limits. A low level of emissions would still occur from facilities in compliance with the proposed emissions limit.

As for new facilities entering the industry, it is assumed that 1 facility per year would have begun operations without installing HVC emission control technologies (if the proposed emission limits were not in place). The remaining facilities are assumed to have installed control technologies such that they control 99% of emissions. There are negligible HVC emissions from these facilities.

Therefore, the proposed emission limits will cause this 1 facility to install emission control technologies which will reduce HVC emissions. The proposed emission limits can only have those emission reductions from the one new facility (that otherwise would not have installed the emission control technology) attributed to it. It is assumed that this one facility per year will reduce its emissions by 99% due to the proposed emissions limits.

Hexavalent Chromium Emission Reductions from Canadian Electroplaters due to Proposed Emission Limits

Year	Level of Emission Reduction (tonnes)					
	Base Case (1.0 mg/m ³)			Alternative Case (0.2 mg/m ³)		
	Existing Facilities	New Facilities	Total	Existing Facilities	New Facilities	Total
1997	1.3	0.145	1.445	2.2	0.145	2.345
2000	1.3	0.580	1.880	2.2	0.580	2.780
2005	1.3	1.305	2.605	2.2	1.305	3.505
2010	1.3	2.030	3.330	2.2	2.030	4.230
2011	1.3	2.175	3.475	2.2	2.175	4.375

8.7 Mortality and Morbidity Incidences Avoided

Due to resource constraints, no formal dose-response relationships, exposure pathway analyses, etc. could be developed in this study which linked mortality/morbidity effects to HVC emissions from Canadian electroplaters. Therefore, existing studies undertaken by the U.S. EPA have been used. The simplifying assumption is that the dose-response relationships, population distribution, exposure pathway analysis, etc. used by the U.S. EPA in developing their estimates also apply to the Canadian situation.¹⁰

The U.S. EPA has estimated cancer health risks attributed to exposure to HVC emissions from electroplaters in the U.S.¹¹ The U.S. EPA used an area source algorithm which allocated emissions to various geographical areas in the U.S. based on electroplating activity within that area. Ambient air concentrations, population distribution, exposure and risk were also estimated. The maximum individual risk identified ranged from 1.5×10^{-5} per microgram per cubic meter for a small chromic acid anodizing plant to 5.0×10^{-3} per microgram per cubic meter for a large hard chrome electroplating facility. In total, the U.S. EPA attributed a total of 110 lung cancer cases annually to exposure to a total of 160 tonnes of HVC emissions from U.S. electroplating facilities. This translates to approximately 0.7 cancer cases per tonne of HVC emitted. This approach provides only a crude upper limit approximation for the Canadian context.¹²

Total Cancer Incidences Avoided Due to Proposed Emission Limits

Year	Base Case (1.0 mg/m ³)			Alternative Case (0.2 mg/m ³)		
	Level of Emission Reduction (tonnes)	Cancer Incidences Avoided per Tonne of HVC Not Emitted	Total Cancer Incidences Avoided	Level of Emission Reduction (tonnes)	Cancer Incidences Avoided per Tonne of HVC Not Emitted	Total Cancer Incidences Avoided
1997	1.445	0.69	0.99705	2.345	0.69	1.6181
2000	1.880	0.69	1.2972	2.780	0.69	1.9182
2005	2.605	0.69	1.7975	3.505	0.69	2.4185
2010	3.330	0.69	2.2977	4.230	0.69	2.9187
2011	3.475	0.69	2.3978	4.375	0.69	3.0188

Note: Number of significant digits provided to follow calculation method. Does not represent corresponding accuracy.

8.8 Values of Mortality and Morbidity Incidences Avoided

¹⁰ Health Canada does not endorse this method. Health Canada recommends application of the Hanna-Gifford model used by the U.S. EPA, along with available ambient air chromium concentration data. It was agreed between CHEMinfo and Environment Canada that it was beyond the resources allocated for this study to incorporate this more costly approach.

¹¹ Vandenberg, John., Smith, Andrew., & Blanchard, Karen. *Exposure and Risk Assessment of Chromium Electroplaters*, U.S. EPA, June 1989.

¹² Health Canada does not endorse this method. (also see footnote 10)

A health benefit realized from a reduction in HVC emissions from electroplaters is reduced incidences of lung cancer. There are two aspects of lung cancer incidences that must be reviewed. First of all, there is the cancer mortality effect. Some people who get cancer die. Secondly, there is the cancer morbidity effect. Some people who get cancer survive, but must go through pain and suffering, monetary expenses, etc. to survive. Therefore, in order to develop economic valuations of human health benefits of reduced HVC emissions, we must:

1. present a value for the avoidance of getting lung cancer and dying (value of a statistical life (VSL) - mortality impact);
2. present a value for the avoidance of getting cancer but surviving (morbidity impact); and
3. present a weighted average economic value of the avoidance of cancer incidences.

There has been a substantial level of effort devoted to determining the value of a statistical life through willingness to pay (WTP) estimates. Most studies have developed these values through one of two procedures:

- revealed preference studies which primarily look at the wage-risk trade-off (e.g. wage premium to work in a dangerous occupation); and
- contingent valuation studies which directly ask respondents for the money they would pay to reduce the risks that they incur through various activities (e.g. flying in an airplane).

It should be noted that most WTP estimates are based on avoidance of accidental deaths (e.g. car accidents) and not on the avoidance of developing cancer. It has been shown that people are more afraid of death from cancer than death through accidents due to the pain, suffering and expense associated with cancer. In addition, people generally find involuntary risks, such as pollution exposure, less acceptable than voluntary risks such as car accidents.¹³ However, due to the lack of literature devoted to calculating a VSL based on cancer avoidance, the available VSLs based on avoidance of accidents will be used. The effect of using these WTP values will be to underestimate the total human health benefits accruing from reduced HVC emissions.

There have been four recent reviews of the body of literature on WTP estimates for small changes in risks of death that can potentially be used by policy makers. These four reviews are:

¹³ Hagler Bailly Consulting Inc., *Environmental and Health Benefits of Cleaner Vehicles and Fuels - Supplemental Report 3: Selected Economic Evidence of Monetary Valuation of Human Health Effects*, prepared for the Canadian Council of Ministers of the Environment, October 1995, pg. 4.

1. Fisher, A., L.G. Chestnut, and D.M. Violette, "The Value of Reducing Risks of Death: A Note On New Evidence", *Journal of Policy Analysis and Management* 8(1) 88-100, 1989;
2. Cropper, M.L. and A.M. Freeman III, "Environmental Health Effects", *Measuring the Demand for Environmental Quality*, 1991;
3. Viscusi, W.K., "Fatal Tradeoffs: Public and Private Responsibilities for Risk", Oxford University Press, 1992; and
4. Miller, T.R., "Willingness to Pay Comes of Age: Will the System Survive?", *Northwestern University Law Review* 83: 876-907, 1989.

The recommended VSLs from these studies ranges from a low of \$2.0 million to a high of \$13.0 million in 1994 Canadian dollars.

Recommended VSLs Based on Review of Existing Literature

Review	VSL Rounded to Millions (1994 C\$)	
	Low	High
Fisher et al (1989)	\$3.0	\$13.0
Cropper and Freeman (1991)	\$3.0	\$8.0
Viscusi (1992)	\$4.0	\$9.0
Miller (1989)	\$2.0	\$5.0

Source: Hagler Bailly

To complement these reviews, there have been a number of Canadian studies which have calculated a range of VSLs.

VSL Estimates from Canadian Studies

Study	VSL (1994 C\$)		
	Low	Mean	High
Martinello and Meng (1992)	\$6.2	\$6.9	\$7.8
Vodden et al. (1994)	-	\$5.9	-
Meng and Smith (1990)	\$1.3	\$7.6	\$10.8
Meng (1989)	\$4.3	\$4.7	\$5.1

Source: Hagler Bailly

A recent report¹⁴, prepared for the Canadian Council of Ministers of the Environment (CCME), reviewed all of these studies and recommended the following VSLs, which we will use in this study.

VSL Estimates to be Used in This Study

VSL (1994 C\$)		
Low	Mean	High
\$3.0	\$5.0	\$10.0

The study prepared for the CCME provided slightly modified VSLs for the population over 65 as the particular health effect that the study concentrated on fell disproportionately on those over 65. Due to limited resources for this study, we have not researched whether the lung cancer incidences attributed to exposure to HVC fall disproportionately on the elderly. Therefore, we are unable to allocate lung cancer incidences among the general population (above and below 65) and as a result, only one set of VSLs are presented.

Developing cancer does not mean that one will die. For instance, for all cancer cases, the survival rate in Canada is 40% (based on a recent five year average in Quebec). Therefore, it is not correct to simply attribute our VSL estimates to the number of cancer incidences avoided to come up with the total economic benefits. Some monetary estimate of avoiding contracting non-fatal lung cancer must be developed.

The recent report prepared for the CCME developed an estimate for cancer morbidity based on the cost of illness (COI) approach. Those factors considered in the estimate were hospitalization, physical, medication, treatment and administrative costs as well as lost earning power of the individuals. It should be noted that it is generally accepted that a COI approach underestimates the full benefits to be realized from avoiding cancer morbidity as it does not take into account increased costs for chores and caregiving (e.g. costs incurred because the individual cannot undertake some normal chores) and other social and economic costs (e.g. reduced enjoyment of leisure activities). WTP estimates are generally regarded as more accurate but were unavailable for the CCME study. Therefore, the report prepared for the CCME adjusted the COI estimates (using WTP/COI ratios) to more closely match WTP estimates. Their adjusted numbers are used in our study.

Value of Avoiding Cancer Incidences From HVC Emissions

¹⁴ Hagler Bailly Consulting Inc., *Environmental and Health Benefits of Cleaner Vehicles and Fuels - Supplemental Report 3: Selected Economic Evidence of Monetary Valuation of Human Health Effects*, prepared for the Canadian Council of Ministers of the Environment, October 1995

	Dollars per Nonfatal Cancer Case	Dollar per Fatal Cancer Case	Weighted Average Dollars for All Cancer Cases
		(1994 Can. \$)	
Low	\$149,000	\$3.0 million	\$1.9 million
Medium	\$297,000	\$5.0 million	\$3.1 million
High	\$594,000	\$10.0 million	\$6.2 million

Note: Due to the low level of inflation over the last two years and the magnitude of these dollar estimates, these values will assume to be in 1996 Canadian dollars from now on in this analysis.

The weighted average dollars for all cancer cases was calculated based on the following formula (using medium as an example):

$$\text{Cancer WTP} = (\text{survival rate} \times \$297,000) + (1 - \text{survival rate}) \times \$5,000,000$$

The average survival rate used was 40% which was based on the five year average survival rate for all cancers in Quebec. This rate is considered similar to rates in the rest of Canada. It should be noted that due to the large difference in the WTP values of avoiding a fatal and non-fatal cancer case, the survival rate chosen has a large impact on the weighted average value of avoiding lung cancer incidences.

Unlike the study prepared for the CCME, we have not made a distinction between incidences of lung cancer developed by those above and below the age of 65 due to the fact that we are uncertain of the population who will be contracting these incidences of lung cancer. For instance, those over 65 are much more likely to contract cancer (e.g. in the U.S. approximately 70% of cancer deaths are from those over 65). However, the workforce in electroplating shops, who are under 65 years of age, are exposed to the highest levels of HVC emissions.

8.9 Estimates of Total Annualized Benefits

The project team has calculated the annualized health benefits that will accrue due to reduced HVC emissions over the next 15 years. Total benefits will depend on the implementation schedule of the emission limits. The project team has assumed that the emission limits are introduced this year. If implementation is phased in over a longer time period, total benefits of the emission limits will be lower. Recall that these annualized benefits represent avoided incidences of lung cancer and incorporate both a mortality and morbidity effect.

The project team has conducted sensitivity analyses on two different variables (over the two scenarios) to provide an indication of the possible range of annualized health benefits:

1. the weighted average dollars for all cancer cases; and
2. the social discount rate.

Other variables could have been chosen to conduct sensitivity analyses. For example, the number of cancer incidences avoided or the level of HVC emission reductions expected could also be used. However, the project team believes that the degree of variability in these estimates is somewhat more rigid than is observed in the variables chosen. For instance, HVC emission reductions are based on a thorough industry survey while the weighted average dollars for all cancer cases is somewhat arbitrary.

Specifically, the project team have used the following combinations to conduct sensitivity analyses over the two scenarios.

Sensitivity Analysis Combinations

Social Discount Rate	Weighted Average Dollars for All Cancer Cases Avoided		
	Low	Medium	High
		(\$ million)	
High - 9%	\$1.9	\$3.1	\$6.2
Medium - 5%	\$1.9	\$3.1	\$6.2
Low - 2%	\$1.9	\$3.1	\$6.2

The project team first calculated the net present value of the stream of health benefits that would accrue over the next fifteen years using the various combinations described in the table above. Steps for the two different scenarios that have been described in this section, namely the base case where an emission limit of 1.0 mg/m³ is imposed and the alternative case where an emission limit of 0.2 mg/m³ is imposed are presented.

8.9.1 Base Case Results

The net present value of the stream of health benefits resulting from a scenario where Canadian electroplaters adhere to an emission limit of 1.0 mg/m³ range from \$24 million to \$132 million. The medium case estimate of the human health benefits is approximately \$52 million. These benefits are calculated over the next 15 years, only.

Net Present Value of Stream of Health Benefits

(millions of 1996 Can. \$)

Social Discount Rate	Weighted Average Dollars for All Cancer Cases Avoided		
	Low (\$1.9)	Medium (\$3.1)	High (\$6.2)
High (9%)	\$23.6	\$38.5	\$77.0
Medium (5%)	\$31.7	\$51.7	\$103.4
Low (2%)	\$40.5	\$66.1	\$132.3

In order to compare the stream of benefits to costs, the project team annualized the net present value of the stream of benefits over the next fifteen years. A 5% social discount rate has been used to develop the annualized stream of benefits, based on the NPV.

Annualized Stream of Health Benefits Over Next Fifteen Years

(millions of 1996 Can. \$)

Social Discount Rate	Weighted Average Dollars for All Cancer Cases Avoided		
	Low (\$1.9)	Medium (\$3.1)	High (\$6.2)
High (9%)	3.9	6.4	12.8
Medium (5%)	3.1	5.0	10.0
Low (2%)	2.5	4.0	8.0

On an annual basis, the health benefits range from \$2.5 million to \$12.8 million with an overall medium estimate of approximately \$5.0 million.

8.9.2 Alternative Case

The net present value of the stream of health benefits resulting from a scenario where Canadian electroplaters adhere to an emission limit of 0.2 mg/m³ range from \$33 million to \$182 million. The medium estimate of the health benefits is approximately \$72 million. These benefits are calculated over the next 15 years, only.

Net Present Value of Stream of Health Benefits

(millions of 1996 Can. \$)

Social Discount Rate	Weighted Average Dollars for All Cancer Cases Avoided		
	Low (\$1.9)	Medium (\$3.1)	High (\$6.2)
High (9%)	\$33.1	\$54.0	\$108.0
Medium (5%)	\$43.9	\$71.7	\$143.4
Low (2%)	\$55.7	\$90.9	\$181.8

On an annual basis, the health benefits range from \$4.1 million to \$14.1 million with an overall medium estimate of approximately \$6.9 million. These estimates were calculated based on the results of the net present value calculation at a 5% social discount rate.

Annualized Stream of Health Benefits Over the Next Fifteen Years, Only

(millions of 1996 Can. \$)

Social Discount Rate	Weighted Average Dollars for All Cancer Cases Avoided		
	Low (\$1.9)	Medium (\$3.1)	High (\$6.2)
High (9%)	5.5	8.9	17.8
Medium (5%)	4.2	6.9	13.8
Low (2%)	3.4	5.6	11.2

Note that the value of the health benefits are sensitive to changes in:

- the value of avoiding a cancer incidence;
- the number of years over which the benefits are calculated;
- the level of HVC emission reductions today and in the future;
- the number of cancer incidences avoided; and
- the social discount rate used.

9. Comparison of Direct Costs and Benefits

9.1 Introduction

The following section provides a summary comparison between the results obtained in the direct cost analysis and the benefits analysis. The net benefit (cost) will be provided for two scenarios, namely:

1. where electroplaters achieve an emission limit of 1.0 mg/m³ in 1997 and beyond (base case); and
2. where electroplaters achieve an emission limit of 0.2 mg/m³ in 1997 and beyond (alternative case).

9.2 Base Case Comparison

There is a positive net benefit across all combinations of (i) social discount rate and (ii) weighted average dollars for all cancer cases avoided. These net benefits range from a high of \$99 million to a low of \$28 million. The medium net benefit is approximately \$48 million. These benefits are those that accrue over the next fifteen years, only.

Net Present Value of Stream of Benefits (Costs)

(millions of 1996 Can. \$)

Social Discount Rate	Weighted Average Dollars for All Cancer Cases Avoided		
	Low (\$1.9)	Medium (\$3.1)	High (\$6.2)
5%	27.7	47.7	99.4

As the present value of the net benefits is positive, the annualized net benefits will be positive as well. We have used the net present values that are realized at a social discount rate of 5% to determine the annualized net benefits over the next fifteen years. Annualized net benefits range from \$2.1 million to \$12.4 million with a medium value of \$4.6 million.

Annualized Stream of Net Benefits (Costs) Over Next 15 Years

(millions of 1996 Can. \$)

Social Discount Rate	Weighted Average Dollars for All Cancer Cases Avoided		
	Low (\$1.9)	Medium (\$3.1)	High (\$6.2)
High (9%)	3.5	6.0	12.4
Medium (5%)	2.7	4.6	9.6
Low (2%)	2.1	3.7	7.7

9.3 Alternative Case Comparison

There is a positive net benefit across all combinations of (i) social discount rate and (ii) weighted average dollars for all cancer cases. These net benefits range from a high of \$139 million to a low of \$39 million. These net benefits are calculated over the next fifteen years.

Net Present Value of Stream of Benefits (Costs)

(millions of 1996 Can. \$)

Social Discount Rate	Weighted Average Dollars for All Cancer Cases Avoided		
	Low (\$1.9)	Medium (\$3.1)	High (\$6.2)
5%	39.3	67.1	138.8

As the present value of the net benefits is positive, the annualized net benefits will be positive as well. Annualized net benefits range from \$3 million to \$17 million with a medium value of approximately \$6 million. We have used the net present values that are realized at a social discount rate of 5% to determine the annualized net benefits over the next fifteen years.

Annualized Stream of Benefits (Costs) Over Next 15 Years

(millions of 1996 Can. \$)

Social Discount Rate	Weighted Average Dollars for All Cancer Cases Avoided		
	Low (\$1.9)	Medium (\$3.1)	High (\$6.2)
High (9%)	5.0	8.4	17.3
Medium (5%)	3.8	6.5	13.4
Low (2%)	3.0	5.1	10.7

10. Assessment of Management Options

10.1 Introduction

Environment Canada has an array of management options in their “tool kit.” These include:

- “command-and-control” regulations that mandate specific actions and delineate the penalties of not complying;
- market-based instruments that create price signals to help meet environmental protection goals; and
- voluntary instruments that encourage environmentally sound behaviour without legally binding consequences if behaviour does not change.

In this section, an assessment of management options begins with the full tool kit and, through the application of assessment criteria, identifies the “best” practical management options for Environment Canada.

10.2 Summary of Management Options Assessment

Mandatory technology standards (i.e., regulations that mandate control technologies with actual operating conditions, possibly monitored through key operational parameters) are assessed to be the most environmentally effective and recommended management option for the electroplaters. This option establishes a level playing field between the majority of electroplaters that have already installed control technologies and the minority that have not.

Jurisdictional issues of enforcement, enforcement costs and potential resistance from that section of the industry that have not already applied control measures or represent minor contributions to total emissions, are potential drawbacks. These may be overcome with preparation of technology standards that consider the unique characteristics of segments of the electroplating industry (i.e., differences between functional and decorative platers, large and small platers, etc.)

Other less attractive options include the following:

- **Structured agreements** with the largest sources could be effective in achieving fairly large and rapid reductions (e.g., one electroplater without controls in place was

responsible for nearly half of the emissions identified in a survey of 70 electroplating facilities). Environment Canada should explore the willingness of the largest HVC emitters to enter into structured agreements. This should be considered a step to reduce emissions in the short term. In the longer term, it would not necessarily control emissions from new sources or smaller sources currently in operation.

- **Mandatory pollution prevention plans** could be considered, particularly for electroplaters that do not currently meet some specified emission standard. (For example, all companies could be required to report amp-hours and their control technologies to allow estimation of actual emissions. Companies with estimated emissions above a minimum standard would be required to submit a full plan). The plans could also be required for all new electroplating operations.
- **Voluntary measures** and **information provision** are potentially applicable, but not likely to be very environmentally effective. Control technologies are well understood and have been adopted by most electroplaters. Electroplaters that continue to operate without control technologies have little incentive to comply given the difficulties in detecting their operations, the difficulties in measuring their emissions and the lack of an industry association encompassing all electroplaters that could create significant pressure to comply.
- Management options that are not as attractive include: quantity controls; performance standards; trading programs; environmental charges and taxes; financial incentives; and environmental liability.

10.3 Approach and General Considerations to Assessment

The assessment of management options is presented as a two-step process:

Step 1: a preliminary screening of a wide range of management options to identify those that are potentially applicable; and

Step 2: a more detailed assessment of those management options deemed potentially applicable in Step 1.

Prior to the preliminary screening, however, it is useful to examine two questions that have important implications for the management options.

How should environmental performance be measured?

The goal of the SOP is to reduce the environmental and human health risks that arise from HVC emissions for electroplating operations. Nonetheless management options do not typically specify the requirements from businesses in terms of reductions in risk *per se*. Rather, the environmental performance targets embedded within the management options are stated in terms such as:

- reduce HVC releases to the air by 75%;
- limit the concentration of HVC in air emissions to 0.2 mg/m³; or
- ensure 100% of electroplating operations have control technologies installed that achieve 99% control efficiency.

The following examples illustrate three generic approaches to actually measuring environmental performance.

1. **Quantity** of HVC emitted, where electroplaters' environmental performance (or compliance with a management option) is measured by the magnitude of their total HVC emissions on, say, a daily, monthly or annual basis. This can be done in two ways. A *direct* approach would require continuous emissions monitoring systems. An *indirect* approach would estimate total emissions from amp-hours, control efficiencies and other operating parameters (i.e., the approach used to create the emissions inventory).
2. **Concentration** of HVC in air emissions, where electroplaters' environmental performance is measured as their compliance with an emissions concentration limit of, for example, 0.5 mg/m³ for existing facilities after 1999, and 0.2 mg/m³ for new facilities; and
3. **Technology-based**, where performance is measured as having specified control technologies installed, functional and operating and, possibly, achieving specified levels of critical operating parameters such as surface tension and pressure drop.

Management options have different advantages and disadvantages depending on what type of performance measurement is being considered. For example, a structured agreement that specifies the quantity of HVC emissions allowed might have enforcement costs that are very different from the costs of enforcing a structured agreement to install specified control technologies.

Given the importance of what environmental performance measures are to be built into management options, the three approaches for measuring environmental performance are assessed in the table below. The conclusions are that:

- a **technology-based** approach is most practical for measuring electroplaters' performance with respect to HVC emissions.
- *indirect* measurement of **quantity** of HVC emissions, from amp-hours and estimated control efficiencies, might be practical and could be used to classify operations;
- *direct* measurement of **quantity** of HVC emissions, based on a continuous monitoring approach, is not practical; and
- **concentration** is not a practical measure of performance given the ease of dilution and high concentration variability depending on operating conditions.

Therefore, for the purposes of the management options assessment, it is assumed that the management options take a technology-based approach to measuring environmental performance.

Assessment of Performance Measurement Options

Performance Measure	Advantages	Disadvantages
Quantity of HVC Released: (Direct Measurement)	<ul style="list-style-type: none"> • Most directly linked to environmental goals, since environmental damage caused by quantity 	<ul style="list-style-type: none"> • Since operating conditions (and emissions) can change frequently at each plant, continuous monitoring may be necessary • Very expensive, particularly for small companies • Expense probably not justified since an estimated 93% of electroplaters already have some emission controls
Quantity of HVC Released: (Indirect Measurement)	<ul style="list-style-type: none"> • Amp-hours used as the basis for emission factors, indicating amp-hours is the measure most highly correlated with emissions • Relatively easy to measure • Already measured at many operations • Less expensive than quantity or concentration 	<ul style="list-style-type: none"> • Provides only a rough estimate of emissions since it does not reflect actual performance of control technologies
Concentration of HVC in Emissions	<ul style="list-style-type: none"> • Less expensive than quantity, but still requiring testing at each operation 	<ul style="list-style-type: none"> • Does not measure total emissions • Allows dilution • Periodic tests may not reflect emissions since operating parameters affecting emissions can change for each job
Technology-based	<ul style="list-style-type: none"> • Proven practical for electroplating in the US and within existing codes of practice • Easily enforced • Least expensive 	<ul style="list-style-type: none"> • Does not measure total emissions

How can chromium electroplating operations be identified?

This study and others dealing with metal finishing have revealed the difficulties in identifying (or locating) operations. Small job shops, as well as internal shops, frequently go undetected. Yet developing, administering and/or enforcing many of the management options require a knowledge of the operations engaged in chromium electroplating.

Some management options (e.g., those not involving any legally binding requirement) will not necessarily require that all chromium electroplaters be identified. However, monitoring compliance with management options that mandate actions will require that electroplaters be identified.

There are options available to identify chromium plating operations.

- *Further research:* This is not very reliable based on previous experience and since electroplaters have an incentive to avoid regulators and there is a high turnover rate in the electroplating sector.
- *CEPA Section 16 or 18 Notice to electroplaters:* Given the small size of operations and lack of cohesion in the electroplating sector, this approach would require an extensive “advertising” campaign, much like that conducted for other toxic substances with widespread users.
- *CEPA Section 16 or 18 Notice to suppliers of chromium plating inputs:* Given the small number of suppliers, this approach would be most effective.

In recommending management options, the mechanism to identify the affected electroplaters must be considered.

10.4 Preliminary Screening

This step of the management options assessment involves a preliminary screening of a wide range of management options. The end result is a classification of each management option into one of two groups:

- potentially applicable; or
- not applicable.

The criteria used in the preliminary screening are:

- *environmental effectiveness*: Would the management option clearly be ineffective at reducing HVC emissions from electroplaters?
- *feasibility*: Are there technical, economic, legal, jurisdictional or other critical constraints that prohibit application of the management option?

If the management option appears at all useful for reducing emissions *and* there are no obvious prohibitive constraints on its use, the management options is assessed as being potentially applicable .

The management options used in this assessment are defined as follows.

- ***Quantity Controls***: Quantity controls limit the amount of a material used. They are usually applied to inputs of a polluting process (i.e., chromic acid).
- ***Mandatory Performance Standards***: Performance standards set maximum allowable emissions or emissions per unit of output, input or other process parameter.
- ***Mandatory Technology Standards***: Technology standards identify specific technologies that must be used to control pollution.
- ***Trading Programs***: Trading programs limit total releases of a pollutant from a given area, by allocating emissions allowances to firms. A firm's allowances may not be exceeded, but they can be bought and sold through allowance markets.
- ***Environmental Charges and Taxes***: Environmental charges and taxes are applied to inputs or outputs of production. They are used to raise the price of polluting activities and to generate revenues (possibly for pollution remediation).
- ***Mandatory Pollution Prevention Plans***: Mandatory pollution prevention plans identify commitments by firms to reduce adverse environmental impacts, including statements of pollution reduction measures.
- ***Structured Agreements***: Structured agreements are negotiated contracts between firms and government, possibly involving other interested parties. In practice, structured agreements would be applicable to a small number of large firms.
- ***Financial Incentives***: Financial incentives are monetary or other financial rewards for undertaking pollution prevention or reduction activities.

- ***Voluntary Measures:*** Voluntary measures are measures which are taken by firms to control emissions without requirements to do so. There may be, however, considerable pressure to undertake voluntary measures without the absolute requirement to do so.
- ***Environmental Liability:*** Environmental liability assigns legal responsibility, to firms undertaking environmentally risky activities, to make environmentally irresponsible actions more costly.
- ***Information Provision:*** Information provision relies on informing polluters of environmental concerns and responsibilities, and providing options for alleviating the concerns and responsibilities.

The classification and the justification for the classification are presented below.

As shown, the screening identifies the following management options as applicable:

- technology standards;
- mandatory pollution prevention plans;
- structured agreements;
- voluntary measures; and
- information provision.

Management Options Assessed as Not Applicable

Management Option	Rationale
Quantity Controls	HVC emissions are not highly correlated to the quantity of any input, but instead depend on operating conditions, control technologies and other factors. The major input (chromic acid) has other applications, rendering quantity controls impractical.
Mandatory Performance Standards	Emissions are not easily measured accurately and enforcement would be very difficult since operating parameters that affect emissions are routinely adjusted for each plating job.
Trading Programs	Trading programs require an underlying performance standard or quantity control, neither of which is potentially applicable.
Environmental Charges and Taxes	Input taxes would not be effective for the same reasons as quantity controls. Emission charges are not practical because of significant implementation and administrative barriers relative to their potential effectiveness.
Financial Incentives	Financial incentives, particularly those targeted at a small number of companies (electroplaters without control technologies), are not realistic given the government's current fiscal priorities. Electroplaters should be eligible for any current incentives for pollution control expenditures.
Environmental Liability	Emissions are not easily detected and establishing links to damages would be extremely difficult.

10.5 Assessment of Applicable Management Options

This step of the management options assessment provides a detailed evaluation of the five management options identified as applicable. The following assessment criteria are applied to each management option:

- **Environmental Effectiveness:** What levels of release reduction could be achieved by this management option?
- **Ease of Enforcement:** How easy will it be to monitor and enforce compliance with this management option?
- **Enforcement Costs:** How costly will it be for government to monitor and enforce compliance with the management option relative to other management options?
- **Cost Effectiveness:** Does this management option provide businesses with the flexibility to select the most cost effective emission reduction strategy that meets the environmental performance required?
- **Innovation Incentives:** Does the management option directly or indirectly stimulate creativity and innovation through some form of incentive to develop and implement cleaner technologies and ways of operation?
- **Allowing Economic Growth:** Can the management option be structured in such a way as to allow for the entry of new businesses into the sector?
- **Fairness:** Does this management option impose a larger cost on certain groups of electroplaters (e.g., in one region, large vs. small)?
- **Minimizing Data Requirements:** What will be the data requirements for the use of this management option (including monitoring data) in terms of quality, intensity, and availability?
- **Jurisdictional Issues:** Is the enabling legislation for this management option currently available? Will the application of this management option support or be in conflict with established jurisdictional responsibilities?
- **Acceptability to Industry:** Are electroplaters likely to prefer the management option relative to other management options?

10.5.1 Mandatory Technology Standards

Mandatory technology standards are legal requirements, implemented through regulations, for electroplaters to install specified technologies (emission controls and/or other technologies - i.e., trivalent chrome). Technology standards may or may not include the following features, depending on their design.

- The standards may offer electroplaters some choice as to which technologies (or combinations of technologies) to adopt.
- Operating conditions may be specified in the standard with which every regulated source must comply.
- Different technologies may be required for different types of operations. For example, hard chrome platers may be required to install different technologies than decorative platers. Alternatively, different technologies might be required based on different ranges of amp-hours.

Environmental Effectiveness

Technology standards are likely to be effective at reducing HVC emissions for the following reasons.

- Control technologies with efficiency ratings up to 99% are available. They have been proven feasible in Canada, where 93% of tanks among surveyed facilities have at least one control technology already in place.
- A large majority (68%) of HVC emissions from electroplating result from a small number (11) of tanks with no controls of any kind. Requiring control technologies with 90% efficiency at just these 11 tanks would reduce national emissions by about 60%.
- Technology standards are enforceable through inspections of electroplating facilities to assess the presence and use of control technologies.
- Technology standards may need to include operating conditions for the control technologies to be effective. There are costs to operating control technologies and therefore, in the absence of operating requirements, businesses that have installed control technologies may not use them.

Technology standards have several potential drawbacks related to environmental effectiveness.

- While technology standards could reduce HVC emissions by up to 99%, they would not be effective at achieving virtual elimination.
- Technology standards would not place legally binding limits on total HVC emissions from electroplating.
- Selection of critical operating parameters to be monitored are key achieving compliance with intended limits and ultimate reductions sought. Limits based on measuring concentration in stacks present problems of potential dilution, high costs to analyse and great variability of operations.

Ease of Enforcement

It is relatively easy to determine if control technologies are in place. Monitoring operating conditions would be more difficult and would require spot checks by inspectors.

Enforcement Costs

Enforcing technology standards would involve costs similar to other Federal environmental regulations that require training of inspectors and periodic inspections.

Cost Effectiveness

Technology standards are often criticised for limiting businesses' ability to select cost effective technologies that would achieve the same environmental objectives. To offset this criticism, technology standards could specify a variety of acceptable technologies or combinations of technologies.

Innovation Incentive

Technology standards are often criticised for stifling innovation. They need to be updated when new technologies become available, but still negate some of the incentive to develop new technologies at all. This is a relatively minor concern given that HVC emission control technologies are already well developed and applied in most electroplating operations.

Allowing Economic Growth

A technology standard would not place any legal constraints to new or expanded operations. As with all management options, however, installing control technologies would increase start-up costs.

Fairness

All operations would be forced to comply with the same requirements and so could be considered fair. Since an estimated 93% of chromium electroplating tanks already have at least one control technology, technology standards could be considered fair as they would create a level playing field by requiring all tanks to have control technologies.

Minimizing Data Requirements

Setting the standard would require detailed research into the available control technologies and their operations. Enforcement would also require identifying operations subject to the standard.

Jurisdictional Issues

CEPA provides authority to implement technology standards in situations where the particular technology is unique to the problem. It is possible, however, that a technology standard could conflict with technology standards implemented by other jurisdictions. (Analysis for this regarding this potential issue was not undertaken.)

Acceptability to Industry

Some electroplaters that have already installed control technologies will welcome a technology standard to create a level playing field. Depending on the stringency of any reporting requirements embedded within the regulation, they may also be preferred to mandatory pollution prevention plans if the “paperwork” is less.

10.5.2 Mandatory Pollution Prevention Plans

This management option would involve electroplaters preparing plans to reduce HVC emissions from their facilities. The Government Response to the CEPA Review identified the following elements of pollution prevention plans:

- a senior level statement of commitment to prepare and implement the plan;
- a clear statement of objectives and goals, and a schedule for meeting those goals;
- a comprehensive quantitative review of all activities related to the substance;
- an identification, feasibility study and ranking of opportunities to avoid or minimize the production, generation or release of the substance;
- a selection of options to meet the plan's environmental goals and preparation of an implementation schedule;
- implementation of the selected options;
- measurement, tracking and evaluation of their success; and
- reporting on progress towards goals.

Given the comprehensiveness of the plans as envisioned in the Government Response, Environment Canada could issue guidelines for plans that would assist operators in preparing the plans without having to "re-invent the wheel." A minimum emission standard would be required, along with a schedule of implementation.

Pollution prevention plans could be required of all HVC emitters, or selected emitters (e.g. those not having specified technologies).

Environmental Effectiveness

An estimated 93% of electroplating shops already have at least one control technology. Therefore, it is likely that many operations would submit plans not containing any new control efforts, unless required to meet a minimum standard.

For those operations without control technologies, there are several factors that suggest they would be reluctant to promise to install additional emissions control technologies.

- Control technologies are well understood and already in place in the large majority of electroplating shops. The remaining shops without control technologies have already had opportunities to install control measures.
- Electroplating operations are small and difficult to detect. Therefore, it is likely that some shops would not comply.

- Many electroplating operations are small, owner-operated companies that are unlikely to incur costs voluntarily for control technologies that do not have offsetting financial returns.

Ease of Enforcement

Environment Canada would need to identify all chromium plating operations. Mandatory or voluntary notification, possibly by suppliers, could facilitate identification. Regulations requiring pollution prevention plans are relatively straightforward to enforce.

Enforcement Costs

A key requirement for pollution prevention plans to be a credible management option is that the plans must be reviewed. Most likely this would be done by trained Environment Canada staff although, depending on confidentiality restrictions, other options might be available (multi-stakeholder review committees, making them open to public review, etc.).

The cost of review would likely not be that great if, as our survey suggests, the large majority of chromium electroplaters already have control technologies in place. In these cases, pollution prevention plans might consist largely of identification of the existing control technologies and operating conditions.

Cost Effectiveness

Pollution prevention plans would allow electroplaters to adopt whatever control strategies they deemed to be most cost effective. Various measures can minimize costs or provide savings.

Innovation Incentive

Pollution prevention plans allow electroplaters to adopt innovative technologies, although presumably the plans would need to include an assessment of the technologies' effectiveness.

Allowing Economic Growth

Pollution prevention plans would not constrain economic growth, except to the extent that electroplaters would incur costs in developing and implementing their plans.

Fairness

Pollution prevention plans do not necessarily create a level playing, unless the plans must involve a minimum level of control that all electroplaters must meet.

Minimizing Data Requirements

Environment Canada would need to have trained staff to assess the pollution prevention plans.

Jurisdictional Issues

The new CEPA is expected to provide Environment Canada authority to require pollution prevention plans. It is unclear at this point when reauthorization may occur.

Acceptability to Industry

Pollution prevention plans are likely to be criticised for creating much paperwork for electroplaters that have already taken measures to control HVC emissions.

10.5.3 Structured Agreements

Structured agreements are contracts negotiated by government and individual companies, sometimes with the involvement of other stakeholders. The agreements would specify the environmental protection actions required and the approach to measuring performance (e.g. quantity of emissions, concentration, technology-based, etc.). The agreements would also likely include provisions for monitoring and reporting to ensure compliance with the agreements. Depending on how they were structured, the agreements could be legally binding.

Environmental Effectiveness

Structured agreements could be used to reduce emissions at the largest sources, if they are willing to participate. They could be effective given that one source alone accounted for 45% of the emissions identified in our survey of companies. A structured agreement with this one source might be a way to reduce emissions quickly while the SOP evolves and the Ministers consider the Issue Table's recommendations.

No other source releasing emissions on a comparable scale was identified. It would not be very effective to enter into agreements with electroplaters responsible for small portions of total emissions, particularly those that already have some emission control technologies.

Entering into agreements with large sources now does not control emissions from any new electroplating operations. While agreements could be entered into with new entrants, this will require on-going monitoring of the sector by Environment Canada.

Ease of Enforcement

Enforcement of agreements with a few of the largest sources would be relatively easy.

Costs of Enforcement

Enforcement costs would be very low, since structured agreements would be entered into with only a few companies.

Cost Effectiveness

A structured agreement with the largest polluters could allow electroplaters to adopt cost effective control technologies as long as they were environmentally effective.

Innovation Incentive

Electroplaters would likely be able to negotiate whatever control technology they prefer as long as it was effective at reducing emissions.

Allowing Economic Growth

Structured agreements with the largest sources would place no limits on economic growth.

Fairness

Structured agreements with the largest sources of HVC emissions would help to level the playing field. However, smaller sources would continue to be exempt from any mandatory reduction requirements and could gain an unfair advantage. Since competition among electroplaters tends to be local, the extent to which this is a problem would have to be assessed individually for each large source. Electroplaters would likely raise these concerns during negotiations.

Minimizing Data Requirements

Data requirements would be minimal.

Jurisdictional Issues

Environment Canada has authority to enter into such structured agreements and has already signed memoranda of understanding with several sectors.

Acceptability to Industry

Direct discussions with the largest sources would be needed to assess their willingness to enter into structured agreements.

10.5.4 Voluntary Measures

Voluntary measures include voluntary codes of practice, guidelines, challenge measures and certification under ISO 14000 series standards. The incentive for companies to comply is limited to avoidance of regulations and, in some cases, positive publicity that goes with compliance.

Environmental Effectiveness

There are several reasons to believe that voluntary measures would not be effective. The first three also apply to mandatory pollution prevention plans.

- Control technologies are well understood and already in place in the large majority of electroplating shops. The remaining shops without control technologies have already had opportunities to install control measures.
- Electroplating operations are small and difficult to detect. Therefore, it is likely that some shops would not comply.
- Many electroplating operations are small, owner-operated companies that are unlikely to incur costs voluntarily for control technologies that do not have offsetting financial returns.
- There is no industry association likely to be effective at encouraging the adoption of control technologies in the minority of electroplating operations that do not already have them.

Ease of Enforcement

Voluntary measures would not be enforced *per se*. However, monitoring compliance could require effort comparable to that required for technology standards.

Enforcement Costs

Since voluntary measures would not be enforced *per se*, there would be no enforcement costs. However, in the event that compliance is not forthcoming voluntarily, there might be costs to develop regulations in the future.

Cost Effectiveness

Voluntary measures would be cost effective, since compliance is voluntary (though backed up with the possibility of command-and-control regulations).

Innovation Incentive

By not mandating any actions, voluntary measures would provide electroplaters flexibility to adopt any control technologies. On the other hand, a code of practice or guideline normally does not contain the full range of technology standards or options available.

Allowing Economic Growth

Voluntary measures would place no limits on economic growth.

Fairness

Voluntary measures might not be considered fair by the large majority of electroplaters that have already adopted control technologies, since there is no guarantee that the playing field would be levelled (i.e., competitors currently without controls would install controls).

Minimizing Data Requirements

Some voluntary measures, including codes of practice and guidelines, require as much information as would be required to develop a technology standard. Challenge measures require substantially less information.

Jurisdictional Issues

Environment Canada has authority to implement voluntary measures.

Acceptability to Industry

Electroplaters would probably prefer voluntary measures to technology standards, although some who have already installed control technologies may prefer technology standards to level the playing field.

10.5.5 Information Provision

Information provision consists of educational programs to inform electroplaters about the options to reduce HVC emissions and the costs and benefits associated with the options. Specific information provision tools range from technical reports, fact sheets and video tapes to certification of control technologies.

Environmental Effectiveness

Information provision might be effective *if lack of information about control technologies was the barrier preventing adoption of emission control technologies*. However, our research suggests that technologies to control HVC emissions are widespread and well understood. Cost appears to be the major factor a minority of operations have not installed emission control technologies.

Information provision might be effective if electroplaters with control technologies were not *operating* their control systems optimally. In this case, training system operators might encourage some emission reductions. However, there is no guarantee owners or operators would act on the information provided.

Ease of Enforcement

Information provision is not enforced.

Enforcement Costs

Information provision is not enforced and , therefore, has no enforcement costs.

Cost Effectiveness

Information provision imposes no mandatory requirements, thereby allowing electroplaters to undertake only cost effective actions. The information may in fact identify lower cost options to platers considering control technologies.

Innovation Incentive

Information provision is unlikely to have any impact on developing new technologies or other innovation. Its purpose is to disseminate existing knowledge.

Allowing Economic Growth

Information provision would not affect economic growth.

Fairness

Like all management options that do not mandate actions by the minority of electroplaters without control technologies, information provision does not create a level playing field. In that sense, information provision could be considered unfair.

Minimizing Data Requirements

Information provision requires data on options to control emissions, but does not necessarily require any data from individual electroplaters.

Jurisdictional Issues

Environment Canada has authority to implement information provision programs and has already done so in the past with the electroplating industry. These programs may be combined with other information programs which have had some success.

Acceptability to Industry

Industry is generally quite receptive to information provision programs when funded by government. Joint funding with industry should be explored if this management option is pursued.

10.6 Ranking of Management Options and Conclusions

The technical, environmental and economic factors associated with HVC emissions from electroplating constrains the list of potentially applicable management options to a relative small number, namely:

- mandatory technology standards;
- mandatory pollution prevention plans;
- structured agreements;

- voluntary measures; and
- information provision.

The following table summarizes the assessment of these five management options. Using letters (A = most preferred, E = least preferred), the table grades the management options according to each assessment criterion.

The criteria are not explicitly weighted because each stakeholder at the Issue Table may attach different importance to each criteria. Nonetheless, the recommendations do reflect a weighting system. Most importantly, environmental effectiveness was weighed most heavily, consistent with the purpose of the SOP. Other important criteria are ease of enforcement, fairness and acceptability to industry.

The assessment criteria that are deemed less important are listed below.

- *Innovation Incentive:* Little need for need for new control technologies was identified. Control technologies are well demonstrated, widely available and, given their currently high rate of use, economically achievable by the large majority of electroplaters. None of the management options provide direct incentives for innovation, although most provide electroplaters flexibility in which control technologies they can adopt.
- *Allowing Economic Growth:* This criterion is usually important in air quality-limited areas where caps on emissions are necessary to prevent further deterioration in air quality. None of the potentially applicable management options limit economic growth, except to the extent that installation of control technologies would require some expenditures on the part of electroplaters. Differences in emission standards (as well as monitoring requirements) for electroplaters in different jurisdictions may also influence business competitiveness. For example, lower emission limits in the U.S. may provide Canadian electroplaters with a competitive advantage.
- *Jurisdictional Issues:* Environment Canada has authority now to implement four of the five management options. The proposed CEPA would provide authority to implement the fifth management option, mandatory pollution prevention plans.

Grading of Management Options

Criterion	Mandatory Technology Standards	Mandatory Pollution Prevention Plans	Structured Agreements	Voluntary Measures	Information Provision
Environmental Effectiveness	A	D	B	E	E
Ease of Enforcement	C	C	A	A	A
Enforcement Costs	D	D	B	B	A
Cost Effectiveness	C	B	B	A	A
Innovation Incentives	D	C	C	C	C
Allowing Economic Growth	B	B	B	A	A
Fairness	A	C	B	E	E
Minimizing Data Requirements	C	E	B	C	C
Jurisdictional Issues	A	B	A	A	A
Acceptability to Industry	C	D	For Discussion with Major Emitters	A	A

The major conclusions are as follows.

Environmental Effectiveness: On the basis of heavily weighing environmental effectiveness, mandatory technology standards are clearly preferred. Structured agreements may be useful for reducing emissions quickly at the largest sources (particularly the one operation identified in our survey).

Ease and Costs of Enforcement: Enforcement of structured agreements and measures that are, by definition, not enforced (voluntary measures and information provision) are relatively easy and inexpensive to enforce. Mandatory technology standards and mandatory pollution prevention plans require potential enforcement at each electroplater.

Cost Effectiveness: Emission control technologies for electroplating operations are well established. The key to cost effectiveness is to allow electroplaters' flexibility in adopting the most cost effective control strategy for their operations. Mandatory technology standards are the only tool that may limit this flexibility, however, flexibility can be built in by allowing choices between acceptable control technologies.

Fairness: Mandatory technology standards would do the most to ensure that electroplaters who are not already using control technologies take steps to reduce emissions. Structured agreements with the largest sources would address some of these electroplaters, but not all. Voluntary measures and information provision provide no assurance that control measures will be adopted by any electroplater. Mandatory pollution prevention plans could provide some assurance if they were accompanied by minimum requirements for the plans.

Minimizing Data Requirements: Mandatory technology standards, information provision and certain voluntary measures (codes of practice and guidelines) all require detailed understanding of the emission control options available to electroplaters. Mandatory pollution prevention plans require a relatively large amount of information from each electroplater, as well as trained staff to review the information. Structured agreements would require little information other than identifying the largest sources.

Acceptability to Industry: Industry is likely to prefer measures without mandatory requirements (voluntary measures and information provision). Mandatory technology standards would require all electroplaters to review their compliance with the standards, but would not necessarily require any submissions (depending on design, some reporting could be required). Pollution prevention plans would likely be the least acceptable to industry, given the paperwork involved.

The assessment suggests the following conclusions.

Mandatory technology standards are the most environmentally effective management option, given enforcement resources at levels comparable to similar regulations. They will, however, be unlikely to generate industry support except perhaps from electroplaters with control technologies who face competition from electroplaters without control technologies.

Structured agreements might be pursued with the largest current sources of HVC emissions. Substantial emission reductions are possible, if large sources can be accurately identified (the survey identified one). However, structured agreements do not address emissions on an on-going or long-term basis.

Mandatory pollution prevention plans are unlikely to be environmentally effective unless minimum requirements are stipulated. monitoring and enforcement costs could be as high as mandatory technology standards. Industry is likely to strongly oppose this management option. Proposed, but not yet promulgated, changes to CEPA would provide full authority to implement pollution prevention plans.

Voluntary measures and *information provision* are unlikely to be environmentally effective.

11. Overview of Regulatory Environment

11.1 Summary

There are no Canadian federal regulations or guidelines directly relating to hexavalent chromium air emissions from electroplating facilities¹⁵. However, certain provinces and municipalities have regulations or by-laws relating to potential emissions of HVC. Under these regulations, electroplaters operate with provincially administered permits or Certificates of Approvals. Typically these regulations stipulate stack concentrations or point of impingement concentrations¹⁶.

Identified Canadian Provincial and Municipal Regulations

Provincial	Limits
Quebec	Stack: 2 mg/m ³
Ontario	Point of impingement 5 µ/m ³
Municipal	
Montreal Urban Community (MUC)	Stack: 2 mg/m ³
Greater Vancouver Regional District (GVRD)	Stack 0.5 mg/m ³
Toronto	Point of impingement 5 µ/m ³

The Ministère de l'Environnement et de la Faune du Québec (MEF) is reviewing its air emission concentration limits in order to establish an "air quality by-law" which should be in application by the fall of 1997. The MEF will maintain the same air emissions concentration limit for HVC (2 mg/m³) as its actual guideline.

¹⁵ Environment Canada: Peter Paine, Chemical Industries Division

¹⁶ *ibid.*

11.1.1 US EPA Air Toxics Rule

The US EPA has proposed the industry apply stringent Maximum Available Control Technology (MACT) to reduce air emissions of HVC. These would apply to both decorative and functional (hard) chrome plating facilities¹⁷.

Summary of US EPA MACT Standards for Chromium Electroplating and Anodizing Facilities

Process	Emission Limit
Existing small hard chromium plating	0.03 mg/m ³
Existing large & all new hard chromium plating	0.015 mg/m ³
New and existing decorative chromium plating and chromic acid anodizing	0.01 mg/m ³
Alternate for decorative chromium plating and chromic acid anodizing	No emission limit. Maintain surface tension below 45 dynes/cm
All new and existing decorative chromium plating using trivalent chromium	No emission limit. No surface tension monitoring. Notification of presence of process.

¹⁷

Environment Canada: Peter Paine, Chemical Industries Division

11.2 Final US EPA Air Toxics Rule for Chromium Emissions

The following section is a duplicate copy of US EPA's summary Fact Sheet of the final air toxics rule for chromium emissions from hard and decorative electroplating and anodizing operations, published on November 15, 1994. It is included here for reference.

November 15, 1994

FACT SHEET

FINAL AIR TOXICS RULE FOR CHROMIUM EMISSIONS FROM HARD AND DECORATIVE ELECTROPLATING AND ANODIZING OPERATIONS

TODAY'S ACTION...

- ◆ The Environmental Protection Agency (EPA) is issuing a final rule to reduce air toxics emissions from chromium electroplating and anodizing operations. Air toxics are those pollutants known or suspected of causing cancer or other serious illnesses.
- ◆ Chromium electroplating and anodizing operations coat metal parts and tools with a thin layer of chromium to protect them from corrosion and wear. Air toxics are released during this process.

WHAT ARE THE HEALTH AND ENVIRONMENTAL BENEFITS?

- ◆ The final rule will reduce emissions of chromium, an air toxic, by 173 tons annually, representing a 99% reduction.
- ◆ There is strong evidence to conclude that hexavalent chromium causes lung cancer in humans.

WHY IS EPA REGULATING CHROMIUM ELECTROPLATING AND ANODIZING OPERATIONS?

- ◆ Under the Clean Air Act Amendments of 1990, EPA is required to regulate emissions of 189 listed toxic air pollutants. On July 16, 1992, EPA published a list of source categories that emit one or more of these air toxics. For listed categories of "major" sources (those that emit 10 tons/year or more of a listed pollutant or 25 tons or more of a combination of pollutants), the Act requires EPA

to develop standards that will require the application of maximum achievable control technology (MACT). "Area" sources are those that emit air toxics below the levels defined for major sources.

- ◆ On July 16, 1992, EPA published a list of industry groups (known as "source categories") to be regulated, which included major and area sources of hard and decorative chromium electroplating and chromium anodizing operations.

WHO WILL BE AFFECTED BY THIS RULE?

- ◆ There are an estimated 1,500 hard chromium electroplating facilities, 2,800 decorative chromium electroplating facilities, and 700 chromium anodizing facilities nationwide that will be affected by this regulation.
- ◆ Hard chromium electroplated parts include large cylinders and industrial rolls used in construction equipment and in printing presses; decorative chromium plated parts include appliances such as toasters, various hand tools, and automotive parts; anodized parts include miscellaneous aircraft parts, including wings and landing gears.
- ◆ The vast majority of the facilities covered by this rule electroplate parts for other industry manufacturers.

WHAT DOES THE FINAL STANDARD REQUIRE?

- ◆ A major source is any chromium electroplating or anodizing operation that emits more than 9.1 megagrams of chromium compounds per year (Mg/yr) [10 tons per year (ton/yr)]. Sources that emit less than this cutoff value are considered area sources.
- ◆ The majority of all chromium electroplating and anodizing sources are considered to be area sources.
- ◆ Owners or operators of new hard chromium electroplating tanks would be required to meet an emission limit of 0.015 milligrams of total chromium per dry standard cubic meter (mg/dscm) (6.6×10^{-6} grain per dry standard cubic foot [gr/dscf]) of ventilation air. This standard is based on the application of the composite mesh-pad system.
- ◆ Owners or operators of existing hard chromium electroplating tanks at facilities with maximum cumulative potential rectifier capacities less than 60 million ampere-hours per year (Ah/yr) would be required to meet an emission limit of

0.03 mg/dscm (1.3×10^{-5} gr/dscf), which is based on the application of packed-bed scrubbers.

- ◆ Owners or operators of existing hard chromium electroplating tanks at facilities with maximum cumulative potential rectifier capacities greater than or equal to 60 millionAh/yr would be required to meet an emission limit of 0.015mg/dscm (6.6×10^{-6} gr/dscf), which is based on the use of the composite mesh-pad system.
- ◆ All new and existing decorative chromium electroplating tanks that use a chromic acid plating process would be required to: (1) meet a total chromium emission limit of 0.01 mg/dscm (4.4×10^{-6} gr/dscf); or (2) use a wetting agent type fume suppressant in the plating bath and maintain a bath surface tension no greater than 45 dynes per centimeter (dynes/cm) (3.1×10^{-3} pound force per foot [lb_f/ft]).
- ◆ All new and existing decorative chromium electroplating operations that use a trivalent chromium plating process that incorporates a wetting agent are required to notify EPA that the trivalent chromium process is being used, and must provide the bath components that comprise the trivalent chromium bath. Subsequent notification is required if a change is made to the bath such that a different standard applies to the tank.
- ◆ All new and existing chromium anodizing operations would be required to: (1) meet an emission limit of 0.01 mg/dscm (4.4×10^{-6} gr/dscf); or (2) use a wetting agent type fume suppressant in the plating bath and maintain a surface tension of no greater than 45 dynes/cm (3.1×10^{-3} lb_f/ft).

Monitoring Requirements

- ◆ All owners or operators must conduct an initial performance test to demonstrate compliance with the emission limit unless the affected source is a decorative chromium electroplating or chromium anodizing tank that uses a wetting agent type fume suppressant and maintains a surface tension of no greater than 45 dynes/cm (3.1×10^{-3} lb_f/ft). During a performance test, the owner or operator must establish values for an operating parameter (e.g., pressure drop) that is subsequently monitored on a daily basis to ensure continued compliance. In the case of packed-bed scrubbers, pressure drop across the unit and the velocity pressure at the inlet to the control device must be monitored on a daily basis. In the case of composite mesh-pad and fiber-bed mist eliminator systems, pressure drop across the unit must be monitored on a daily basis. Operation of a control device outside of the operating parameter value ranges established in accordance with the rule is a violation of the standard.

- ◆ All owners or operators that choose to comply with the emission limit by using a foam blanket must conduct an initial performance test to demonstrate compliance with the standard. Ongoing compliance is to be demonstrated by maintaining a foam blanket thickness of 2.5 centimeters (1 inch), or alternate thickness as established during the performance test. Foam blanket thickness is initially to be measured and recorded at least once every hour during tank operation. Monitoring frequency can decrease to once every 8 hours of tank operation, as allowed by the rule. Operation of the electroplating or anodizing tank below the acceptable foam blanket thickness constitutes noncompliance with the standard.
- ◆ All owners or operators that choose to comply with the surface tension requirements must either establish system-specific surface tension limits through a performance test or adhere to the limits established by the standards. Surface tension is initially to be measured and recorded at least once every 4 hours during tank operation. Monitoring frequency can decrease to once every 40 hours of tank operation, as allowed by the rule. Operation of the electroplating or anodizing tank above the acceptable surface tension constitutes noncompliance with the standards.
- ◆ Work practice standards require all owners or operators of affected tanks to prepare and follow an operation and maintenance plan to ensure that equipment or process malfunctions due to poor maintenance or other performance conditions do not occur.
- ◆ Operation and maintenance plans require the following: a standardized checklist to document the inspection and maintenance of the equipment, a systematic procedure for identifying malfunctions, and procedures to be followed to ensure that equipment or process malfunctions due to poor maintenance or other preventable conditions do not occur. Owners/operators must perform quarterly inspections of the add-on air pollution control devices and monitoring equipment expected to be used to comply with the standards.

Recordkeeping/Reporting

- ◆ The owner/operator of a tank that uses an add-on air pollution control device to meet an emission standard is required to maintain records of inspections and maintenance, daily velocity pressure and/or pressure drop readings, and any emission tests at the facility. All records should be maintained for a minimum of 5 years. Each inspection record would identify the device inspected and include the following: the date and approximate time of inspection, a brief description of the working condition of the device during the inspection, and any actions taken to correct deficiencies found during the inspection.
- ◆ The owner/operator of a tank that uses a fume suppressant to comply with the standard would be required to maintain the following records at the facility for at least 5 years: the date and time of fume suppressant maintenance additions; the surface tension of the bath or measurements of foam blanket thickness, as applicable; and any emission tests to assure compliance with the standard. Each record of a surface tension measurement would identify the tank and include the date, approximate time, and measured surface tension. Each record of a foam blanket thickness measurement would identify the tank and include the date, approximate time, and measured thickness.
- ◆ The owner/operator of a tank that uses a trivalent chromium plating process that incorporates a wetting agent would be required to maintain records of the bath chemicals purchased, with the wetting agent clearly identified as a bath component, for at least 5 years.
- ◆ All owners or operators of affected tanks are required to submit an initial notification that the source is subject to the standards no later than 180 days after the effective date. A notification of compliance status, including the results of performance tests, must be submitted by all owners and operators no later than 90 days after the completion of the performance demonstration, or no later than 30 days after the compliance date if no performance test is required by the rule.
- ◆ All owners or operators of any affected source, other than a decorative chromium electroplating tank that uses a trivalent chromium plating process, that is located at a major source site must submit semi-annual reports of the ongoing compliance status. If the affected source is located at an area source site, an ongoing compliance status report must be prepared annually and maintained onsite.

HOW MUCH WILL THE FINAL RULE COST?

- ◆ For existing hard chromium plating operations, the total nationwide capital cost is projected to be about \$45 million. The nationwide annualized cost is estimated to be \$22 million. No capital costs or increased annualized costs are anticipated for existing decorative chromium plating operations and existing chromium anodizing operations.

FOR MORE INFORMATION...

Anyone with a computer and a modem can download the rule from the Clean Air Act board of EPA's electronic Technology Transfer Network bulletin board by calling (919) 541-5742. For further information about how to access the board, call (919) 541-5384. For further information about the rule, contact Lalit Banker at (919) 541-5420.

12. Bibliography

1. Cropper, M.L. and A.M. Freeman III, "Environmental Health Effects", *Measuring the Demand for Environmental Quality*, 1991.
2. Fisher, A., L.G. Chestnut, and D.M. Violette, "The Value of Reducing Risks of Death: A Note On New Evidence", *Journal of Policy Analysis and Management* 8(1) 88-100, 1989.
3. Hagler Bailly Consulting Inc., Environmental and Health Benefits of Cleaner Vehicles and Fuels - Supplemental Report 3: Selected Economic Evidence of Monetary Valuation of Human Health Effects, prepared for the Canadian Council of Ministers of the Environment, October 1995
4. Memorandum from Peter Paine to SOP Issue Table Members; MFIT Meeting No. 7, November 12, 1996, Montreal Quebec.
5. Miller, T.R., "Willingness to Pay Comes of Age: Will the System Survive?", *Northwestern University Law Review* 83: 876-907, 1989.
6. Minutes from Metal Finishing Issue Table meeting number 7, November 12, 1996.
7. Technical Assessment Of New Emission Control Technologies Used In The Hard Chromium Electroplating Industry, Industries Studies Branch (Prepared by Midwest Research Institute), Office of Air Quality and Standards, US EPA, Research Triangle Park, NC, 27711, July 1993, EPA No. 453-R-93-031.
8. US EPA, Fact Sheet, Final Air Toxics Rule For Chromium Emissions From Hard And Decorative Electroplating And Anodizing Operations
9. Practical Pollution Prevention Guide Chromium Emission Reduction For Electroplaters And Anodizers, Program for Toxic Air Pollutant Studies, University of Northern Iowa, Copyright 1993, Iowa Waste Reduction Center, University of Northern Iowa.
10. Vandenberg, John., Smith, Andrew., & Blanchard, Karen. *Exposure and Risk Assessment of Chromium Electroplaters*, U.S. EPA, June 1989.
11. Viscusi, W.K., "Fatal Tradeoffs: Public and Private Responsibilities for Risk", Oxford University Press, 1992