ADDENDUM TO "ESTIMATES OF POPULATION EXPOSURE
TO AMBIENT CHROMIUM EMISSIONS" OCTOBER 1983 FINAL REPORT

July 1984

Prepared for:

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1.0 INTRODUCTION

The purpose of this Addendum is to present chromium emissions and exposure information that has been developed subsequent to the finalization of the October 1983 chromium exposure report, "Estimates of Population Exposure to Ambient Chromium Emissions." The source categories for which information is presented include cooling towers and chromium electroplating. Cooling towers were assessed in the October 1983 exposure study while chromium electroplating was not.

An additional examination of these two source categories was made primarily because both are sources of hexavalent chromium emissions. For the cooling tower source category, the Addendum presents data on the estimated total quantity of chromium that could be emitted into air nationwide. An approach to estimate total national emissions is explained, key assumptions and input data are presented, and calculations leading to the final chromium emission estimate are shown. No exposure assessments were conducted for cooling towers because of a lack of key data such as the number, sizes, and locations of sources, and the number of towers using chromium corrosion inhibitors.

The discussion of chromium emissions from chromium electroplating is organized very similar to the cooling tower discussion. Total national chromium emissions from chromium electroplating are estimated and the accompanying estimation methodologies, assumptions, and calculations are presented. In addition, an attempt has been made to assess the national exposure to chromium emissions from chromium electroplating using the Human Exposure Model, a chromium electroplating model plant, a representative subset of source locations, and an extrapolation of the subset to the total population of approximately 10,000 platers. All information pertinent to the exposure assessment is presented in the Addendum.

2.0 COOLING TOWERS

This section of the Addendum presents the methodology used to calculate an estimate of national chromium emissions from cooling towers and the results of that calculation. The primary method used to calculate chromium emissions from cooling towers is based on an analysis of the energy consumed by utilities and industry, the waste heat produced by this energy consumption, and the quantity of water required to reject this heat. Each step of the emission estimating process is described below.

The first input to the chromium emission estimating process is to determine fuel consumption in the utility and industrial sectors. These data for 1983 are as follows.[1]

Utilities

Coal - 13.226 x 10^{15} Btu consumed

Oil - 1.544 x 10^{15} Btu consumed

Gas - 3.011 x 10^{15} Btu consumed

Nuclear - 3.235 x 10^{15} Btu consumed

Industry

Coal - 2.458 x 10^{15} Btu consumed

Oil - 6.763 x 10^{15} Btu consumed

Gas - 7.733 x 10^{15} Btu consumed

For utilities the assumption was made that all consumed energy went to produce electricity. The efficiency of the electricity-generating process is only about 30 percent, such that 70 percent of the consumed heat energy is lost as waste heat. Of the 70 percent waste heat fraction, 10 percent is heat losses in the plant and 60 percent is heat rejected in cooling towers,

3

cooling ponds, or by once-through cooling.[2] The total quantity of waste heat from utilities to be rejected by cooling is calculated as follows.

$$(21.016 \times 10^{15} \text{ Btu}) \times 0.60 = 12.6096 \times 10^{15} \text{ Btu}$$

The fraction of heat rejected by various cooling means at utilities is shown below.[3]

Cooling towers - 70 percent
Cooling ponds - 20 percent
Once-through cooling - 10 percent

For industry the assumption is not made that all energy consumed goes to produce energy in the forms of steam and electricity. In industry, energy (as coal, oil, and gas) is consumed as a process raw material and there are direct fired sources that just burn fuel for heat. The estimated fractions of industrial energy consumption that are used for energy (steam or electricity) production are as follows.[4]

Coal - 30 percent
Oil - 70 percent
Gas - 50 percent

The energy conversion efficiency in the industrial sector is assumed to be about 40 percent. Like the utility sector, 10 percent is lost within the plant as heat and the remaining 50 percent is rejected as waste heat in cooling towers.

For industry, the amount of waste heat to be rejected in cooling towers can be calculated as shown below.

Coal: 2.458×10^{15} Btu

         $\underline{\quad\quad\quad \times 0.30}$

         7.374×10^{14} Btu to Energy

         $\underline{\quad\quad\quad \times 0.50}$

         3.687×10^{14} Btu as Waste Heat

Oil: 7.733×10^{15} Btu

         $\underline{\quad\quad\quad \times 0.70}$

         5.413×10^{15} Btu to Energy

         $\underline{\quad\quad\quad \times 0.50}$

         2.707×10^{15} Btu as Waste Heat

Gas: 6.763×10^{15} Btu

         $\underline{\quad\quad\quad \times 0.50}$

         3.382×10^{15} Btu to Energy

         $\underline{\quad\quad\quad \times 0.50}$

         1.691×10^{15} Btu as Waste Heat

Total as Waste Heat = 4.766×10^{15} Btu

To determine the quantity of water required to reject the heat loads in the utility and industry sectors, the following equation is used.

Heat Rejected (Q_R) = Mass Water (W) x (1 Btu/lb • F°) x Temperature
    Change to be Effected ($\Delta T°$)

The $\Delta T°$ value in the equation represents the temperature differential between the incoming hot water containing waste heat from combustion and the effluent water stream to be discharged or recycled to the plant. The $\Delta T°$ to be achieved varies from plant to plant. For the purposes of these emission estimation calculations, $\Delta T°$ is assumed to be 40°F, i.e., water temperature is being decreased from 120°F to 80°F.

5

The results of applying this equation to the waste heat loads calculated from the utility and industry sectors is given below.

Utilities

$$Q_R = 12.6096 \times 10^{15} \text{ Btu}$$

$$(12.6096 \times 10^{15} \text{ Btu}) = W_u \text{ (1 Btu/lb F°) (40°F)}$$

$$W_u = 3.1524 \times 10^{14} \text{ lb water}$$

Seventy percent of W_u in the utility sector goes to cooling towers and is expressed as W_u'.

$$W_u' = (3.1524 \times 10^{14} \text{ lb}) \times 0.70 = 2.2067 \times 10^{14} \text{ lb water}$$

Of the total quantity W_u', some fraction occurs as cooling tower drift. Drift is entrained water droplets that are mechanically formed in the tower and carried out into ambient air by the cooling tower air flow. The quantity of drift formed and released is a function of several factors including:

- the quantity of heat to be rejected,
- tower air flow,
- tower design, and
- ambient meteorological conditions.

The amount of drift occurring from a tower is generally designed to be a percentage of the total quantity of water recirculating in the tower. Drift fraction like the $\Delta T°$ value is site specific and very difficult to typify for all sources. Drift losses reported in the literature range from 0.002 - 0.2 percent. For the purposes of these calculations a drift fraction of 0.01 percent is assumed.

$(2.2067 \times 10^{14} \text{ lb water}) \times 0.0001 = 2.2067 \times 10^{10}$ lb water emitted as drift

2.2067×10^{10} lb water $\times \dfrac{1 \text{ gal}}{8.3 \text{ lb}} = 2.659 \times 10^9$ gal water as drift

This quantity of drift is assumed to contain 20 ppm chromium (as chromates) based on typical values reported in the literature.[5-7]

$(2.659 \times 10^9 \text{ gal}) \times 0.00002 = 5.318 \times 10^4$ gal chromium

To calculate the mass of chromium emitted in the drift, the typical density of the various proprietary chromate corrosion chemicals would have to be known. This value is unavailable, therefore, the density of sodium chromate was used for the purposes of these calculations since it is a raw material in the production of the corrosion inhibiting chemicals. The total quantity of chromium calculated to be emitted from utility cooling towers is shown below.

$(5.318 \times 10^4 \text{ gal}) \times 22.67 \text{ lb/gal} =$ approximately 600 tons of chromium as sodium chromate

The quantity of hexavalent chromium contained in this 600 tons is approximately 192 tons.

$\underline{\text{Utility Cooling Tower Emissions of } Cr^{+6} \cong 192 \text{ tons}}$

This estimated total of 192 tons is an upper bound because it assumes that all towers use chromium corrosion inhibitors. No information could be developed to approximate the fraction of utility towers using chromium.

Industry

The same methodology described above for utilities was also applied to the waste heat load estimated for industry of 4.766×10^{15} Btu. The calculations are briefly illustrated below.

(1) $(4.766 \times 10^{15}$ Btu$) = W_i$ (1 Btu/lb F°) (40°F)
$W_i = 1.1915 \times 10^{14}$ lb water to cooling towers

(2) $(1.1915 \times 10^{14}$ lb$) \times \dfrac{1 \text{ gal}}{8.3 \text{ lb}} = 1.4355 \times 10^{13}$ gal water

(3) $(1.4355 \times 10^{13}$ gal$) \times 0.0001 = 1.4355 \times 10^9$ gal water as drift

(4) $(1.4355 \times 10^9$ gal$) \times 0.00002 = 2.871 \times 10^4$ gal chromium

(5) $(2.871 \times 10^4$ gal$) \times 22.67$ lb/gal = approximately 325 tons of chromium as sodium chromate

The quantity of hexavalent chromium contained in this 325 tons is approximately 104 tons.

Industrial Cooling Tower Emissions of $Cr^{+6} \cong 104$ tons

This estimated total, like that from utility towers, is an upper bound because it assumes that all towers use chromium corrosion inhibitors.

The total amount of Cr^{+6} estimated to be released from utility and industrial cooling towers, assuming all use chromium corrosion inhibitors, equals 296 tons/yr.

Additional information is available in reference 2 from which to calculate another estimate of chromium emissions from utility cooling towers. The different estimate is based on a cooling water requirement

presented in the reference that is different from that calculated by the heat capacity equation. Reference 2 reports that 0.16 m^3 water are needed for cooling at utilities per kWh of power produced. According to Department of Energy statistics, power plants producing electricity and requiring cooling water generated 1,971,698 x 10^6 kWh of electricity in 1983. Total water requirements can be calculated as follows.

$$(1) \quad (1,971,698 \times 10^6 \text{ kWh}) \times \frac{0.16 \text{ m}^3}{\text{kWh}} = 3.1547 \times 10^{11} \text{ m}^3$$

$$(2) \quad 3.1547 \times 10^{11} \text{ m}^3 \times \frac{264.2 \text{ gal}}{\text{m}^3} = 8.3347 \times 10^{13} \text{ gal water}$$

Of this amount of water, 70 percent is used for cooling towers.

$$0.70 \times (8.3347 \times 10^{13} \text{ gal}) = 5.8343 \times 10^{13} \text{ gal}$$

Assuming a 0.01 percent drift fraction, total drift can be calculated as follows.

$$0.0001 \times (5.8343 \times 10^{13} \text{ gal}) = 5.8343 \times 10^9 \text{ gal}$$

By applying the chromium concentration in drift of 20 ppm and the sodium chromate density factor used in the previous emission estimating calculations, a chromium (as Cr^{+6}) emission rate from utility cooling towers of approximately 423 tons/yr can be calculated. This emission rate, like that in the previous calculations, represents an upper bound because it assumes that all utility cooling towers use chromium corrosion inhibiting chemicals.

If the 423 tons/yr chromium emission number for utility cooling towers is used in the emission estimating assessment, the range of hexavalent chromium emissions from utility and industrial cooling towers would be 296 - 527 tons/yr.

It is expected that this range overstates emissions because it assumes all utility cooling towers use chromium, but most references indicate that utilities use much less chromium than industry.[8-11] Quantitative data on chromium usage is generally not available; however, the Electric Power Research Institute (EPRI) has indicated that it has such data on its member utilities but the information is confidential and cannot be released.[12]

3.0 CHROMIUM ELECTROPLATING

3.1 PROCESS DESCRIPTION

Chromium is plated onto various substrates in order to provide a decorative and corrosion resistant surface. Steel, brass, aluminum, plastics, and zinc die castings may serve as substrates. The two major types of chromium plating are decorative and hard. Decorative plate consists of a thin (0.25 µm thick) layer of chromium which is applied over a layer of nickel to provide a bright, tarnish-resistant surface. Decorative chrome plate is popular for consumer items such as auto trim. Hard plating produces a thicker chromium layer (10 to over 300 µm thick) which has excellent hardness and wear-resistance and a low coefficient of friction.[13,14] Applications include drills, reamers, burnishing bars, drawing plugs or mandrels, drawing dies, plastic molds, gages, pump shafts, rolls and drums, hydraulic rams, and printing plates.[15] The electroplating process used to produce the two types of chromium plates are similar.

Figure 1 provides a generalized flow chart for decorative chromium plating on a steel substrate. Figure 2 shows the hard plating process, for which steel is the usual substrate. Possible variations on the processes shown in Figures 1 and 2 are discussed below. Plating operations generally involve dipping the substrate into tanks containing various solutions. The substrate items may be moved between tanks manually or using automation. The decorative and hard plating processes both involve cleaning and preparing the substrate followed by the electrodeposition of chromium. It should be noted that rinsing is carried out between every cleaning and plating step. When a part being plated is moved from one tank to the next, some of the solution from the first tank will remain on the part and be transferred to the next tank. This process is termed drag-in, and rinsing between plating steps is necessary to reduce contamination of plating solutions by drag-in.
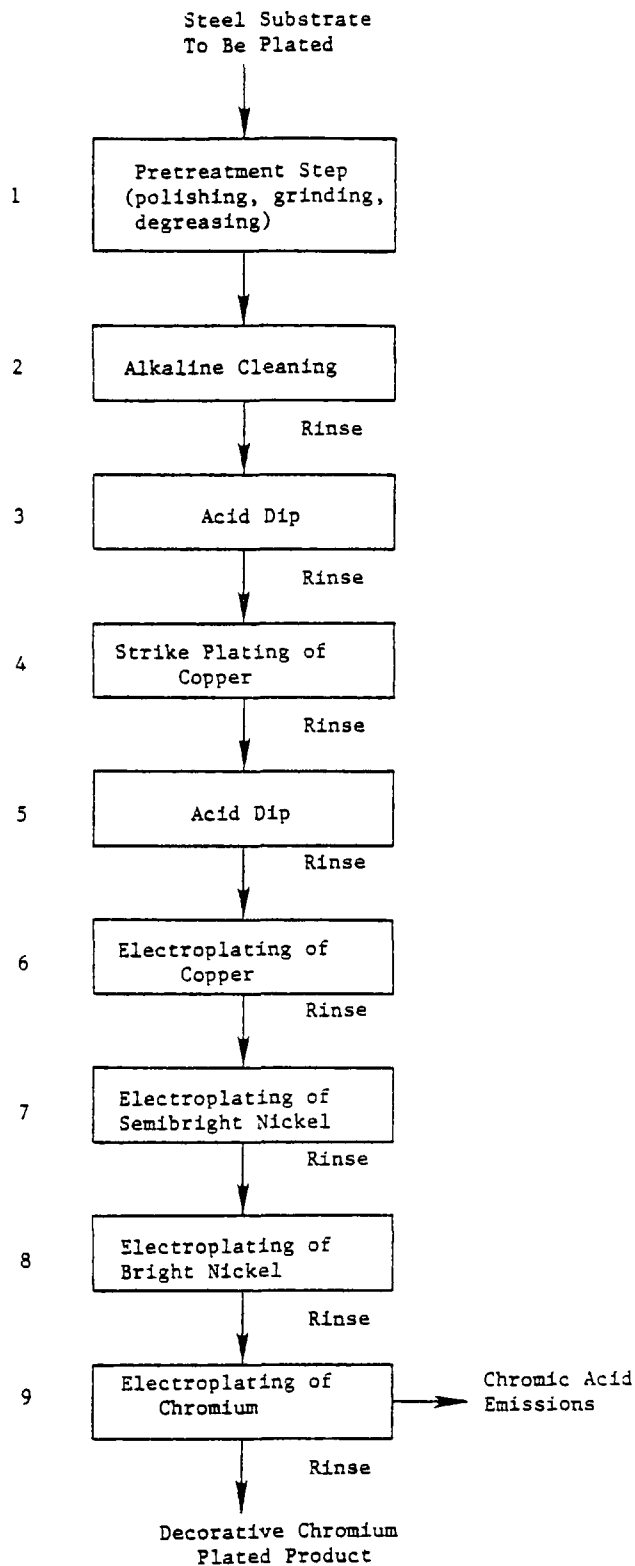
```
                    Steel Substrate
                    To Be Plated

                           |
                           v
          ┌──────────────────────────────┐
          │      Pretreatment Step        │
     1    │   (polishing, grinding,       │
          │        degreasing)            │
          └──────────────────────────────┘
                           |
                           v
          ┌──────────────────────────────┐
     2    │      Alkaline Cleaning        │
          └──────────────────────────────┘
                           |  Rinse
                           v
          ┌──────────────────────────────┐
     3    │           Acid Dip            │
          └──────────────────────────────┘
                           |  Rinse
                           v
          ┌──────────────────────────────┐
     4    │      Strike Plating of        │
          │           Copper              │
          └──────────────────────────────┘
                           |  Rinse
                           v
          ┌──────────────────────────────┐
     5    │           Acid Dip            │
          └──────────────────────────────┘
                           |  Rinse
                           v
          ┌──────────────────────────────┐
     6    │      Electroplating of        │
          │           Copper              │
          └──────────────────────────────┘
                           |  Rinse
                           v
          ┌──────────────────────────────┐
     7    │      Electroplating of        │
          │      Semibright Nickel        │
          └──────────────────────────────┘
                           |  Rinse
                           v
          ┌──────────────────────────────┐
     8    │      Electroplating of        │
          │        Bright Nickel          │
          └──────────────────────────────┘
                           |  Rinse
                           v
          ┌──────────────────────────────┐       Chromic Acid
     9    │      Electroplating of        │ ───>  Emissions
          │          Chromium             │
          └──────────────────────────────┘
                           |  Rinse
                           v
                  Decorative Chromium
                    Plated Product
```

[15]

Figure 1. Flow chart for decorative chromium plating on a steel substrate.

Substrate to be
Plated

↓

```
        ┌─────────────────────────────┐
   1    │ Pretreatment Step           │
        │ (Polishing, grinding,       │
        │ degreasing)                 │
        └─────────────────────────────┘
```

↓

```
        ┌─────────────────────────────┐
   2    │ Alkaline Cleaning           │
        └─────────────────────────────┘
```

Rinse
↓

```
        ┌─────────────────────────────┐
   3    │         Acid Dip            │
        └─────────────────────────────┘
```

Rinse
↓

```
        ┌─────────────────────────────┐        Chromic Acid
   4    │ Chromic Acid                │ ──────▶ Emissions
        │ Anodic Treatment            │
        └─────────────────────────────┘
```

Rinse
↓

```
        ┌─────────────────────────────┐        Chromic Acid
   5    │ Electroplating of           │ ──────▶ Emissions
        │ Chromium                    │
        └─────────────────────────────┘
```

Rinse
↓

Hard Chromium Plated
Product
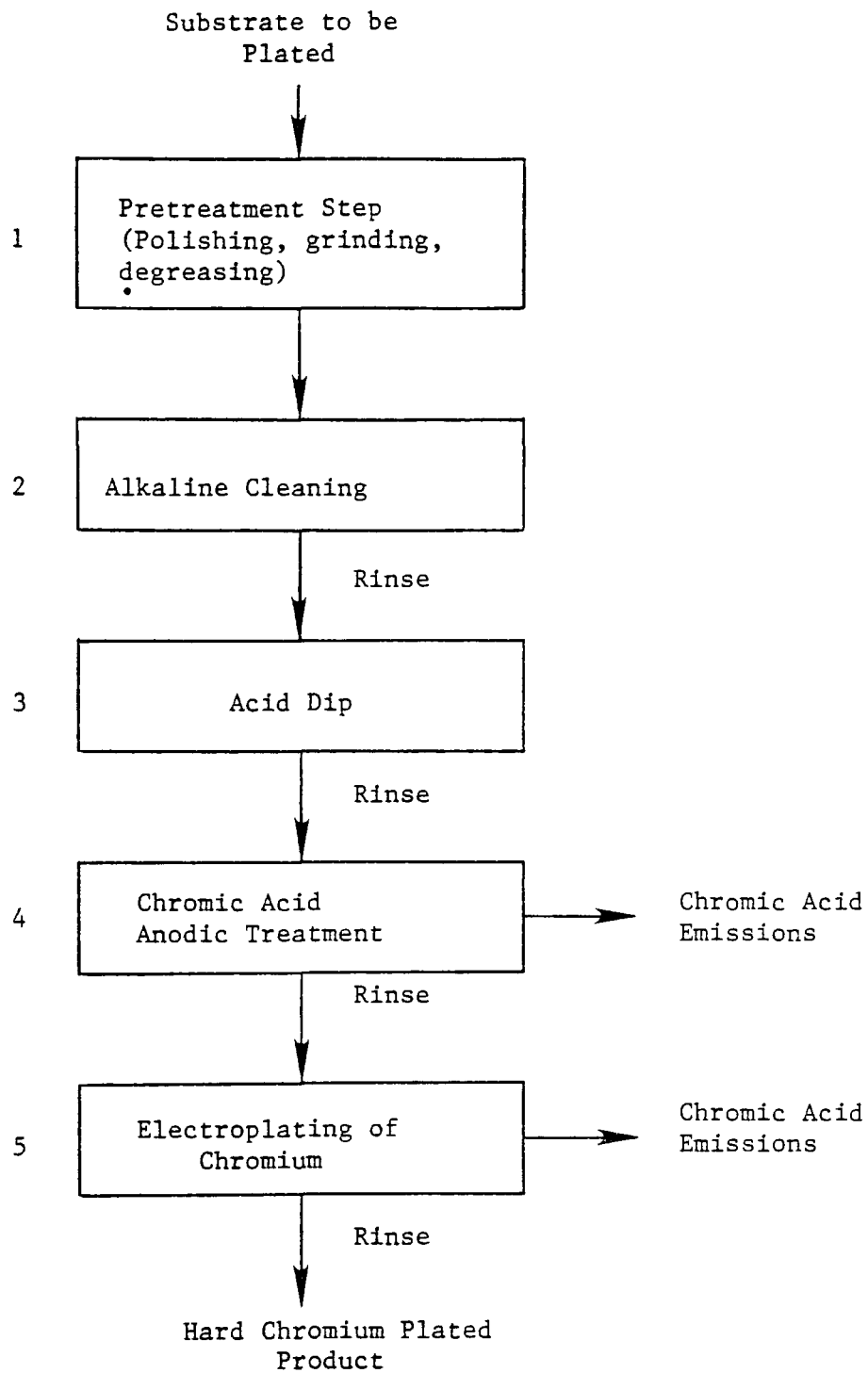
Figure 2 .   Flow chart for hard chromium plating.[15]

13

The chromium plating processes start with a pretreatment step (Figure 1, pt. 1 and Figure 2, pt. 1) which can consist of mechanical buffing, polishing, and vapor degreasing or soaking in an organic solvent. Alkaline cleaning (Figure 1, pt. 2 and Figure 2, pt. 2), removes surface soil and is accomplished by soaking and/or electrolytic processes. Gas evolution on the surface of the substrate aids the cleaning agent's action in electrolytic alkaline cleaning. More details on electrolytic processes are given in reference 14 in connection with chromium electroplating tanks. After cleaning, the substrate is dipped in acid (Figure 1, pt. 3 and Figure 2, pt. 3) to remove tarnish and to neutralize the alkaline film on its surface. At this point, the steel substrate is clean and ready to accept a metal deposit.

In the case of decorative chromium plating, an undercoat of copper is applied to the steel in two plating steps, with an acid rinse between each step (Figure 1, pts. 4-6). Next a nickel plate is applied by electrodeposition (pts. 7 and 8). These undercoats prohibit undesirable reactions between the substrate and the final plate which could embrittle the final product. Nickel also provides the basic protection and wear-resistance of the plated part since the decorative chrome layer is very thin. The final step in the decorative plating process is the electrodeposition of a thin layer of chrome (pt. 9).

In the hard chromium plating process, the cleaned substrate undergoes an anodizing treatment (pt. 4). This puts a protective oxide film on the metal by an electrolytic process in which the substrate serves as the anode. Then the hard chromium layer is electrodeposited (pt. 5) without any undercoating of copper or nickel.[13-15]

A typical chromium electroplating tank is pictured in Figure 3.[15] The system consists of a cathode and an anode, both immersed in electrolyte. Generally the part to be plated functions as the cathode, and the anode is a bar of lead-antimony or lead-tin alloy. The electrolyte contains ions of
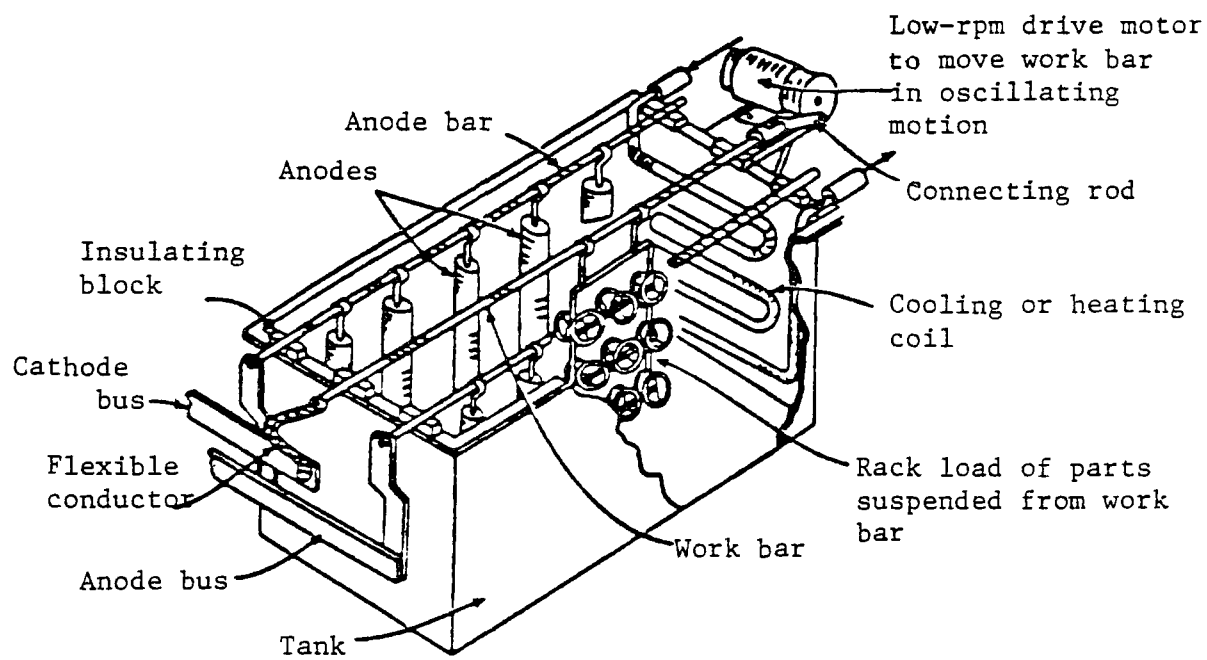
14

Figure 3 . Cut away view of electroplating tank.[15]

hexavalent chromium (from chromic acid) and small amounts of another anion, usually sulfate. The sulfate, or sometimes flouride, improves the electrical conductivity of the electrolyte bath.[15]

To accomplish the plating process, low voltage direct current process electricity is charged through the electrolyte bath. Electrolytic decomposition of water in the bath releases hydrogen gas at the cathode and oxygen at the anode. As these gases rise to the surface of the bath, a mist of electrolyte is formed and chromium metal is deposited on the substrate.

Table 1 shows the composition of conventional chromium plating solutions, and the temperature and current densities in a typical tank. Recently developed proprietary processes substitute flouride or flousilicate ions for sulfate ions in the electrolytic plating solution, resulting in more efficient chromium plating. Another area of present investigations involves using trivalent chromium baths as an alternative to hexavalent chromic acid plating baths. The extent of use of trivalent chromium plating solutions is unknown.

Current efficiency of chromium deposition is low, about 8 to 12 percent for conventional baths and up to 20 percent for newer flouride ion solutions. This and other factors combine to require long plating times for depositions of the thickness required in hard chromium plating. Table 1 gives typical chromium plate deposition rates.[15]

The chromium electrodeposition step is the same no matter what substrate material is used. However, the cleaning and preparation of other metal substrates may differ from those discussed for steel (Figures 1 and 2). For example, the copper undercoat may be applied in one plating step rather than the two copper plating steps for steel substrates shown in Figure 1. Similarly, nickel underplate may be applied in one rather than two steps. On aluminum substrate, a zinc plate is usually applied before the copper plate. When plating on plastic, the cleaned surface must be

TABLE 1. TYPICAL CHROMIUM-PLATING CONDITIONS USING
CONVENTIONAL BATHS[15]

| | | Hard Chromium | |
	Decorative Plates	Dilute	Concentrated
Chromic acid (CrO_3), g/l	250-400	250	400
Sulfuric acid (H_2SO_4), g/l	2.5-4	2.5	4
Cathode current density, A/m^2	1,250-1,750	3,100	2,200
Temperature, °C	38-43	55	50
Deposition rate, μm/hr	8-13	25	13

activated, rendered catalytic, and given an electroless deposit of nickel or copper before the electrolytic deposition of copper, nickel, and chromium.[13] These process variations, however, do not affect the procedures used in or emissions from the final chromium electroplating step.

Emission Factors--

The potential source of chromium emissions from the decorative chromium plating process is the electroplating step (Figure 1, point 9). Chromium emissions from the hard plating process (Figure 2) are generated in the electroplating step and in the chromic acid anodizing treatment step. In the chromium electroplating steps of the decorative and hard plating processes, mists or aerosols of the electrolyte (primarily chromic acid) are generated. Variables that affect electroplating emission rates include the bath temperature, the concentration of bath constituents, the amount of work being plated, and the plating current. The chromium plating tank in the hard chromium process generates more chromic acid mist than the plating tank in the decorative process because a higher current density is used for metal deposition (see Table 1). The higher current density causes higher rates of gassing thereby generating more chromic acid mist.[13]

Hooding is generally used on chromium electroplating tanks to collect chromium containing gases and convey them out of the plating building. Wet scrubbers are often used to control chromic acid emissions from plating operations. The efficiency of wet scrubbers in collecting chromium emissions from electroplating tanks is reported to be 95 percent.[16,17] A system developed at one plating operation combines a wet scrubber, multiple stages of electrostatic precipitators, and an activated carbon filter. The tested chromium removal efficiency is 99.7 percent.[17]

Chromium emission factors for electroplating operations are limited, particularly for the decorative plating process. Table 2 shows chromium emission factors developed from the testing of one hard chromium plating operation.[18] Emission factor data for decorative plating are much more

TABLE 2. UNCONTROLLED EMISSION FACTORS FOR CHROMIUM ELECTROPLATING[18]

Source of Emissions	Chromium Emission Factor lb/hr · ft^2 tank area[a]
Hard Plating Tank	0.000044
Hard Plating Tank	0.000028 – 0.00015
Hard Plating Tank	0.000046 – 0.00013

[a]Factors are expressed in terms of hexavalent chromium (Cr^{+6}).

limited; however, uncontrolled emissions from one 4,920 liter (1,300 gallon) tank used for decorative chromium plating were reported to be 0.20 kg (0.45 lb) of chromic acid per hour.[13]

3.3 NATIONAL EMISSIONS

National chromium emissions from chromium electroplating operations were estimated using the emission factors in Table 2 and assumptions generated from contacts with the plating industry. The key assumptions to estimating national emissions involve the following factors.

- number of shops plating chromium
- number of chromium tanks per shop
- size of chromium plating tanks
- operating schedule of chromium plating shops

The number of shops plating chromium was estimated using data generated by EPA in its characterization of the electroplating industry for wastewater pretreatment standards[19] and using estimates from the electroplating industry.[20-23] The total number of electroplating shops in the U. S. has been estimated to be 13,000.[19] Of this 13,000, approximately 75 percent are assumed to be plating chromium.[20-23] The 9,750 shops assumed to be plating chromium includes both captive and job shop platers. Contacts in the plating industry stressed that there are no complete or well developed data bases for this industry in regard to the number of shops, the number of tanks per shop, tank sizes, and shop locations. The estimates used in this assessment for these parameters were judged by the people contacted to be reasonable. Therefore, the following assumptions were applied for the purpose of calculating national chromium emissions from chromium electroplating.

Number of shops plating chromium - 9,750
Number of chromium tanks per shop - 2

20

Size of each plating tank - 32 ft^2 (4' x 8')

Operating schedule - 8 hrs/day, 250 days/yr

From the data presented in Table 2, an average chromium emission factor of 0.000080 lb/hr ft^2 (as Cr^{+6}) was estimated. Using this factor and the assumptions given above, a national emission estimate can be calculated as follows.

(1) $2 \dfrac{\text{tanks}}{\text{shop}} \times 9{,}750 \text{ shops} \times 32 \dfrac{\text{ft}^2}{\text{tank}} = 624{,}000 \text{ ft}^2$

(2) $624{,}000 \text{ ft}^2 \times 0.000080 \dfrac{\text{lb}}{\text{hr ft}^2} = 49.9 \dfrac{\text{lb}}{\text{hr}}$

(3) $49.9 \dfrac{\text{lb}}{\text{hr}} \times 250 \dfrac{\text{days}}{\text{yr}} \times 8 \dfrac{\text{hrs}}{\text{day}} = 99{,}800 \dfrac{\text{lb}}{\text{yr}} = 49.9 \dfrac{\text{tons } Cr^{+6}}{\text{yr}}$

National chromium emissions (as Cr^{+6}) from chromium electroplating are estimated to be approximately 50 tons/yr. This estimate is based on the average emission rate. The range of potential emissions is 17.5 - 93.6 tons/yr Cr^{+6}. All the national chromium emission estimates presented here are for uncontrolled emissions. A vendor of control systems for electroplating shops indicated that shops built in the last 10 years probably have some type of chromic acid control.[20] He expects, however, that the majority of the chromium plating shops are uncontrolled. No quantitative estimate is available on the percentage of chromic acid emissions that are controlled.[20]

3.4   POPULATION EXPOSURE TO CHROMIUM FROM CHROMIUM ELECTROPLATING

In this section, the ambient chromium concentrations attributable to chromium electroplating sources are estimated and the level of population exposure to these estimated concentrations are determined using the EPA's

Human Exposure Model (HEM). A description of the HEM is provided in Appendix A of the original October 1983 final report.

Source-specific input data for the HEM analysis could not be determined for the chromium electroplating source category because of the large number of individual sources. As an alternative, a chromium electroplating model plant was developed for use in the HEM analysis. The source parameters of the model plant are presented in Table 3. A model plant of the type given in Table 3 was assumed to be located in 117 cities in the country where chromium plating is expected to be found. The locations of these platers were obtained from the Thomas Register industrial directory. It is assumed that these 117 model plant sites are representative of the total population of chromium platers and that the HEM results for the subset can be extrapolated to the total population.

The summary results of the HEM analysis for the subset of chromium platers are presented in Table 4. Problems exist in extrapolating these results to the total population of chromium platers due to a large amount of double-counting of exposed people. Double-counting occurs because the number of sources is large and the sources are concentrated in mostly urban locations such that the population grids defining exposure overlap. The overlapping occurrence is easily illustrated in that about twice as many people as are in the country are predicted to be exposed to chromium from plating, and this estimate only represents 1 percent of the sources. The public exposure results should likewise be evaluated cautiously because they are related directly to the population exposed numbers.

The most meaningful results from the HEM analysis of the subset of chromium platers appear to be the chromium (as Cr^{+6}) concentrations predicted to occur in ambient air around plating shops. The maximum concentration to which anyone is estimated to be exposed to is 0.00539 $\mu g/m^3$. This exposure concentration ranges from one to about four orders of magnitude less than the maximum exposures estimated for the other

TABLE 3. SOURCE CHARACTERIZATION PARAMETERS OF THE CHROMIUM
ELECTROPLATING MODEL PLANT

Parameter	Value
Chromium Emission Rate	4.6 kg (10.2 lb)/yr[a]
Stack Height	6.1 m (20 ft)
Stack Diameter	0.31 m (1 ft)
Stack Gas Velocity	18.6 m/sec (61.1 ft/sec)
Stack Gas Exit Temperature	305°K (32°C)
Cross Sectional Area[b]	100 m^2 (1076.4 ft^2)
Vertical Stack	Not Applicable

[a] Emissions expressed as hexavalent chromium (Cr^{+6}).

[b] This represents the vertical cross sectional area of the emission point to
the mean wind direction for the purpose of calculating downwash.

TABLE 4. POPULATION EXPOSURE TO CHROMIUM FROM CHROMIUM ELECTROPLATING
SHOPS AS PREDICTED BY THE HUMAN EXPOSURE MODEL[a]

Concentration Level ($\mu g/m^3$)	Population Exposed (Persons)	Public Exposure (Persons-$\mu g/m^3$)
0.00539	1	< 1
0.0050	1	< 1
0.0025	5,710	18
0.001	50,300	83
0.0005	162,000	161
0.00025	391,000	240
0.0001	1,150,000	355
0.00005	2,670,000	460
0.000025	6,190,000	582
0.00001	18,600,000	770
0.000005	41,000,000	924
0.0000025	84,500,000	1,080
0.000001	201,000,000	1,260
0.0000005	328,000,000	1,350
0.00000025	416,000,000	1,380
0.0000001	437,000,000	1,380
0.00000005	438,000,000	1,380
0.000000046	438,000,000	1,380

[a]These results apply only to the 117 model chromium electroplating shops
analyzed as a representative subset of the total population of plating
shops.

[b]This column displays the computed value, rounded to the nearest whole
number, of the cumulative number of people exposed to the matching and
higher concentration levels found in column 1. For example, 0.5 people
would be rounded to 0 and 0.51 people would be rounded to 1.

[c]Column 3 displays the computed value of the cumulative exposure to the
matching and higher concentration levels found in column 1.

chromium source categories given in the October 1983 report. The minimum ambient chromium concentration to which people are predicted to be exposed to from chromium electroplating emissions is 0.000000046 $\mu g/m^3$. Although precise quantification is not possible with the results of the HEM analysis, it is probable that a large distinct number of people (on the order of tens of millions) are exposed to ambient chromium levels equal to this minimum level or greater. This estimation is based on the raw HEM results which showed that the population affected by each model plant ranged from 10^5 – 10^7 people and the consideration that most sources are in or located close to urban areas.

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