FINAL REPORT

ESTIMATES OF POPULATION EXPOSURE

TO AMBIENT CHROMIUM EMISSIONS

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TO AMBIENT CHROMIUM EMISSIONS

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Prepared for:

Karen L. Blanchard
EPA Project Officer
Pollutant Assessment Branch
Strategies and Air Standards Division
U. S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Prepared by:
Garry Brooks
Radian Corporation
3024 Pickett Road
Durham, North Carolina 27705

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FINAL REPORT

ESTIMATES OF POPULATION EXPOSURE
TO AMBIENT CHROMIUM EMISSIONS

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EXECUTIVE SUMMARY

This report summarizes the results of a study that estimated the potential levels of human exposure to average annual atmospheric concentrations of chromium in the United States. Chromium or chromium compounds are emitted from a wide variety of source categories. These source categories of chromium emissions generally fall into one of two groups. The two groups are labeled direct and inadvertent emission sources. Direct sources are those which use chromium or chromium compounds as process inputs and generate chromium products. Examples of direct sources are chromium chemical plants, chromium refractory plants, and stainless and alloy steel mills. Inadvertent sources are those which unintentionally release chromium due to its being a component of fuels, wastes, or naturally-occurring minerals. Coal and oil combustion sources, incinerators, and cement plants are examples of inadvertent chromium sources.

The source categories of potential chromium emissions that were assessed in this study are steel manufacturing, ferrochromium manufacturing, refractory manufacturing, chromium chemicals manufacturing, coal and oil combustion, sewage sludge and municipal refuse incineration, cement manufacturing, leather tanning, asbestos production, chromium ore refining, and cooling towers.* In the initial analysis of these source categories, atmospheric chromium emissions from asbestos production and leather tanning were found to be negligible or nonexistent. The extent to which these source categories could contribute to atmospheric chromium exposure concentrations was determined to be very minimal; therefore, they were dropped from further consideration.

For the source categories studied in detail (all except asbestos and leather tanning), the valence state(s) of their chromium emissions was investigated because of the variable toxicities exhibited by different

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*Subsequent to the finalization of this report in October 1983, additional information was gathered and analyses performed for the cooling tower source category and a previously untreated source category, chromium electroplating. The information developed for these source categories is presented in the July 1984 addendum to this report.

chromium valences. Trivalent (Cr^{+3}) and hexavalent (Cr^{+6}) forms of chromium predominate in the various source category emissions with the available health evidence suggesting that hexavalent chromium is more toxic than the trivalent form. The major trivalent emitting source categories are steel, ferrochromium, refractory, and cement manufacturing, chromium ore refining, and coal and oil combustion. Hexavalent chromium is expected to be emitted from chromium chemical plants, sewage sludge and municipal refuse incinerators, and cooling towers, although cooling towers and chemical plants can also be trivalent chromium sources.

The potential national population exposure to chromium was assessed using the U. S. EPA Human Exposure Model (HEM). The HEM is a general model capable of producing quantitative expressions of public exposure to ambient air concentrations of pollutants emitted from stationary sources. A detailed description of how the HEM works is provided in Appendix A. Chromium emissions estimates and other source category information (stack geometries, geographic coordinate locations) needed for the HEM analyses were obtained from State air quality permits, State and U. S. EPA emission source test reports, the National Emissions Data System (NEDS), and other published literature. For some of the larger source categories data on all individual facilities within the category were unavailable. In these cases model plants were developed that were representative of the distribution of actual facilities in the source category. A summary of the exposure results is presented in Table S-1.

Although studied in depth, the cooling tower and coal/oil combustion source categories were not included in the population exposure analysis performed with the HEM. The reasons these source categories were not included are twofold. First and primary, the characterization of individual sources in both categories could not be done to the level of detail required by the HEM to produce meaningful results because of a lack of information. Particularly for the cooling tower source category, characterization data on the number, size distribution, location, and chromium use patterns of cooling towers were not available. Second, by assessing the emissions and resultant ambient concentrations of example or model case cooling towers and

TABLE S-1.   SUMMARY OF THE CHROMIUM POPULATION EXPOSURE RESULTS
AS PRODUCED BY THE HUMAN EXPOSURE MODEL.

Source Category	Maximum Concentration Level $(\mu g/m^3)^a$	Population Exposed to Maximum Concentrations (Persons)[b]	Total Population Exposed (Persons)[c]
Chromium Ore Refining	0.0118	< 1	364,726
Chromium Chemicals[d]	1.89	1	1,849,992
Refractory Production[d]	13.5	< 1	8,242,165
Municipal Refuse Incinerators[d]	0.0245	< 1	44,944,086
Sewage Sludge Incinerators[d]	0.0838	< 1	45,516,677
Ferrochromium Production	2.87	< 1	22,132
Steel Manufacturing[d]	0.0877	< 1	70,304,856
Cement Production	0.0469	< 1	50,450,530

[a] The numbers in this column represent the maximum chromium concentration predicted to occur in that source category by the HEM.

[b] The numbers in this column represent the number of people estimated by the HEM to be exposed to the corresponding maximum chromium concentration.

[c] The numbers in this column represent the total population exposed to all concentration levels of ambient chromium within 20 km of the emission sources.

[d] Emissions of some of these sources are known to contain some hexavalent chromium.

* Subsequent to the finalization of this report in October 1983, additional information was gathered and analyses performed for the cooling tower source category and a previously untreated source category, chromium electroplating. The information developed for these source categories is presented in the July 1984 addendum to this report.

combustion sources, ambient downwind concentrations of chromium from sources in these categories were estimated to be relatively minor compared to the concentrations resulting from other chromium source categories (i.e., chromium chemical planrs, refractory plants, ferrochromium plants). It should be noted, however, that the emissions of these two source categories may contain forms of chromium that are particularly toxic such that exposure to even small quantities may produce a significant health risk. For this reason, detailed exposure studies of the cooling tower and coal/oil combustion source categories may be conducted at a later date when a more complete source characterization data base can be developed.

Near the end of this study two other source categories of potential chromium air emissions were identified. These categories are large scale spray painting operations (e.g., ships and planes) where zinc chromate paints are used and glass plants. Glass plants potentially emit chromium because chromium compounds can be used in glass batches as colorants and because chromium refractory used to line glass furnaces can degrade and break down to the point that chromium-containing particles are able to be entrained in furnace flue gases. These source categories were not included in the present study because the project was essentially complete at the time of identification and there was no clear definition of each source category (i.e., number of plants, plant sizes, etc.) and consequently no readily available characterization data base. Based on the results of continuing examinations by EPA, these categories may be included in future exposure studies of chromium air emission sources.

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CHAPTER 1

INTRODUCTION AND OVERVIEW OF CHROMIUM PROPERTIES, PRODUCTION, AND USE

1.0 INTRODUCTION

The primary purpose of this report is to summarize the results of a study that estimated the potential levels of human exposure to atmospheric concentrations of chromium in the United States. The purpose of the exposure analysis is to provide an approximate and relative idea of the severity of atmospheric chromium levels that are attributable to various emission source categories. The results of the exposure analysis will function as one of several inputs to a U. S. Environmental Protection Agency (EPA) decision process to determine which if any chromium emission source categories require further, more in-depth study towards the potential point of developing regulations for chromium air emission sources.

Twelve potential source categories of chromium emissions were assigned for investigation in this study including:

- steel manufacturing,
- ferrochromium manufacturing,
- refractory manufacturing,
- chromium chemicals production,
- coal and oil combustion,
- sewage sludge incineration,
- municipal refuse incineration,
- cement manufacturing,
- chrome ore refining,
- cooling towers,
- leather tanning, and
- asbestos production.

Asbestos production and leather tanning were eventually deleted from consideration after a preliminary assessment indicated that their potential for atmospheric chromium emissions are very slight.

The ambient chromium exposure concentrations potentially encountered by the general population from the emissions of the source categories were assessed in this study using the U. S. EPA Human Exposure Model (HEM). The HEM is a general model capable of producing quantitative expressions of public exposure to ambient air concentrations of pollutants emitted from stationary sources. The results of the exposure analysis and the methods by which they were obtained are presented in Chapter 3 and Appendix A. Although studied in depth, the cooling tower and coal/oil combustion source categories were not included in the population exposure analysis performed with the HEM. The reasons these source categories were not included are twofold. First, the characterization of individual sources in both categories could not be done to the level of detail required by the HEM to produce meaningful results. Particularly for the cooling tower source category, data on the number, size distribution, location, and chromium use patterns of cooling towers were not available. Second, by assessing the emissions and resultant ambient concentrations of example or model case cooling towers and combustion sources, ambient downwind concentrations of chromium from sources in these categories were estimated to be relatively minor compared to the concentrations resulting from other chromium source categories (i.e., chromium chemical plants, refractory plants, ferrochromium plants).

In Chapter 2, background information and emission characteristics of each identified chromium emission source category are presented. For each source category a description is given of the origin of the sources' chromium emissions (e.g., raw material or fuel) and factors affecting chromium emissions. For source categories where it has been determined, the valence state and solubility of the sources' chromium emissions is given. The methodologies, assumptions, and sources used to estimate chromium emissions from each of the source categories (for the purpose of the exposure analysis) are also explained in Chapter 2.

In the remaining sections of Chapter 1, brief background descriptions are presented on the physical and chemical properties of chromium, the sources of chromium and chromium-containing material production, and the end product uses for chromium and chromium materials.

1.1 PHYSICAL AND CHEMICAL PROPERTIES OF CHROMIUM

Pure chromium is a steel-gray, lustrous, hard crystalline metal. It occupies the 24th position in the Periodic Table and belongs to transition group VIB along with molybdenum and tungsten. It comprises about 0.037 percent of the earth's crust and therefore ranks 21st in relative natural abundance. It is more abundant than cobalt, copper, lead, nickel, cadmium, molybdenum, or zinc.[1,2,3] Elemental or pure chromium metal is not found in nature. Instead, it occurs primarily in nature as chromite ore or chrome iron ore which is a member of the spinel mineral group. The Cr/Fe ratio in chromite varies considerably; therefore, the mineral is best represented by the general formula (Fe, Mg)O (Cr, Fe, Al)$_2$O$_3$. The ideal chromite ore has the composition FeO Cr$_2$O$_3$ which contains about 46 percent chromium. The majority of the world's chromite supply comes from South Africa, Finland, the Philippines, and the U.S.S.R. Although chromite deposits are found in the United States, concentrations are so low that chromite mining is not economically feasible, and as such is not performed in this country.[3]

The major physical properties of elemental chromium are presented in Table 1-1.

Chromium exhibits several oxidation states ranging from -2 to +6 which dictate its chemical reactivity, and therefore, its environmental and biological significance. The range of oxidation states chromium chemicals can take is well illustrated by the list of typical chromium chemicals and their physical properties given in Table 1-2.[4] The most common oxidation states of chromium are +3 and +6, or trivalent and hexavalent chromium.[3,4] Trivalent chromium is chemically basic and the most stable form of the element because of its strong tendency to form kinetically inert hexaco-ordinate complexes with water, ammonia, organic acids, sulfate, halides, and urea.[4] This characteristic has great relevance to the behavior of trivalent

TABLE 1-1. PHYSICAL PROPERTIES OF CHROMIUM[1]

Property	Value
atomic weight	51.996
isotopes, %	
50	4.31
52	83.76
53	9.55
54	2.38
crystal structure	body centered cube
density at 20°C, g/cm^3	7.19
melting point, °C	1875
boiling point, °C	2680
vapor pressure, 130 Pa[a], °C	1610
heat of fusion, kJ/mol[b]	13.4–14.6
latent heat of vaporization at bp, kJ/mol[b]	320.6
specific heat at 25°C, kJ/(mol-K)[b]	23.9 (0.46 kJ/kg-K)
linear coefficient of thermal expansion at 20°C	6.2×10^{-6}
thermal conductivity at 20°C, W/(m-K)	91
electrical resistivity at 20°C, $\mu\Omega$-m	0.129
specific magnetic susceptibility at 20°C	3.6×10^{-6}
total emissivity at 100°C nonoxidizing atm	0.08

reflectivity, R				
λ, nm	300	500	1000	4000
%	67	70	63	88

Property	Value
refractive index	
α	1.64–3.28
λ	2,570–6,080
standard electrode potential, valence 0 to 3+, V	0.71
ionization potential, V	
1st	6.74
2nd	16.6
half-life of ^{51}Cr isotope, days	27.8
thermal neutron scattering cross section, m^2	6.1×10^{-29}
elastic modulus, GPa[c]	250
compressibility[a,d] at 10–60 TPa	70×10^{-3}

[a] To convert Pa to mm Hg, multiply by 0.0075.

[b] To convert J to cal, divide by 4.184.

[c] To convert GPa to psi, multiply by 145,000.

[d] 99% Cr; to convert TPa to megabars, multiply by 10.

TABLE 1-2. CHROMIUM COMPOUNDS OF VARIOUS OXIDATION STATES AND THEIR MAJOR PHYSICAL PROPERTIES

Compound	Formula	Appearance	Density (g/cm^3)	Melting Point (°C)	Boiling Point (°C)	Solubility
Oxidation state 0						
chromium carbonyl	$Cr(CO)_6$	Colorless crystals	1.77_{18}	150 (decomposes) (sealed tube)	151 (decomposes)	Slightly soluble in CCl_4; insoluble in H_2O, $(C_2H_5)_2O$, C_2H_3OH, C_6H_6
Dibenzene-chromium(0)	$(C_6H_6)_2Cr$	Brown crystals	1.519	284-285	Sublimes 150 (vacuum)	Insoluble in H_2O; soluble in C_6H_6
Oxidation state +1						
Bis(biphenyl)-chromium (1) iodide	$(C_6H_5C_6H_5)_2CrI$	Orange plates	1.617_{16}	178	Decomposes	Soluble in C_2H_5OH, C_5H_5N
Oxidation state +1						
Chromous acetate	$(Cr_2(C_2H_3O_2)_4 \cdot 2H_2O$	Red crystals	1.79			Slightly soluble in H_2O; soluble in acids
Chromous chloride	$CrCl_2$	White crystals	2.93	815	1120	Soluble in H_2O to blue solution, absorbs O_2
Chromous ammonium sulfate	$CrSO_4$ $(NH_4)_2SO_4 \cdot 6H_2O$	Blue crystals				Soluble in H_2O, absorbs O_2
Oxidation state +3						
Chromic chloride	$CrCl_3$	Bright purple plates	2.87_{25}	Sublimes	885	Insoluble in H_2O, soluble in presence Cr
Chromic acetyl-acetonate	$Cr(CH_3COCHCOCH_3)_3$	Red-violet crystals	1.34	208	345	Insoluble in H_2O; soluble in C_6H_6
Chromic potassium sulfate (chrome alum)	$KCr(SO_4)_2 \cdot 12H_2O$	Deep purple crystals	1.826_{15}	89 (incongruent)		Soluble in H_2O
Chromic chloride hexahydrate	$[Cr(H_2O)_4Cl_2]Cl \cdot 2H_2O$	Bright green crystals	1.835_{25}	95		Soluble in H_2O, green solution turning green-violet
Chromic chloride hexahydrate	$[Cr(H_2O)_6]Cl_3$	Violet crystals		90		Soluble in H_2O, violet solution turning green-violet
Chromic oxide	Cr_2O_3	Green powder or crystals	5.22_{25}	2435	ca. 3000	Insoluble
Oxidation state +4						
Chromium(IV) oxide	CrO_2	Dark-brown or black powder	4.98 (calculated)		Decomposes to Cr_2O_3	Soluble in acids to Cr^{3+} and Cr^{6+}

TABLE 1-2 (CONTINUED). CHROMIUM COMPOUNDS OF VARIOUS OXIDATION STATES AND THEIR MAJOR PHYSICAL PROPERTIES[4]

Compound	Formula	Appearance	Density (g/cm³)	Melting Point (°C)	Boiling Point (°C)	Solubility
Chromium(IV chloride	$CrCl_4$				≥10	
Oxidation state + 5						
Barium chromate(V)	$Ba_3(CrO_4)_2$	Black-green crystals				Slightly decomposes in H_2O; soluble in dilute acids to Cr^{3+} and Cr^{6+}
Oxidation state + 6						
Chromium(VI) oxide	CrO_3	Ruby-red crystals	2.7_{25}	197	Decomposes	Very soluble in H_2O; soluble in CH_3COOH conc., $(CH_3CO)_2O$
Chromyl chloride	CrO_2Cl_2	Cherry-red liquid	1.9145_{25}	-96.5	115.8	Insoluble in H_2O, hydrolyzes; soluble in CS_2, CCl_4
Ammonium dichromate	$(NH_4)_2Cr_2O_7$	Red-orange crystals	2.155_{25}	Decomposes 180		Soluble in H_2O
Potassium dichromate	$K_2Cr_2O_7$	Orange-red crystals	2.676_{25}	398	Decomposes	Soluble in H_2O
Sodium dichromate	$Na_2Cr_2O_7 \cdot 2H_2O$	Orange-red crystals	1.348_{25}	84.6 (Incongruent)	Decomposes	Very soluble in H_2O
Potassium chromate	K_2CrO_4	Yellow crystals	2.732_{18}	971		Soluble in H_2O
Sodium chromate	Na_2CrO_4	Yellow crystals	2.723_{25}	792		Soluble in H_2O
Potassium chlorochromate	$KCrO_3Cl$	Orange crystals	2.497_{19}	Decomposes		Soluble in H_2O, hydrolyzes
Silver chromate	Ag_2CrO_4	Maroon crystals	5.625_{25}			Very slightly soluble in H_2O; soluble in dilute acids
Barium chromate	$BaCrO_4$	Pale yellow solid	4.498_{25}	Decomposes		Very slightly soluble in H_2O; soluble in strong acids
Strontium chromate	$SrCrO_4$	Yellow solid	3.895_{15}	Decomposes		Slightly soluble in H_2O; soluble in dilute acids
Lead chromate	$PbCrO_4$	Yellow solid / Orange solid	6.12_{15}	844		Practically insoluble in H_2O; soluble in strong acids

chromium in biological systems. Hexavalent chromium is acidic
and is the most commercially, biologically, and environmentally important
state of chromium. Hexavalent forms of chromium are almost always linked to
oxygen and are, therefore, strong oxidizing agents. Characteristically
acidic hexavalent chromium forms chromate $(CrO_4)^{2-}$ and dichromate $(Cr_2O_7)^{2-}$
ions.[3]

At normal temperatures chromium metal resists corrosive attack by a
wide variety of chemicals. It will, however, dissolve in several common
acids including hydrofluoric, hydrochloric, hydrobromic, and sulfuric with
the evolution of hydrogen. Chromium is not attacked by phosphoric acid or
organic acids such as formic, citric, and tartaric; however, it is slowly
attacked by acetic acid. The corrosion resistance properties of chromium
can be increased by depositing a thin oxide film on the metal surface, and
thereby introducing a condition to the chromium known as passivity.
Chromium can be made passive and rendered relatively nonreactive by the
action of nitric acid (in which it is insoluble), chromic acid, or other
oxidizing agents. It can also be passivated by superficial exposure and
oxidation of the metal in air, although this technique is not as effective
as oxidation by nitric or chromic acid.[3]

1.2 OVERVIEW OF PRODUCTION

All chromium metal and chromium compounds that are produced in the
United States are derived from various grades of chromite ore as illustrated
in Figure 1-1. Three basic grades of chromite ore are used to produce chor-
mium compounds (including chromium metal) and these are summarized as
follows.[1]

- high chromium chromite ore, contains 46 percent or more of chromic
  oxide (Cr_2O_3)
- high iron chromite ore, contains 40-46 percent of Cr_2O_3
- high aluminum or low chromium chromite ore, contains more than
  20 percent aluminum oxide (Al_2O_3) and more than 60 percent
  $Al_2O_3 + Cr_2O_3$
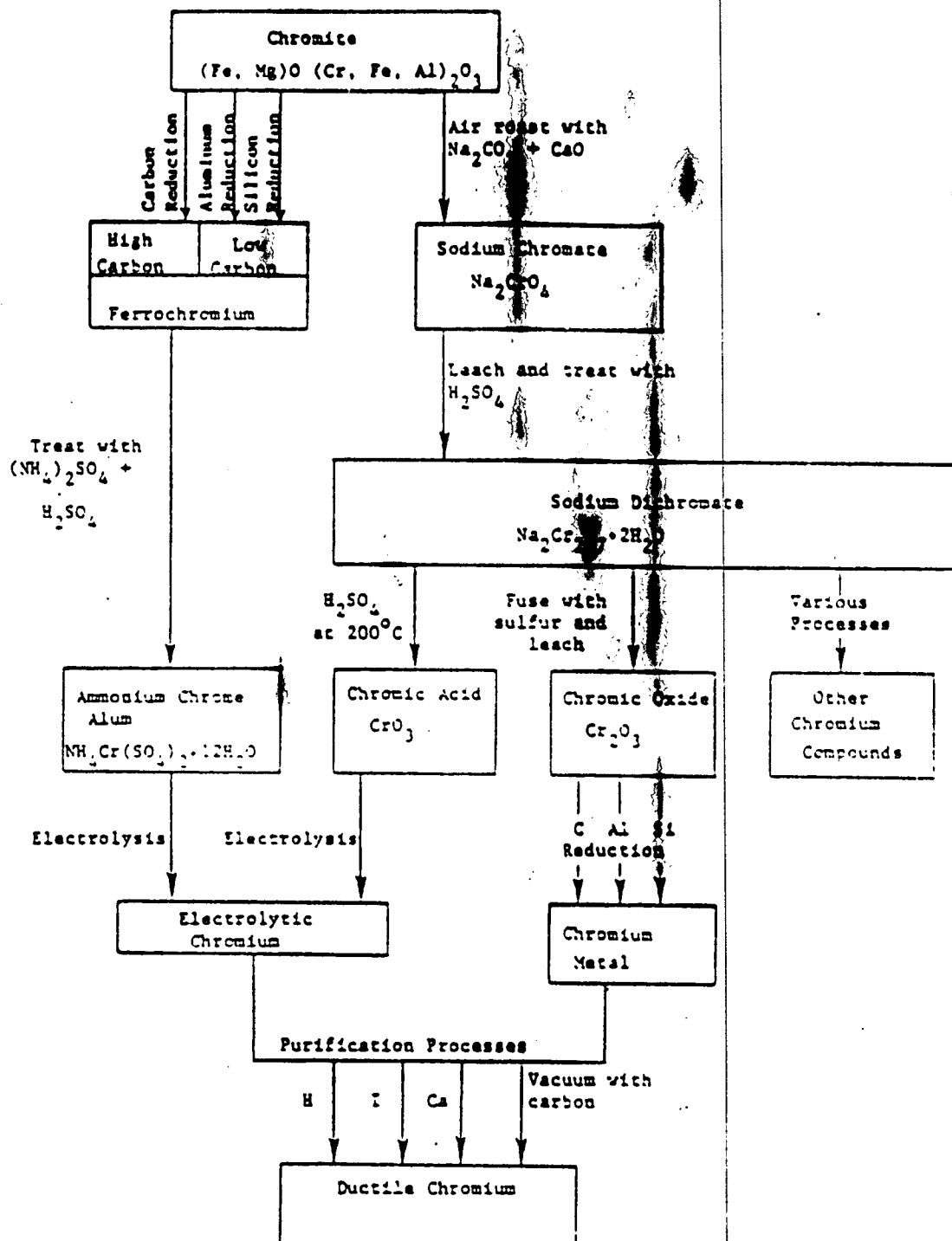
Figure 1-1. Simplified flowchart for the production of chromium compounds and metallic chromium from chromite.[1]

Chromite ores are generally described according to the type of production use the chromite ore eventually has. Metallurgical chromite refers to the high chromium content chromite ore, chemical chromite to the high iron content chromite ore, and refractory chromite to high aluminum/low chromium content chromite ore.

Currently, chromite ore is not commercially mined in the United States. It has not been mined domestically since 1961 when the federal government's Defense Production Act was phased out. The phasing out of this program eliminated government sponsorship and subsidization of chromite mining activities, thereby making them economically infeasible.[5] The United States has chromite deposits located in Maryland, Montana, North Carolina, California, Wyoming, Washington, Oregon, Texas, and Pennsylvania; however, the low chromium content of these deposits makes mining excessively expensive in the present market. All of the United States' chromite in 1981 was imported from Albania (1.5 percent), Finland (8.5 percent), Madagascar (2 percent), the Phillippines (16.1 percent), South Africa (54 percent), Turkey (5.5 percent), and the U.S.S.R. (12.4 percent).[6] In 1981 a total of 808 Gg (898,000 tons) of chromite was imported by the United States. This total represents the lowest chromite importation level since 1946.[6]

The types of chromite available and the types of chromium compounds they are used to produce are discussed in the following sections.

1.2.1 Metallurgical Chromite and Chromium

Metallurgical grade chromite refers to chromite that is used to produce several grades or types of ferrochromium, chromium metal, and chromium additives. Very little chromite is processed all the way to chromium metal or ductile chromium because the majority can be used effectively and at a lower cost as the intermediate ferrochromium forms. Although there are several composition specific subgroups, the primary forms of ferrochromium are classified as high-carbon ferrochromium, low-carbon ferrochromium, and ferrochromium-silicon. High-carbon ferrochromium generally contains 5 to 6.5 percent carbon and 65 to 70 percent chromium. Low-carbon ferrochromium contains 67 to 75 percent chromium but only 0.025 to 0.05 percent carbon. Ferrochromium-silicon has a chromium content ranging from 35 to 41 percent

and a maximum carbon content of 0.05 percent. Table 1-3 summarizes the
compositions of the more prominent types of ferrochromium and chromium
metal.[1]

High-carbon ferrochromium is produced in a submerged electric arc
furnace by reducing chromite with coke. Low-carbon ferrochromium is
produced by reducing chromite with silicon in an electric arc furnace. The
intermediate product of this reaction is ferrochromium-silicon. To obtain
low-carbon ferrochromium, this intermediate product is further treated in an
open, arc-type furnace with additional chromite or a chromic oxide-
containing slag. With all the ferrochromium production processes, molten
product ferrochromium is tapped from the furnace, hardened by rapid cooling,
broken into chunks, and graded into compositional subgroups.[1,7]

The principal production techniques for chromium metal are a
pyro-metallurgical reduction process using aluminum (aluminothermic process)
or a chrome-alum electrolysis process (electrolytic process). In the
aluminothermic process chromic oxide is mixed with powdered aluminum, placed
in a refractory vessel, and ignited. The reaction is exothermic and self-
sustaining with chromium metal and aluminum oxide being generated. Chromium
metal produced by this method is 97 to 99 percent pure. Additional thermal
methods of chromium metal production involve the reduction of chromic oxide
with silicon in an electric arc furnace and the low pressure reduction of
chromic oxide with carbon in a refractory vessel.[6,8]

In the most prevalent electrolytic method of chromium metal production,
high-carbon ferrochromium, in solution with other compounds, is used to
generate a chromium ammonium sulphate solution or ammonium chrome-alum
electrolyte. This chrome-alum electrolyte solution undergoes electrolysis
to produce chromium metal. The deposition cycle for this process lasts 72
hours with chromium metal eventually being deposited on stainless steel
cathodes. The final product chromium metal from this operation is about
99.3 percent pure. The second type of electrolytic chromium metal
production involves the electrolysis of a chromic acid/ionic catalyst
solution with the resultant deposition of chromium metal. The deposition

TABLE 1-3.   COMPOSITION OF TYPICAL FERROCHROMIUM ALLOYS AND CHROMIUM METAL.[1]

Grade	Chromium	Silicon	Carbon	Sulfur[b]	Phosphorus[b]	Other[a]
ferrochromium						
high-carbon	66-70	1-2	5-6.5	0.04	0.03	
high-carbon, high-silicon						
blocking chrome	55-63	8-12	4-6	0.03		
exothermic ferrochrome	41-51	9-14	3.6-6.4	0.03		
foundry ferrochrome	55-63	8-12	4-6			
refined chrome	53-61	2.5	3-5	0.03		
SM ferrochrome	60-65	4-6	4-6			4-6 manganese
charge chromium						
50-55 percent chromium	50-56	3-6	6-8	0.04	0.03	
66-70 percent chromium	66-70	3[b]	6-6.5	0.04	0.03	
low-carbon:						
0.025 percent carbon	67-75	1[b]	0.025[b]	0.025	0.03	
0.05 percent carbon	67-75	1[b]	0.05[b]	0.025	0.03	
Simplex	63-71	2.0[b]	0.01 or 0.025			
ferrochromium-silicon:						
36/40 grade	35-37	39-41	0.05[b]			
40/43 grade	39-41	42-45	0.05[b]			
chromium metal						
electrolytic	99.3[c]	0.01[b]	0.02[b]	0.03		0.5 oxygen[b] 0.05 nitrogen[b]
aluminothermic	99.3[c]	0.15[b]	0.05[b]	0.015	0.01	0.2 oxygen[b] 0.3 aluminum[b]

[a]Difference between sum of percentages shown and 100 percent is chiefly iron content.

[b]Maximum value.

[c]Minimum value.

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cycle for this process lasts 80 to 90 hours and produces a final chromium
metal that is of slightly higher purity than that obtained from chrome-alum
electrolysis.[6]

The only other source of chromium metal production comes from recycling
chromium scrap metal. The main source of scrap chromium is scrap stainless
steels and chromium alloys. It is estimated that only about 15 percent of
the available scrap chromium is being recovered and recycled as new chromium
metal.[1] The flow of chromium scrap through industry is shown in
Figure 1-2.[9] Generally recycling is performed by firms producing the
stainless steels and alloys and by specialty firms engaged in secondary
metals recovery. Although there is a considerable amount of chromium
contained in various industrial waste products such as baghouse dusts,
slags, pickling liquors, plating and etching wastes, used refractories, and
processing sludges, collection and processing costs hinder economical
recovery on a large scale.[9]

The current structure of the United States ferrochromium and chromium
metal industry contains 11 plants operated by eight different companies. In
1981 these plants produced a combined total of approximately 148 Gg
(165,000 tons) of high- and low-carbon ferrochromium and 56 Gg (62,000 tons)
of ferrochromium-silicon, chromium metal, and chromium additives.[6] Data are
not available in the literature to separate the production totals of
individual ferrochromium grades. However, in the first quarter of 1983, the
Ferroalloy Association reported that only one plant in the country was
actively producing ferrochromium. All other plants had suspended production
of ferrochromium due to low demand which was brought on by a depressed steel
industry and the ability of the steel industry to obtain their ferrochromium
requirements cheaper from foreign sources. The Ferroalloy Association
estimated that in the latter part of 1982 and in early 1983, 95 percent of
the ferrochromium consumed in the United States was imported.[10] The
increase in ferrochromium importation and the resulting decline in domestic
ferrochromium production is attributable to a worldwide trend in chromite-
producing countries to vertically integrate their chromium industry. Now,
instead of exporting all of their chromite, chromite producers are only
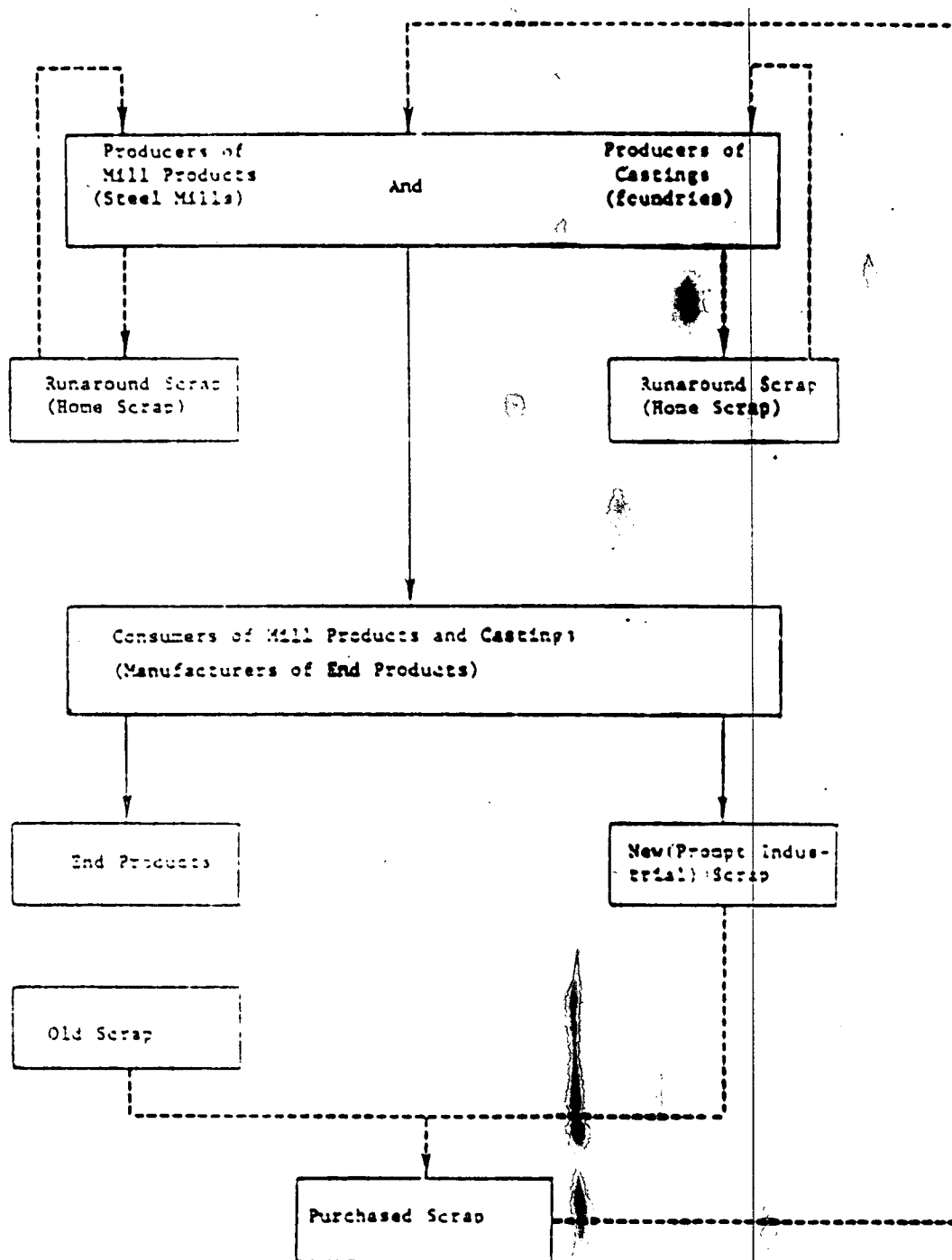
Figure 1-2. Industrial recycling/reuse flow of chromium scrap.[9]

exporting a portion. The major part of the chromite supply is being processed by the producing country directly into ferrochromium and sold to the industrial users such as the United States or Japan. Lower labor, energy, and transportation costs allow the chromite-producing countries to sell their ferrochromium at lower prices than domestic ferrochromium companies.[6,10] Changes or upturns in the domestic steel industry that significantly alter the demand for ferrochromium could help bring several of the domestic ferrochromium plants back on line.[10]

1.2.2 Chemical Chromite and Chromium Compounds

Chemical grade chromite refers to chromite that is used to produce sodium chromate ($Na_2CrO_4 \cdot 10\ H_2O$) and sodium dichromate ($Na_2Cr_2O_7 \cdot 2H_2O$). the basic chemicals from which all other chromium chemicals originate.[11,12,13] In the United States there are three companies producing sodium chromate and dichromate chemicals at three plant locations. Sodium chromate is only produced as an end product chemical at two of the sites.[14] Because of concerns of disclosing proprietary data, production information on sodium chromate is unavailable. However, the national sodium dichromate production capacity as of January 1983 was 205 Gg (228,000 tons) per year.[15]

Sodium chromate is produced by roasting finely ground chromite ore with soda ash or with soda ash and lime in a kiln. When sodium chromate is the desired endproduct, recovery is accomplished by leaching and crystallization steps. However, generally sodium chromate is not recovered, but instead is converted directly to sodium dichromate by treating it with sulfuric acid.[1,16] Following sulfuric acid treatment, the final sodium dichromate product is obtained after a series of evaporation, crystallization, and drying steps. A sodium sulfate by-product is also produced during the dichromate process and is generally sold to the kraft paper industry.

As many as 40 other chromium chemicals are produced from sodium dichromate raw materials. A list of the chromium chemicals commercially produced in the United States is given in Table 1-4 (excluding sodium chromate and dichromate). The more significant secondary chromium chemicals include potassium chromate and dichromate, ammonium dichromate, chromic acid, basic chromic sulfate, and chrome pigments (chrome oxide green, chrome yellow,

TABLE 1-4. LIST OF COMMERCIALLY PRODUCED CHROMIUM CHEMICALS AND THEIR GENERAL USES [1,14,17]

Chromium Chemical[a]	Number of Production Sites[b]	General Use
Chromic acid (Chromium trioxide)	2	Electroplating
Chromium acetate	6	Printing and dyeing textiles
Chromium acetylacetonate	1	Catalysts, antiknock compounds
Chromium monoboride	1	
Chromium carbide	1	Metallurgy
Chromium carbonyl	2	Catalysts
Chromium chloride, basic	1	Metal treatment
Chromium chloride	2	Metal treatment
Chromium difluoride	1	--
Chromium difluoride	1	Catalysts
Chromium dioxide	1	Magnetic tape
Chromium 2-ethylcaproate (Chromic octoate)	2	--
Chromium fluoride	1	Mordants, catalysts
Chromium hydroxide	1	Pigments, catalysts
Chromium hydroxy diacetate	1	--
Chromium hydroxy dichloride	1	--
Chromium naphthenate	2	Textile preservative
Chromium nitrate	2	Catalysts, corrosion control
Chromium oleate	2	--
Chromium oxide (Chrome oxide green)	6	Pigments
Chromium phosphate	2	Pigments, catalysts
Chromium potassium sulfate (Chrome alum)	1	Photographic emulsions
Chromium sulfate	2	Catalysts, dyeing, tanning
Chromium sulfate, basic	1	Tanning
Chromium triacetate	1	--
Chromium trifluoride	1	Printing, dyeing, catalysts
Chrome lignosulfate	1	Drilling muds
Potassium chromate	1	Metal treatment
Potassium dichromate	1	Tanning, dyeing, pigments
Lead chromate	5	Pigments
Zinc chromate	1	Corrosion control
Ammonium dichromate	2	Printing, pyrotechnics
Barium chromate	2	Pyrotechnics
Calcium chromate	1	Corrosion control
Cesium chromate	1	Electronics
Copper chromate, basic	1	Wood preservative
Magnesium chromate	1	Refractory, catalysts
Strontium chromate	1	Corrosion control pigment
Iron chromite	2	Refractory

[a] List does not include sodium chromate and sodium dichromate.

[b] Several often produce multiple chromium chemicals.

chrome orange, molybdate chrome orange, and chrome green).[1] To illustrate
the importance of sodium dichromate in the manufacture of these chemicals,
the following examples are given. To produce potassium and ammonium
dichromate, sodium dichromate is reacted with potassium chloride and
ammonium sulfate, respectively. Potassium chromate can be generated by
additional reactions of the produced potassium dichromate with potassium
hydroxide. Chromic acid is produced by heating sodium dichromate with
sulfuric acid. Several formulations of basic chromic sulfate (most of which
are proprietary) are prepared with sodium dichromate as the main ingredient.
Varying amounts of sulfuric acid, sodium sulfate, organic acids, and other
undisclosed additives are reacted with sodium dichromate to produce
different basic chromic sulfates depending on their eventual end use.[1] The
majority of the chrome pigments are produced in a similar manner. Sodium
dichromate is generally reacted with an oxide form of the basic inorganic
constituent element (lead, zinc, molybdenum, etc.) of the chromate. There
are approximately 30 companies engaged in manufacturing chromium compounds
that have as their base ingredient sodium dichromate.[15,17]

1.2.3 Refractory Chromite

Refractory chromite refers to the grade of chromite that is used in the
production of refractory brick and shapes. Principally, refractory chromite
is used to manufacture basic (as opposed to acidic) non-clay refractories.
Pure chromite ore, mixtures of chromite and magnesite, and mixtures of
chromite and alumina are used to manufacture the refractory brick. The
proportion of chromite used is related to the specific temperature and
corrosion resistance requirements imposed by the refractory's end use.[18]

The production of chromite-containing refractory consists of four
general steps, raw material processing, materials forming, firing, and final
processing. In the raw material processing step chromite, magnesite,
dolomite, and other raw materials are crushed, calcined, ground, and sized.
In the forming step, the prepared raw materials are homogeneously mixed and
formed into brick and shapes. In the firing step, the formed brick and
shapes are either dried and fired in a kiln or they are fusion melted and
cast into molds. The final processing step can consist of simple product

packaging or it can involve more detailed operations such as final grinding and milling, tar impregnation, and tempering.[19] Each of the more detailed finishing operations is performed to impart certain characteristics to the refractory to improve its end use performance. Twenty-two companies operating a total of 35 plants have been identified to be producing refractory using chromite ore raw material.[20]

1.3 CHROMIUM USES

In 1981, 791 Gg (879,000 tons) of chromite ore were consumed in the United States and converted into chromium-containing products.[6] The domestic consumption of chromite raw materials can essentially be attributed to three primary user groups or industries, metallurgical, chemical, and refractory. Of the total chromite consumed in 1981, 57 percent or 451 Gg (501,000 tons) was for metallurgical uses, 27 percent or 214 Gg (237,000 tons) was for chemical uses, and 16 percent or 126 Gg (141,000 tons) was for refractory uses.[6] Within these primary consumption groups several secondary chromium materials are produced that function either as a final product (e.g., refractory) or as an intermediate in the manufacture of other consumer goods (e.g., stainless steel). Figure 1-3 illustrates the qualitative distribution of chromium use in both the primary and secondary consuming sectors.[22] A broader and more quantitative perspective of chromium consumption in the United States, as defined by the Standard Industrial Classification (SIC) category in which final use of the chromium occurs, is presented in Figure 1-4.[9] Domestic consumption and distribution patterns of chromium within the metallurgical, chemical, and refractory use groups are summarized in the following sections.

1.3.1 Metallurgical Uses

Chromium's use in the metallurgical industry is to enhance such properties as hardenability, creep and impact strengths, and resistance to corrosion, oxidation, wear, and galling.[9] In the metallurgical use group in 1981, 70 percent of the chromium consumed (as ferrochromium) was used in the production of stainless steels. Eighteen percent of the chromium was used to produce full-alloy steels, 3 percent was used for low-alloy and
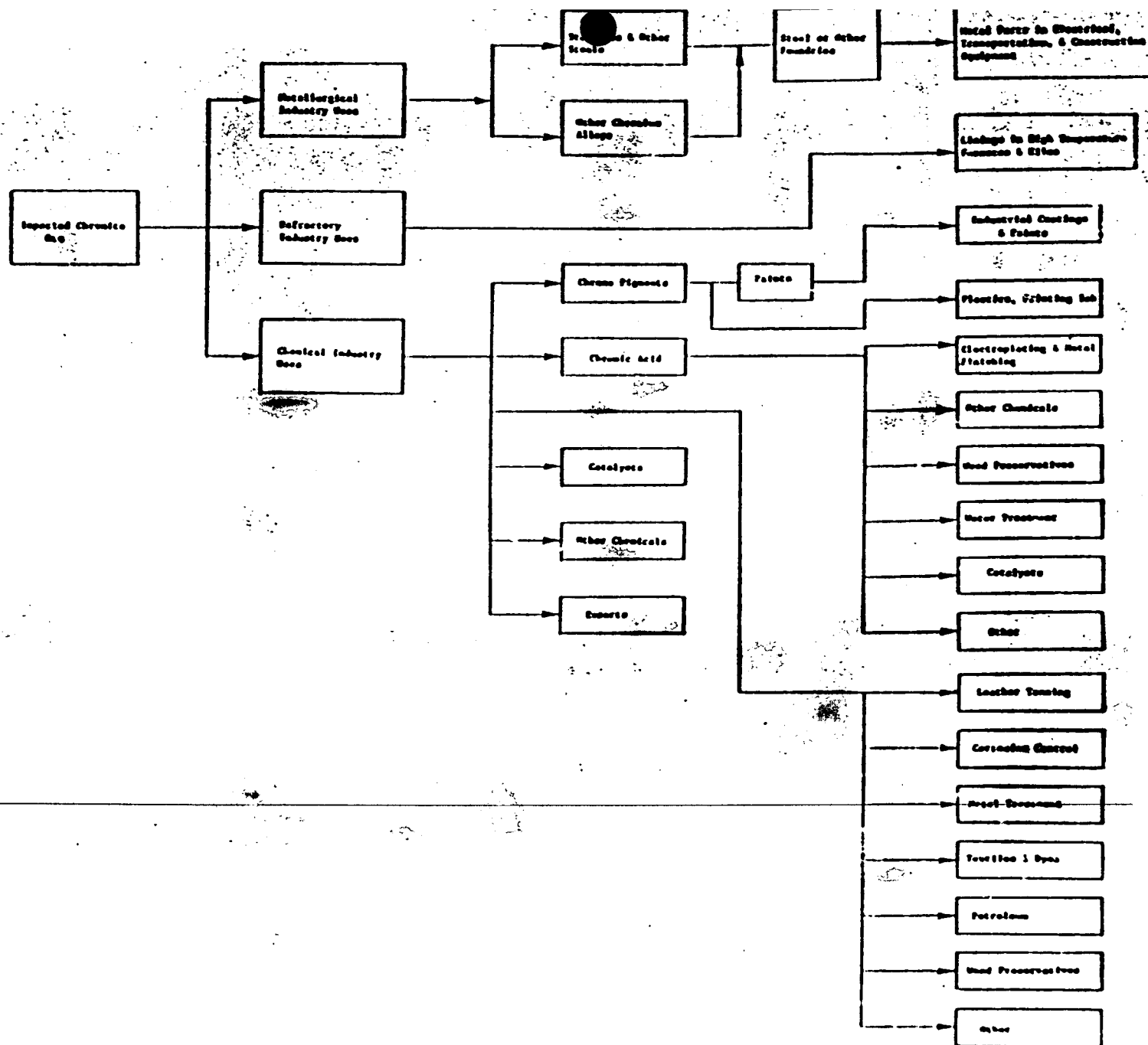
Figure 1-3. Primary and secondary use distribution of chromium in the United States.[22]

Transportation Equipment
SIC 37
108,000 Mg (120,000 tons)

Construction Products
SIC 15,16
90,000 Mg (100,000 tons)

Machinery - SIC 35,36
85,000 Mg (94,000 tons)

Fabricated Metal Products
SIC 363
40,000 Mg (44,000 tons)

United States
Chromium Demand
531,000 Mg
(590,000 tons)

Refractory Products
SIC 33,3297
63,000 Mg (70,000 tons)

Plating of Metals
SIC 3471
17,000 Mg (19,000 tons)

Chemicals - SIC 281
66,000 Mg (73,000 tons)

Other Miscellaneous Products
63,000 Mg (70,000 tons)

Figure 1-4. Final consumer use distribution of chromium in the
United States in 1978.[9]

electrical steels, and 2 percent was processed into carbon steels.[6] The remaining 7 percent was used in a variety of other metallurgical products including cast irons and nonferrous alloys. The function of chromium in these products is to enhance their mechanical properties or to impart special properties of electrical or abrasive resistance. The chromium steels, alloys, and cast irons produced by the metallurgical industry are used primarily in the manufacture of transportation, electrical, and construction equipment, heavy machinery, and fabricated metal products. Chromium is used to produce a wide variety of transportation vehicles including automobiles, motorcycles, bicycles, boats, trains, and snowmobiles. Both commercial and military aircraft engines are produced with chromium. Chromium is also used in volume in stainless steel tankers to haul milk, acids, and chemicals, and in bulk hopper trailers to haul fertilizers and hygroscopic materials. In the construction industry chromium metallurgical products are used for oil and gas exploration and production, petroleum refinery fabrication, power plant sulfur dioxide wet scrubbers, and bridge construction.[9]

In the machinery industry chromium metals are used to manufacture food processing equipment, high speed machine tools, cutting and forming equipment, and machine tool accessories, including dies and measuring devices. Chromium use in the fabricated metal products industry covers such products as cutlery, hand tools, general hardware, hospital equipment, and home appliances.[9] Based on 1978 figures, the combination of transportation, construction, machinery, and fabricated metal products consume- uses of chromium constituted about 60 percent of the total chromium used in the United States (see Figure 1-4).[1]

1.3.2 Chemical Uses

In the chemical use group, chromium chemicals, primarily sodium chromate and sodium dichromate, are used to manufacture a wide slate of other consumer-oriented chromium chemicals and products that have uses in the following areas.

- paints and pigments
- leather tanning liquors
- metal plating and finishing solutions

- corrosion inhibitors
- catalysts
- drilling muds
- wood preservatives
- textile mordants and dyes

A percentage breakdown of the amount of chromium (as sodium dichromate) used in each of the areas given above is shown in Figure 1-5.[15] Approximately 70 percent of the chromium consumed domestically for chemical uses is accounted for in the preparation of pigment, metal plating, and leather tanning compounds.[15] Chromium pigments are used primarily in paints, inks, and roofing granules. Metal plating solutions, primarily chromic acid, are used in producing decorative automobile trim and appliance exteriors. Chromium leather tanning liquors are the most widely used tanning products, except for the tanning of heavy cattle hides in which vegetable tanning oils are predominant.[1] A list of the key chromium chemicals applied in all the end use areas given above is presented in Table 1-5.

1.3.3 Refractory Uses

In the refractory use group, chromium in the form of chromite ore, is used primarily to produce chrome brick, chrome-magnesite brick, and magnesite-chrome brick refractory, which is used to line furnaces, kilns, converters, incinerators, and other high temperature industrial equipment.[2] Chromium refractory materials are also used as coatings to close pores and for joining refractory brick within a furnace or kiln.[12] By far, the major consuming industry for chromium refractory materials is the iron and steel industry. Other significant chromium refractory consuming industrial sectors include glass manufacturing, nonferrous metal production, primary minerals smelting, and ceramic production.[18]

Chromium (in the form of chromite) consumption in the refractory industry has recently demonstrated a declining trend. In the period from 1980 to 1981, chromite consumption by the refractory industry declined 10 percent.[6] From 1977 to 1981, chromite consumption by the refractory industry declined by approximately 37 percent.[22] The increased use of magnesite is a major reason for the decline in the use of chromium for the manufacture of refractory.[9]

Chromic Acid/Metal Plating-25 %
37,923 Mg (42,137 tons)

Pigments and Paints - 24 %
32,506 Mg (36,118 tons)

Leather Tanning Liquors - 17 %
23,025 Mg (25,583 tons)

Chromium Consumed as
Sodium Dichromate in
1982 - 135,441 Mg
(150,490 tons)

Drilling Muds/ Textiles - 8 %
10,835 Mg (12,039 tons)

Corrosion Inhibitors - 7 %
9,481 Mg (10,534 tons)

Exports - 8 %
10,835 Mg (12,039 tons)

Wood Preservatives,Catalysts,
Other - 8 %
10,835 Mg (12,039 tons)

Figure 1-5.   End use tree for sodium dichromate in 1982.[15]

TABLE 1-5.   MAJOR CHROMIUM USES AND KEY CHROMIUM CHEMICALS INVOLVED[1]

Chromium Chemical Use Area	Key Chromium Chemicals Involved
Paints and Pigments	Chrome Yellow[a] Chrome Orange[a] Chrome Oxide Green Molybdate Orange[a] Chrome Green Zinc Chromate
Leather Tanning Liquor	Basic Chromium Sulfate
Metal Finishing and Plating	Chromic Acid
Corrosion Inhibitors	Zinc Chromate Zinc Tetroxychromate Strontium Chromate Lithium Chromate
Catalysts	Cadmium Chromate Copper Chromate Magnesium Dichromate Nickel Chromate Copper Chromite
Drilling Muds	Chromium Lignosulfonate
Wood Preservatives	Chrome Copper Arsenate Chrome Zinc Chloride
Textile Mordants and Dyes	Chromic Chromate Chromic Chloride (hydrated) Chromic Fluoride Chromic Lactate

[a]Contains lead chromate.

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CHAPTER 2.

CHROMIUM SOURCE CATFGORIES AND EMISSIONS

2.0 GENERAL

The list of chromium source categories that were analyzed in this study for their ambient exposure impacts is consistent with the chromium production and use industries outlined in Sections 1.2 and 1.3 of the previous chapter. The only source categories analyzed that were not related to the general chromium production and use structure are the combustion categories (i.e., coal and oil combustion and incinerators) and the categories where chromium is a natural component of processed materials (i.e., cement and asbestos manufacture).

In the following sections the chromium emissions potential from each of the 12 source categories studied is summarized. Each source category summary explains the source or sources of the category's chromium emissions, factors affecting emissions, the valence state(s) of the emissions, and how chromium emissions estimates were obtained for individual plants in the category.

2.1 CHROMIUM ORE REFINING

This source category pertains to plants that process or refine chromium ore (chromite) for use by other industries such as chromium refractory manufacturing. The only domestic facility of this type identified to be in operation is American Minerals, Inc. in New Castle, Delaware.

The chromite refining process consists basically of an ore crushing step, a screening or sizing step, an ore drying step, and an ore grinding step. The flow chart in Figure 2-1 illustrates the chromite refining process.[2,3,4] The operations performed to refine the chromite are relatively low temperature such that only particulate emissions are

Chromite
Ore

Primary
Crusher ▲

Screens

Oversized
Ore

Rotary
Dryer ▲

Hardinge
Mill ▲

Oversized
Ore

Classifier

Cyclone
Separator

Partial Ore
Recycle

▲ Primary Chromium Emission Point

Ore
Storage ▲

Ore
Packaging ▲

Refined Chromite
Ore
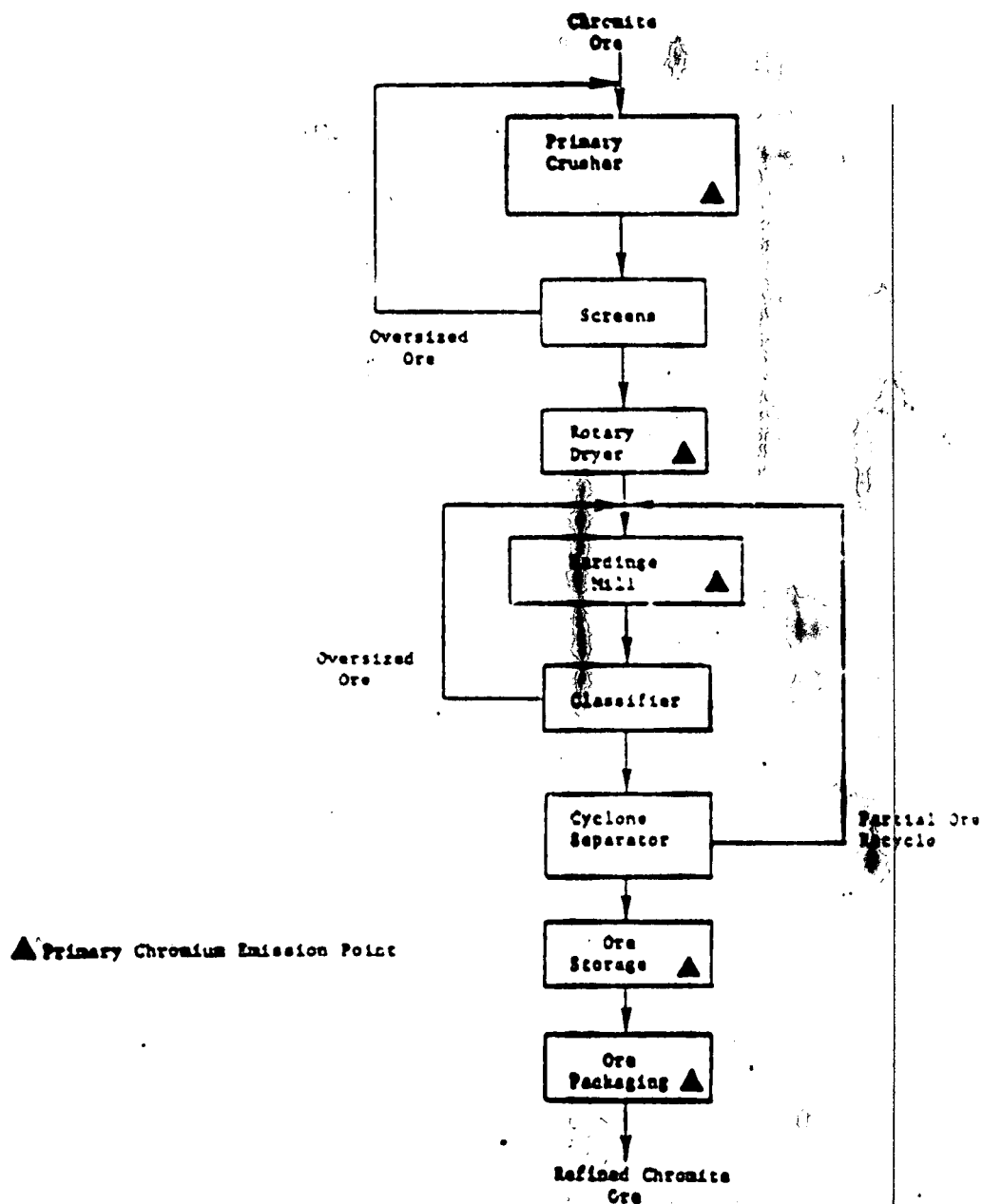
Figure 2-1.   Flow chart of the chromite ore refining plant in
New Castle, Delaware.[2,3,4]

generated. The particulate emissions are chromite ore particles of which
the chromium fraction is chromium oxide (Cr_2O_3). Chromium oxide is an
insoluble chromium compound (see Table 1-2) which contains chromium in its
trivalent state.

Chromium emissions and stack geometry data on the Delaware facility
that are needed for the modelling/exposure analysis were obtained from
Delaware state air quality permits.[2,3,4] Precise longitude/latitude
coordinates for the chromite refining plant, which are also needed for the
modelling/exposure analysis, were unavailable. Coordinates for the plant
were estimated using an atlas containing a longitude/latitude coordinate
system and a knowledge of the approximate location of the plant in New
Castle, Delaware. Even though exact coordinates are not available, the
impact on the modelling/exposure analysis is not expected to be significant
because the surrounding area of the New Castle plant has a consistently
urban population structure out to the 20 km limit examined by the dispersion
model.

2.2 CHROMIUM CHEMICALS MANUFACTURE

Over 30 chromium-containing chemicals are produced in the United
States, but only 2, sodium chromate (Na_2CrO_4) and sodium dichromate
($Na_2Cr_2O_7$), were specifically addressed in the modelling/exposure analysis.
The analysis was limited to these two chemicals because they are the most
commercially important chromium chemicals and their production exhibits the
greatest potential for atmospheric chromium release (in the chemical
industry). Sodium chromate and dichromate are the most commercially
important chromium chemicals because of their volume of production and most
importantly because they are the basic chemicals from which all other
domestically produced chromium chemicals are made.[5,6,7]

Generalized flow charts showing how sodium chromate and dichromate are
produced are given in Figures 2-2 and 2-3.[5,8-15] In the production of
sodium chromate (Figure 2-2), chromium emissions originate with the chromite
ore raw material that is brought into the plant. Chromite ore generally
undergoes some type of preparation such as drying or grinding before it is
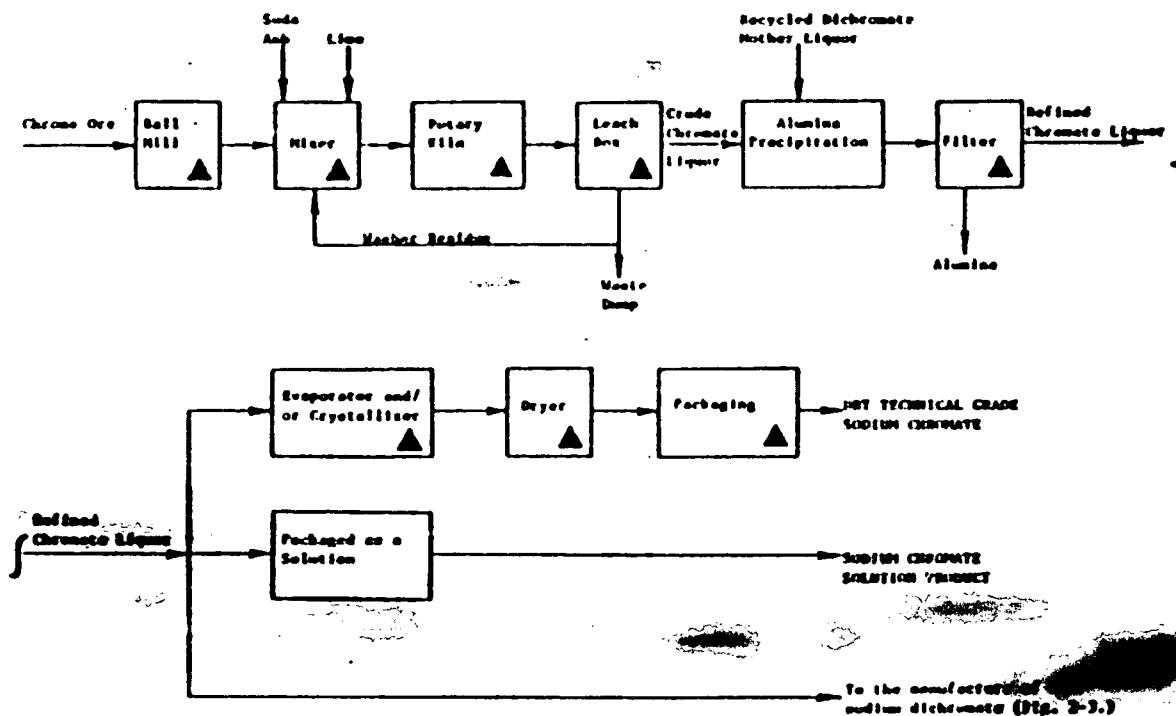
Figure 2-2. Flow chart of a sodium chromate production process. 5.8-15
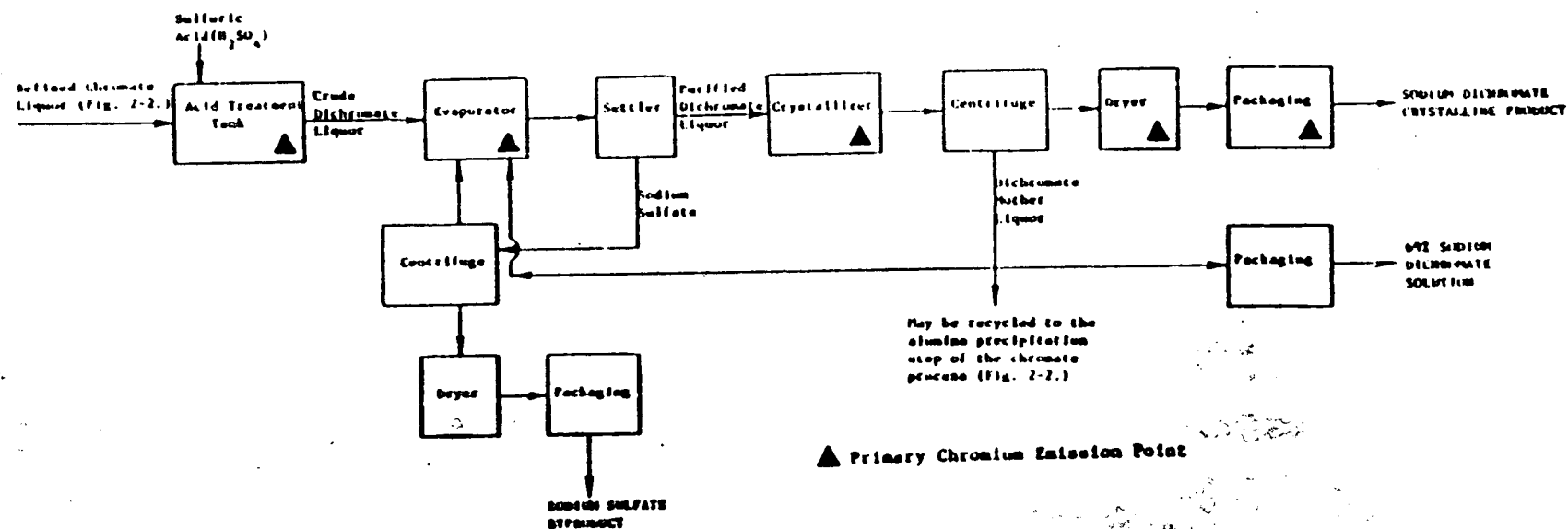
Figure 2-3. Flow chart of a sodium dichromate production process. 5,8-15
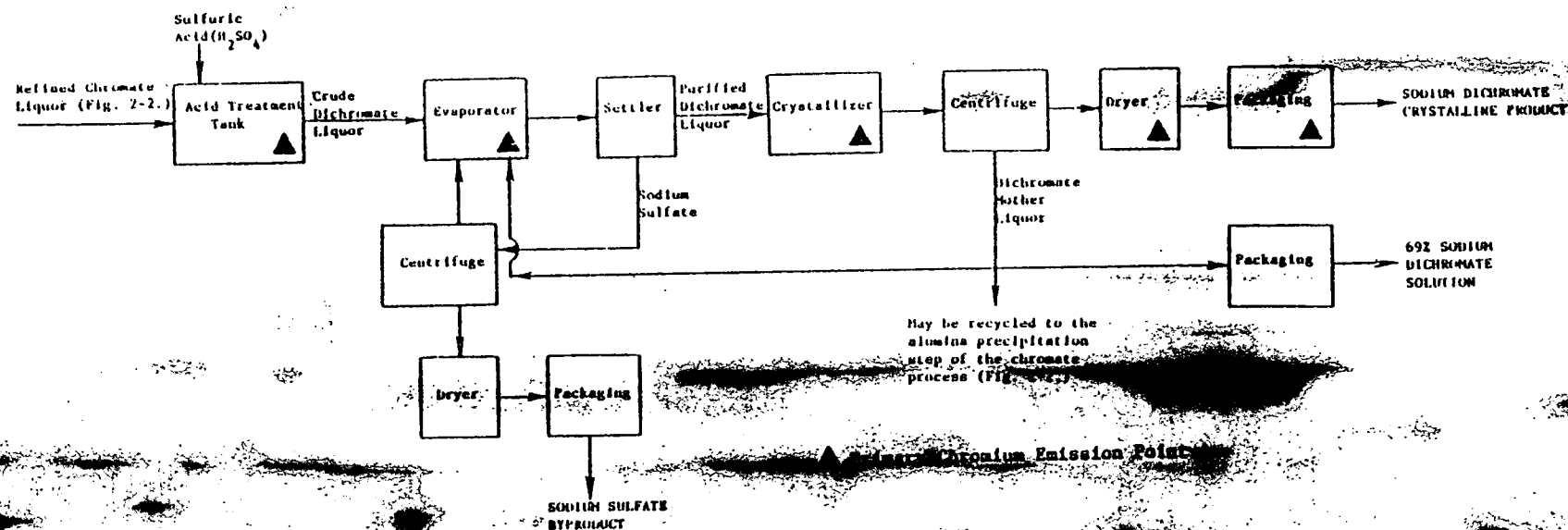
Figure 2-3.   Flow chart of a sodium dichromate production process.[5,8-15]

ready to be entered into the chromate process. Chromium emissions are released during these preparatory steps as insoluble chromite particles (Cr_2O_3) containing trivalent chromium. The chromite ore is then mixed with other process reactar : prior to being heated in a kiln. This mixing operation also generates chromite particulate emissions.

After mixing, the chromite ore-containing mass is fed into a rotary kiln for roasting. It is in the kiln that the sodium chromate compound is produced. Chromium particulate emissions from the kiln may then be in the form of unreacted chromite or sodium chromate. Sodium chromate emissions contain chromium in a hexavalent state, whereas chromite emissions generally contain a trivalent form of chromium. The chromium particulate emissions of all processing steps after the rotary kiln contain essentially only hexavalent chromium.

In the production of sodium dichromate (Figure 2-3), chromium particulate emissions contain only hexavalent chromium because only chromate (Cr^{+6}) materials are input to the process and no reducing reactions occur. It should be noted that the solubilities of the hexavalent chromium compounds emitted in the sodium chromate and dichromate processes are much different from the trivalent chromium oxide particles emitted from the pre-kiln steps of the sodium chromate process. Chromium oxide (Cr_2O_3) is insoluble in water, but sodium chromate and sodium dichromate are very water soluble exhibiting solubility values in cold water of 87.3 and 238 grams per 100 milliliters, respectively.[16]

The locations of the three domestic plants currently producing sodium chromate and sodium dichromate are given in Table 2-1 along with an indication of other chromium chemicals they often produce.[17] Chromium emissions data used in the modelling/exposure analysis for all three plants were obtained from state air quality permits. Stack geometry and geographic coordinate location data for all three plants were also available state air permits.[9-15,18,19,20]

2.3 REFRACTORY MANUFACTURE

Chromium emissions from the manufacture of refractory materials occur because chromite ore, chromium oxide and much lesser amounts of chromic

TABLE 2-1. LOCATIONS OF PLANTS IN THE UNITED STATES PRODUCING SODIUM CHROMATE AND SODIUM DICHROMATE[17]

Plant Name	Location	Chromium Chemicals Produced in Addition to Sodium Chromates
Allied Chemical Corp.[a]	Baltimore, MD	Ammonium dichromate Chromic acid Potassium dichromate Potassium chromate
Diamond Shamrock Corp.[b]	Castle Hayne, NC	Chromic acid
American Chrome & Chemicals, Inc.[a]	Corpus Christi, TX	None

[a]Produce sodium chromate as an end product.

[b]Uses all sodium chromate production captively to produce sodium dichromate.

acid, sodium chromate, and potassium chromate are used as refractory process raw materials,[7,21,22,23] Chromite ore and chromium oxide are used to produce refractory brick and shapes and castable refractories such as mortars and gunning and ramming mixes. Generally chromium is input to a refractory process as pure chromite ore, as chromium oxide, as a mixture of chromite and magnesite, or as a mixture of chromite and alumina. The proportion of chromite or chromium oxide used in various refractory processes is related to the specific temperature and corrosion resistance requirements imposed by the refractory's end use.[24] Figure 2-4 illustrates a typical flowchart for the production of chromium refractory brick.[25] Castable refractory materials are produced by simply mixing and bagging together dried and ground raw materials such as chromite, magnesite, and fluxes and bonding agents.

Chromium emissions from refractory manufacture occur primarily during raw materials handling and preparation operations such as drying, crushing, screening, storage and conveyance, grinding, and mixing. Particulate emissions from these operations contain trivalent chromium as chromite or chromium oxide and/or hexavalent chromium as chromic acid, sodium chromate, or potassium chromate. Particulate emissions streams may also contain other refractory materials such as magnesite, dolomite, and alumina. The exact composition depends on the particular type of refractory material being produced. Trivalent chromium particulate emissions predominate over hexavalent emissions in the refractory industry because the usage of trivalent chromium compounds greatly outweighs hexavalent chromium compound usage by two to three orders of magnitude.[23]

There are approximately 298 refractory plants in the United States, however, only 35 are known to be producing chromium-containing refractory materials.[30] Table 2-2 contains a list of the 35 plant locations. Chromium emissions estimates and stack geometry data for these facilities were obtained from state air quality permits and the U. S. EPA National Emissions Data System (NEDS).[18,22,26-29,31] NEDS information was used only in the cases of a few plants for which no state permit data were available. For
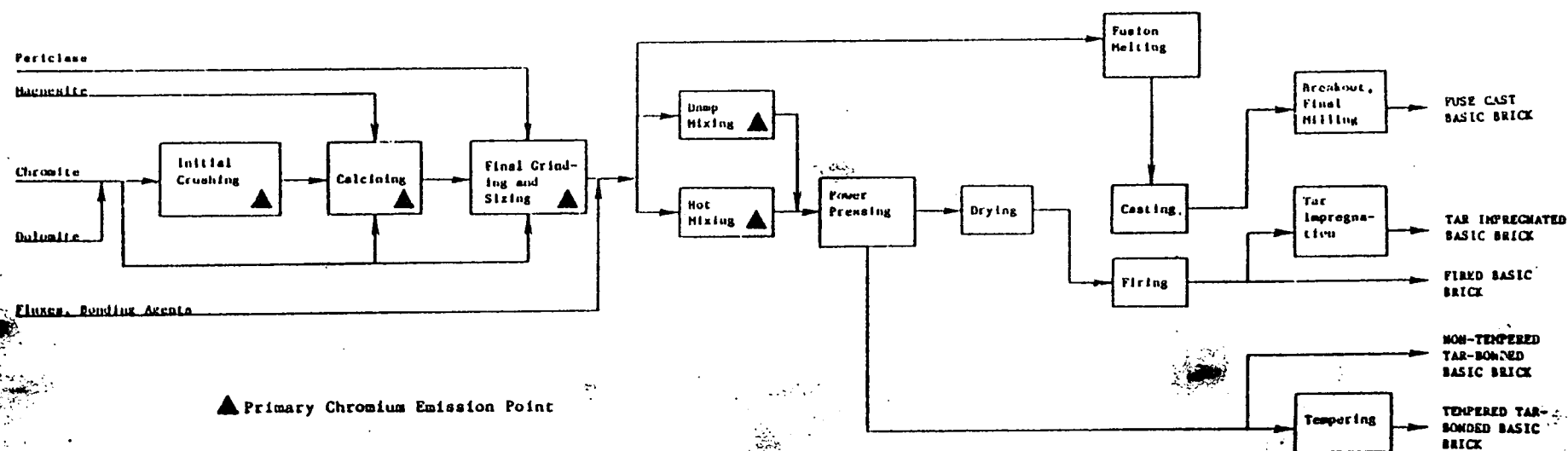
Figure 2-4. Flow chart illustrating chromium refractory brick production.[24]

TABLE 2-2. FACILITIES IDENTIFIED TO BE PRODUCING CHROMIUM-CONTAINING REFRACTORY MATERIALS[30]

Company	Plant Location
Basic Refractories	Maple Grove, OH
BMI, Inc.	Crown Point, IN
	South Webster, OH
	South Rockwood, MI
Bognar and Company, Inc.	Somerset, PA
C-E Refractories	Aurora, IL
	Chicago Heights, IL
Carborundum Company	Falconer, NY
	New Carlisle, IN
	New Iberia, LA
Chicago/Wellsville Fire Brick Companies	Wellsville, MO
	Chicago, IL
Coastal Refractories	Cincinnati, OH
Corhart Refractories Co.	Buckhannon, WV
	Pascagoula, MS
Didier Taylor Refractories Corporation	South Shore, KY
	Cincinnati, OH
General Refractories Co.	Lehi, UT
A. P. Green Refractories Co.	Mexico, MO
	Tarentum, PA
	Pueblo, CO
Harbison-Walker Refractories	Baltimore, MD
	Hammond, IN
Kaiser Refractories	Columbiana, OH
	Moss Landing, CA
	Plymouth Meeting, PA
Lava Crucible Refractories Company	Zelienople, PA
Magneco/Metnel, Inc.	Negley, OH
Martin Marietta	Manestee, MI
North American Refractories	Womelsdorf, PA
The Quigley Company	Old Bridge, NJ
Resco Products, Inc.	Norristown, PA
Riverside Refractories, Inc.	Pell City, AL
Salazar & Sons, Inc.	Chicago, IL
Zedmark, Inc.	Dover, OH

the few small plants with no available state permit data or NEDS
information, chromium emissions were assumed to be comparable to other
refractory plants of similar size producing similar refractory materials.

2.4 ASBESTOS PRODUCTION

Chromium is potentially emitted from asbestos mining and milling
operations because it is a constituent of chrysotile the primary
asbestos-containing mineral. Chromium levels in chrysotile have been found
to be about 1,500 weight parts per million (wt ppm) or 0.15 percent of total
mineral weight. Particulate emissions from chrysotile mining and milling
operations have been estimated to contain chromium at the same level.[32]

During the chrysotile mining and particularly the milling processes,
particulate emissions are released because the chief objective of the
processes is to break down the chyrsotile mineral and extract the asbestos
fibers. To extract the asbestos fibers the waste rock components of the
chrysotile (including chromium) are eliminated in a series of cleaning
circuits in which crushing, screening, and various separation operations are
performed. These cleaning circuits generate chromium-containing particulate
emissions.

The magnitude of chromium emissions from asbestos production operations
is estimated to be low because of the stringent level of control required on
these facilities for asbestos emissions by Federal and State authorities.[33]
The control measures applied for asbestos emissions are equally as effective
on chromium emissions. The most recent studies available estimated
controlled chromium emissions from asbestos production to be essentially
zero tons per year or not significant enough to be reported.[32] This
estimate is based on data from the early 1970's and it is probable that
control measures since that time have improved.

The chromium air pollution potential from asbestos production appears
to be insignificant. The asbestos production source category was therefore
not included in the modelling/exposure analysis of this study.

2.5 LEATHER TANNING

Chromium can potentially be emitted from leather tanning facilities because sodium dichromate-based chemicals are used as tanning liquors for the majority of animal hides tanned in the United States.[24,35] Chromium tanning liquors are prepared by mixing sodium dichromate (Cr^{+6}) with other chemicals such as sulfuric acid. Chromium tanning solutions containing predominantly basic chromium sulfate are prepared on-site at the tannery or they can be purchased already formulated from specialty chemical producers. When prepared at the tannery the potential exists for emissions of highly soluble sodium dichromate containing hexavalent chromium as a result of handling and mixing procedures. When purchased from off-site formulators no chromium emissions potential exists because the chromium tanning compounds are in solution. Many tanneries purchase pre-formulated chromium tanning liquors as opposed to formulating their own.[35] In tanneries that do formulate their own liquors, the process is generally short in duration and very intermittent, thereby lessening potential chromium emissions. In addition, because of the value of the sodium dichromate raw material, every reasonable attempt is made to minimize dichromate losses.

Another minor method by which chromium emissions can be released at leather tanning facilities involves a process known as leather buffing. Buffing is a technique in which tanned leather is brushed repeatedly to produce a type or form of leather known as suede. The brushing or buffing procedure can dislodge small leather particles containing chromium from the tanning process. Chromium in these particles is in the form of trivalent chromium (Cr^{+3}) because the basic chromium sulfate tanning liquors that are used contain trivalent chromium.[34,35] Trivalent chromium has the function in tanning of fixing or stabilizing collagen fibers in the hides so that they can no longer biodegrade. Particulate emissions from buffing are not exhausted to the atmosphere but instead are contained within the tannery building.[35,36] Buffing operations are not continuous, but are dependent on the demand for suede leather production.

Contacts with states such as Massachusetts that have many leather tanneries indicated that tanning operations are not viewed as chromium air emissions sources by State regulatory agencies.[35,36] This viewpoint appears justified based on an examination of the potential severity of chromium air emissions from tanning operations such as tanning liquor preparation and buffing. One state, Maine, has partially verified its non-regulation of tanning operations by conducting ambient chromium monitoring to determine increases in background chromium levels in areas containing tanneries. In tests of similar areas with and without a tannery, atmospheric chromium levels are measured to be the same or slightly less in the tannery area as opposed to the non-tannery area.[35] Though certainly not conclusive, the results indicate that tanneries are not contributing to atmospheric chromium levels in the areas where they are located.

Based on their low potential for atmospheric chromium emissions and the indication that they do not increase ambient air chromium levels, leather tanning operations using chromate tanning liquors were not included in the modelling/exposure analysis of this study.

2.6 CEMENT MANUFACTURING

The types of facilities that were addressed in this source category are those producing portland cement. The production of portland cement is a source of chromium emissions because chromium can be a trace component of the cement process raw materials such as limestone and iron ore and of coal and oil fuels burned in cement operations such as kilns. Chromium levels in finished cement have been measured and found to range from 27.5 - 60 wt ppm with an average concentration being 41.2 wt ppm. Of the 41.2 wt ppm that was chromium, only 4.1 wt ppm was soluble and of this amount 2.9 wt ppm was chromium in a hexavalent form.[37] The insoluble chromium component of these samples is predominantly chromium oxide (Cr^{+3}). Though limited in extent these data agree with the available chromium emissions information on the cement industry. The majority of chromium emissions from the cement industry appear to be released as trivalent chromium in the form of chromium oxide.[38]

As illustrated in Figure 2-5, cement is produced by one of two methods known simply as the wet and dry processes.[39] The only distinction between the two is that in the wet process water is added to the cement raw materials mixture prior to its entering the kiln. The major sources of chromium and general particulate emissions in both processes are the kiln, clinker cooler, and clinker grinder operations.[38,39] Chromium levels in the particulate emissions of these operations have been measured and the available results are given in the Table 2-3. As shown in the table chromium levels may vary greatly, even by two orders of magnitude for the same process operation.[40] The chromium levels in particulate emissions that can occur during raw materials preparation operations such as drying, crushing, grinding, and mixing and blending have not been reported in the available literature.

For the purposes of the chromium modelling/exposure analysis, chromium emissions from the kiln, clinker cooler, and clinker grinder operations were estimated for the existing portland cement plants in the United States. Most plants have multiple kilns, clinker coolers, and clinker grinders. The kiln, clinker cooler, and clinker grinder sources were analyzed because they represent the greatest particulate and chromium emissions sources in the cement process and they are the only cement process sources for which chromium component information has been determined. Chromium emissions from each individual plant were estimated using the chromium data in Table 2-3 and general particulate emissions and emission factor data from NEDS and the cement industry new source performance standard (NSPS) background information document (BID).[43] For the kiln and clinker cooler sources an average chromium content of 900 wt. ppm was assumed for calculation purposes. Stack geometry and geographic coordinate location information for all facilities was obtained from NEDS. The total number of cement plants analyzed was 163.[31,44] The locations of these facilities are given in Table 2-4.

2.7 MUNICIPAL REFUSE AND SEWAGE SLUDGE INCINERATION

Chromium is released during the incineration of municipal refuse and wastewater sewage treatment sludge because these materials contain varying

```
┌──────────────┐   ┌──────────────┐   ┌──────────┐  Dry        ┌──────────────┐   ┌──────────┐   ┌──────────┐
│ Quarrying Raw│──▶│ Primary and  │──▶│ Raw      │  Process  ┌▶│ Raw Material │──▶│ Grinding │──▶│ Air      │──▶∫
│ Materials    │   │ Secondary    │   │ Materials│──────────┤  │ Proportioned │   │ Mill     │   │ Separator│
└──────────────┘   │ Crushing     │   │ Storage  │          │  └──────────────┘   └──────────┘   └──────────┘
                   └──────────────┘   └──────────┘          │
                                                            │  ┌──────────────┐              ┌──────────┐
                                                            └─▶│ Raw Material │ ─ ─ ─ ─ ─ ─▶│ Grinding │─ ─ ─ ─ ─▶∫
                                                     Wet       │ Proportioned │      ▲       │ Mill     │
                                                     Process   └──────────────┘      │       └──────────┘
                                                                                   Water
```

```
        ┌──────────────┐   ┌──────────┐                         Fuel                              Gypsum
        │ Dry Mixing   │   │          │                          │                                  │
∫ ─────▶│ and          │──▶│ Storage  │─────────┐                ▼                                  ▼
        │ Blending     │   │          │         │            ┌──────┐  ┌──────────┐  ┌──────────┐  ┌┴─────────┐  ┌──────────┐
        └──────────────┘   └──────────┘         ├───────────▶│ Kiln │─▶│ Clinker  │┄▶│ Storage  │─▶│ Air      │─▶│ Storage  │─▶ CEMENT
                                                │            │  ▲   │  │ Cooler ▲ │  │          │  │ Separator│  │          │   PRODUCT
        ┌──────────────┐   ┌──────────┐         │            └──────┘  └──────────┘  └──────────┘  └──┬───────┘  └──────────┘
        │ Slurry Mixing│   │          │         │                                                     ▲ │
∫ ─────▶│ and          │──▶│ Storage  │─────────┘                                                     │ ▼
        │ Blending     │   │          │                                                            ┌──┴───────┐
        └──────────────┘   └──────────┘                                                            │ Grinder  │
                                                                                                   │     ▲    │
                                                                                                   └──────────┘
```

▲ Primary Chromium Emission Point

Figure 2-5. Basic process flow diagram for wet and dry cement production plants.[39]

TABLE 2-3. CHROMIUM LEVELS FOUND IN THE PARTICULATE EMISSIONS
OF CEMENT PLANT OPERATIONS[38,40,41]

Process Operation	Total Chromium Concentration in Particulate Emissions (wt ppm)
Kilns	41 (0.0041%) 1700 (0.17%)[a] 110 (0.011%)[c]
Clinker Coolers	41 (0.0041%) 1700 (0.17%)[a]
Clinker Grinders	390 (0.039%)[b]

[a] Average value of three tests.

[b] Average value of several tests total number of which was unspecified.

[c] Single measurement of dust from one kiln.

TABLE 2-4. LOCATIONS OF CEMENT PLANTS IN THE UNITED STATES[31,44]

State, City (number of plants per city if more than 1)	Total Number of Plants per State
Alabama	
Birmingham (3)	
Calcera	
Demopolis	
Leeds	
Mobile	
Ragland	
Alaska	0
Arizona	2
Clarkdale	
Pima County	
Arkansas	2
Foreman	
Okay	
California	10
Colton	
Davenport	
Lebec	
Lucerne Valley	
Mojave	
Monolith	
Redding	
San Andreas	
San Juan Bautista	
Victorville	
Colorado	4
Boulder County	
Florence	
LaPorte	
Portland	
Connecticut	0
Delaware	0
District of Columbia	0

TABLE 2-4 (CONTINUED). LOCATIONS OF CEMENT PLANTS

State, City (number of plants per city if more than 1)	Total Number of Plants per State
Florida	7
Brooksville	
Dade County (3)	
Hialeah	
Miami	
Tampa	
Georgia	3
Atlanta	
Clinchfield	
Rockmont	
Hawaii	2
Honolulu County	
Nanakuli	
Idaho	1
Inkom	
Illinois	4
Dixon	
Joppa	
LaSalle	
Oglesby	
Indiana	5
Buffington (2)	
Logansport	
Mitchell	
Speed	
Iowa	5
Buffalo	
Des Moines (2)	
Mason City (2)	
Kansas	5
Bonner Springs	
Chanute	
Fredonia	
Humboldt	
Independence	

TABLE 2-4 (CONTINUED). LOCATIONS OF CEMENT PLANTS

State, City (number of plants per city if more than 1)	Total Number of Plants per State

Kentucky
    Kosmosdale
    Louisville
	2

Louisiana New Orleans (3)	3
Maine Thomaston	1

Maryland
    Hagerstown
    Lime Kiln
    Union Bridge
	3

Massachusetts	0

Michigan
    Alpena
    Charlevoix
    Detroit (3)
    Essexville (2)
    Monroe County
    Petroskey
    Port Huron
    Wyandotte
	11

Minnesota	0
Mississippi Artesia	1

Missouri
    Cape Girardeau
    Clarksville
    St. Louis (2)
    Sugar Creek
	5

Montana
    Jefferson County
    Trident
	2

TABLE 2-4 (CONTINUED). LOCATIONS OF CEMENT PLANTS

State, City (number of plants per city if more than 1)	Total Number of Plants per State

Nebraska
    Louisville
    Superior
	2

Nevada Fernley	1
New Hampshire	0
New Jersey	0
New Mexico Tijeras	1

New York
    Cementon (2)
    Glen Falls
    Howes Cave
    Ravena
	5

North Carolina Castle Hayne	1
North Dakota	0

Ohio
    Fairborn
    Greene County (2)
    Paulding
    Superior
    Toledo
    Zanesville
	7

Oklahoma
    Ada
    Pryor
    Tulsa
	3

Oregon
    Huntington
    Lake Oswego
	2

TABLE 2-4 (CONTINUED). LOCATIONS OF CEMENT PLANTS

State, City (number of plants per city if more than 1)	Total Number of Plants per State
Nebraska	2
Louisville	
Superior	
Nevada	1
Fernley	
New Hampshire	0
New Jersey	0
New Mexico	1
Tijeras	
New York	5
Cementon (2)	
Glen Falls	
Howes Cave	
Ravena	
North Carolina	1
Castle Hayne	
North Dakota	0
Ohio	7
Fairborn	
Greene County (2)	
Paulding	
Superior	
Toledo	
Zanesville	
Oklahoma	3
Ada	
Pryor	
Tulsa	
Oregon	2
Huntington	
Lake Oswego	

TABLE 2-4 (CONTINUED). LOCATIONS OF CEMENT PLANTS

State, City (number of plants per city if more than 1)	Total Number of Plants per State
Pennsylvania	16
Bessemer	
Cementon	
Evansville	
Lehigh County	
Nazareth (2)	
Neville Island	
Northampton (3)	
Northampton County (2)	
Pittsburgh	
Wampum	
West Winfield	
York	
Rhode Island	0
South Carolina	3
Harleyville (2)	
Holly Hill	
South Dakota	2
Rapid City (2)	
Tennessee	4
Chattanooga	
Cowan	
Nashville	
Richard City	
Texas	18
Amarillo	
Buda	
Corpus Christi	
Dallas	
El Paso	
Ft. Worth	
Galena Park	
Houston	
Midlothian (2)	
Odessa	
Orange	
San Antonio (3)	
Sweetwater	
Waco (2)	

TABLE 2-4 (CONTINUED). LOCATIONS OF CEMENT PLANTS

State, City (number of plants per city if more than 1)	Total Number of Plants per State
Utah	2
Morgan	
Salt Lake City	
Vermont	0
Virginia	2
Botetourt	
Chesapeake	
Washington	4
Bellingham	
Metaline Falls	
Seattle (2)	
West Virginia	1
Martinsburg	
Wisconsin	4
Manitowoc	
Milwaukee (2)	
Superior	
Wyoming	0
Laramie	

amounts of chromium. The chromium content of municipal refuse consisting of paper and plastics ranges from 10 - 175 wt ppm with an average content being 30 wt ppm.[45] Dry sewage treatment sludges have chromium contents ranging from 22 - 30,000 wt ppm, with a mean content of 1,800 wt ppm and a median of 600 wt ppm.[46] The chromium content of sewage sludge is highly dependent on the types of facilities discharging into the local sewer. Treatment plants receiving wastewaters from electroplating shops and leather tanneries are likely to have sludges containing relatively high amounts of chromium that can be released upon incineration of the sludges.

The majority of municipal refuse incinerators are simple in design and have either refractory-lined or water-walled combustion chambers that are equipped with a grate upon which refuse is burned. The grate can be stationary, travelling, or vibrating depending on the design of the incinerator. In most cases, natural draft or slight induced draft is used to pull air up through the grate and carry out the primary refuse combustion process. The combustion gases from the primary chamber are then passed through a flame port where they are reheated and mixed with air to achieve more complete oxidation. Exhausts from the secondary combustion chamber are either sent to atmosphere or to a control device. The basic configuration of a representative municipal refuse incinerator is given in Figure 2-6.[47]

The most prevalent types of sewage sludge incinerators are multiple-hearth and fluidized-bed units. Multiple-hearth incinerators are relatively simple pieces of equipment, consisting of a steel shell lined with refractory. The interior of the incinerator is divided by horizontal brick arches into separate compartments or hearths. Alternate hearths are designed with openings to allow solid material to drop onto the hearth below. At the center of the unit, a shaft rotates rabble arms that are located on each hearth. To enable the incinerated material to move inward and then outward on alternate hearths, teeth on the rabble arms are placed at an angle. As sludge is fed through the roof of the incinerator, the rotating rabble arms and rabble teeth push the material across the hearth to drop holes where it falls to the next hearth. This process continues until
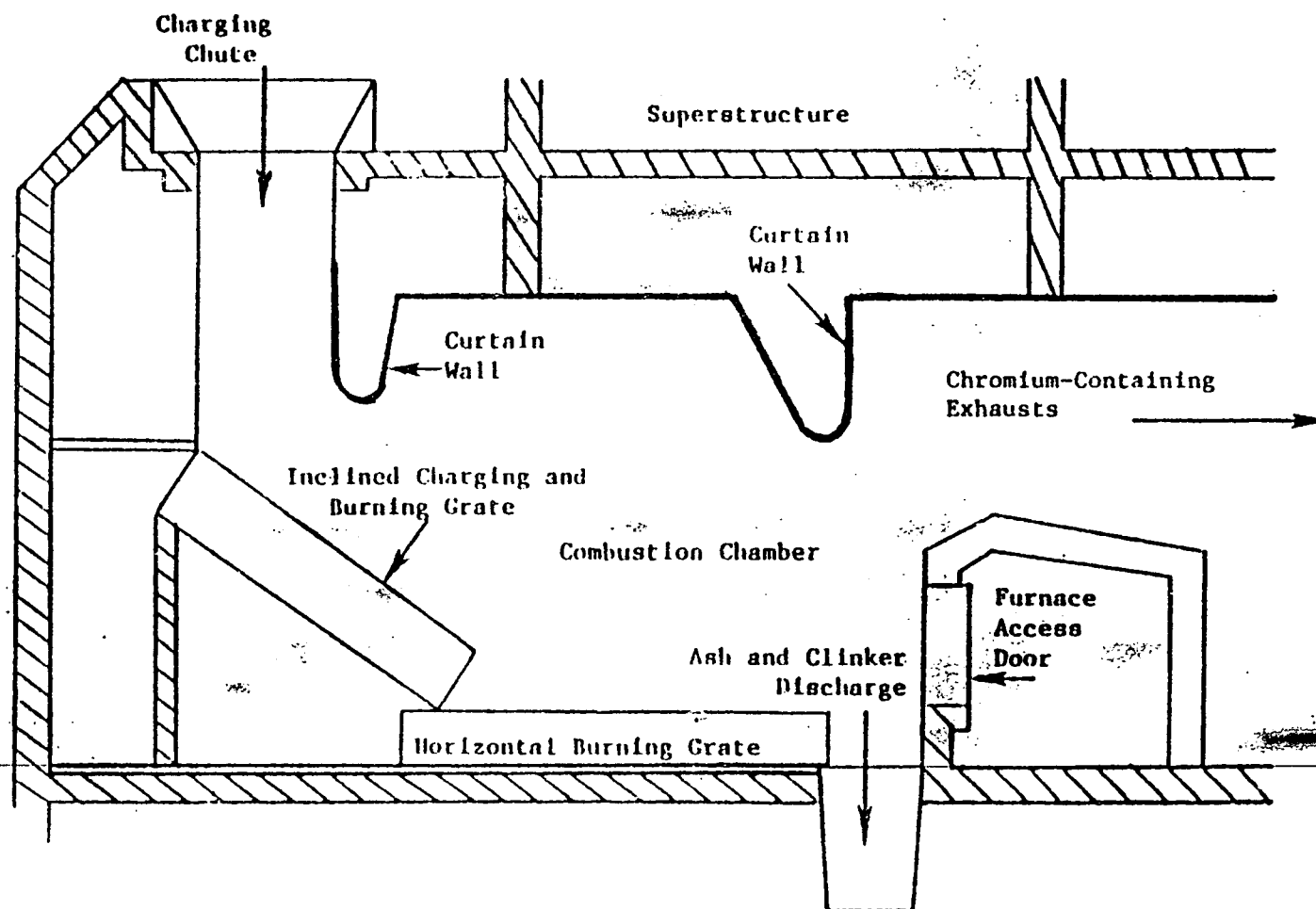
Figure 2-6. Basic configuration of a municipal refuse incinerator.[47]

the sterile ash produced by the oxidation steps is discharged from the bottom of the incinerator. Figure 2-7 presents a schematic diagram of a typical multiple-hearth sewage sludge incinerator.[48]

Figure 2-8 represents the basic operations found in a fluidized-bed unit.[50] In this operation dewatered sludge is introduced into the freeboard area of the incinerator just above the fluidized bed material (which is usually sand). Hot combustion gases rising from the bed evaporate remaining water in the sludge and sludge solids then enter the fluidized bed. The organic constituents of the sludge are oxidized to carbon dioxide and water vapor which exit the system as exhaust gases. During this reaction the bed is vigorously mixed and the bed temperature is maintained at 704-816°C (1,300-1,500°F). Remaining inorganic sludge material either deposits on the bed sand particles and is removed from the bottom of the reactor, or it can be made to exit with the exhaust gases. Air velocity through the bed is used to control the method of inorganic sludge material removal. Chromium emissions from this type of system are dependent on air flow velocity through the bed and the chromium content of the sludge.[50]

The potential for the volatilization of chromium during the incineration of refuse and wastewater treatment sludge is lessened because of the low vapor pressures exhibited by chromium at the temperatures encountered in these combustion systems. At 760°C (1,400°F) the vapor pressure of chromium is 6.1×10^{-8} mm Hg and at 980°C (1,800°F) the vapor pressure is 4.4×10^{-5} mm Hg.[46] Test data from one sludge incinerator indicate that uncontrolled chromium emissions can be as low as 8 percent of the potential amount present in the waste sludge.[46,50] Similar test data from another sludge incinerator controlled by a wet scrubber indicated that only about 0.01 percent of the potential chromium emissions from the controlled system were being released into the atmosphere.[46,51] It appears that the majority of the chromium components of incinerator wastes remain in the ash produced by the combustion.[46]

Information was not available in the literature on the chemical forms in which chromium is found in municipal refuse and sewage sludge. The chemical forms and resultant valence states that occur are probably varied
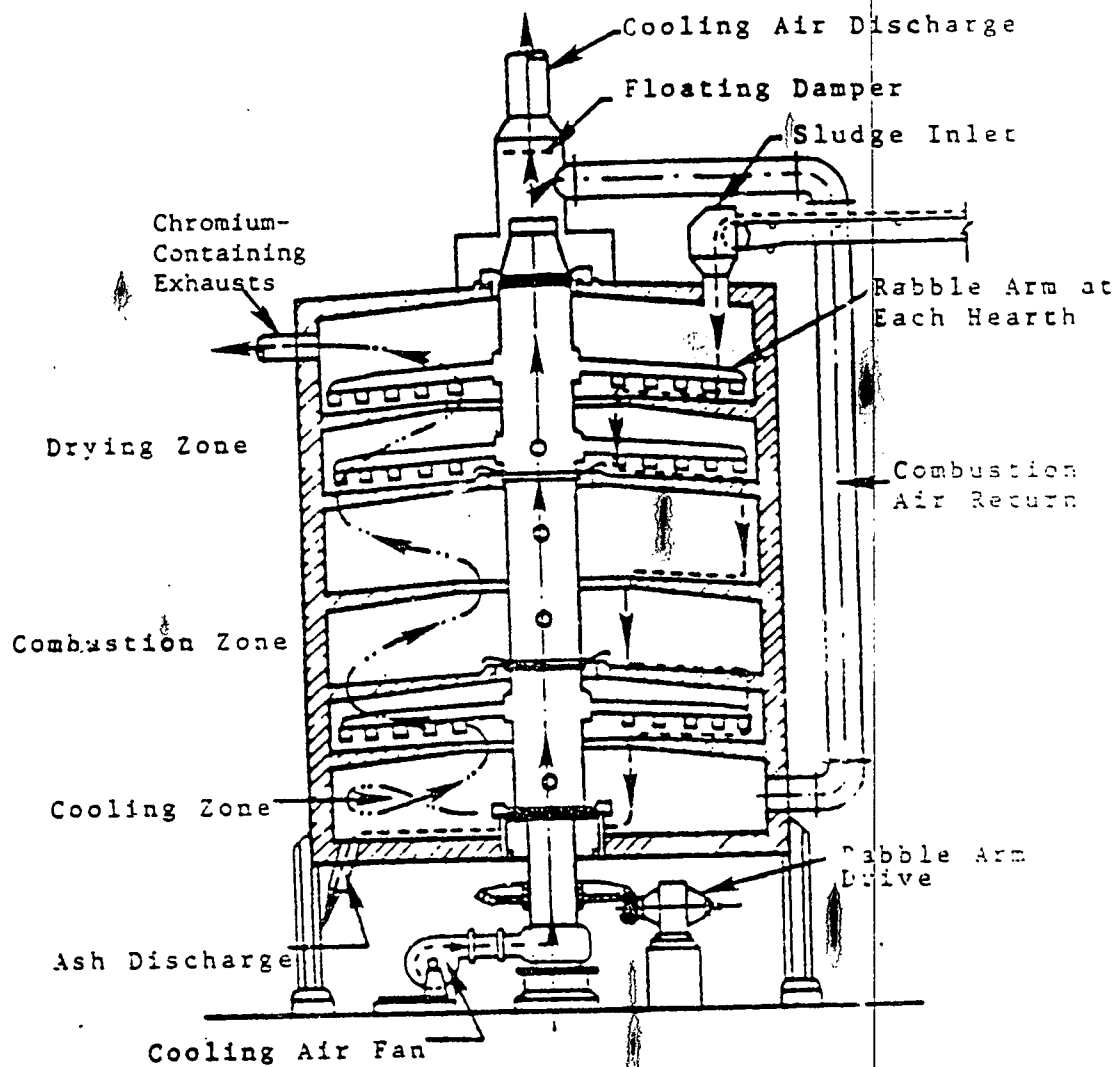
Figure 2-7. Schematic diagram of a typical multiple-hearth
sewage sludge incinerator.[48]
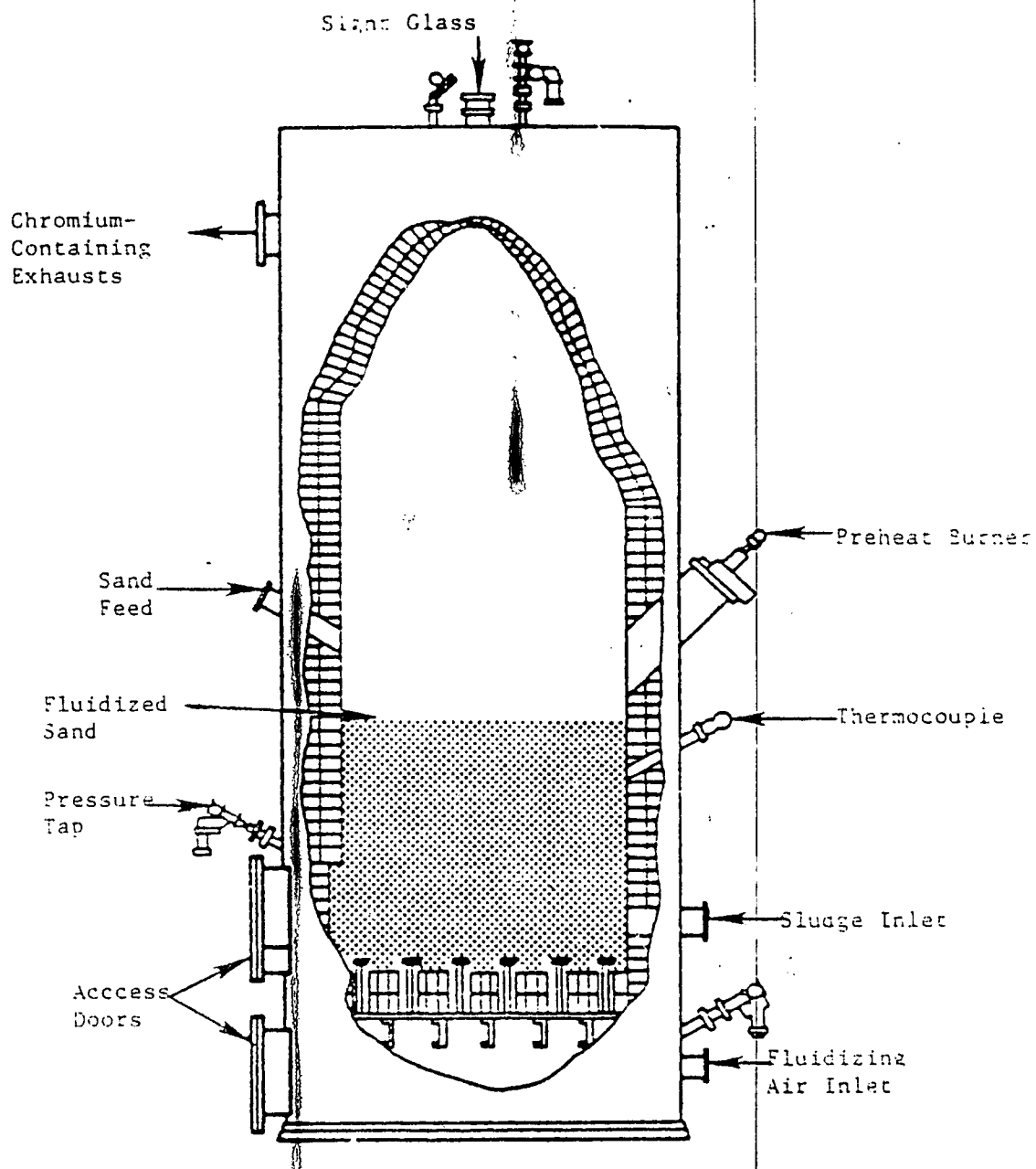
Figure 2-8. Schematic diagram of a typical fluidized-bed
sewage sludge incinerator.[50]

and depend on the nature of the primary waste sources. Because of the highly oxidizing conditions present in refuse and sludge incinerators, trivalent chromium compounds in the sludge would tend to be oxidized to hexavalent chromium compounds. This condition would be important in the case of wastewater treatment plants that receive large wastewater loads from trivalent chromium sources such as leather tanneries.

All chromium emissions data that are available in the literature are in terms of total elemental chromium. Table 2-5 summarizes the chromium emissions data used to determine incinerator chromium emissions for the modelling/exposure study. The average values for both refuse and sludge incinerators shown in Table 2-5 were applied to controlled, overall particulate emissions data to determine chromium emissions estimates for the modelling/exposure analysis. Particulate emissions estimates for municipal refuse incinerators were obtained from the results of a previous U. S. EPA investigation of these sources.[57] For the sewage sludge incinerator sources particulate emissions estimates were obtained from NEDS.[31]

Stack geometry data for municipal refuse incinerators used in the modelling/exposure analysis were obtained from Reference 58. Location information for refuse incinerators was obtained from references 57 and 58. Both stack geometry and location data for sewage sludge incinerators were obtained from NEDS information.[31]

From the available literature 129 municipal refuse incinerators and 141 sewage sludge incinerators were identified to be existence and were included in the modelling/exposure analysis. Tables 2-6 and 2-7 provide the city/state locations of the refuse and sludge incinerators, respectively.[31,47-49,57-64]

2.8 STEEL MANUFACTURING

Chromium is emitted during the production of steel because various forms of chromium are used in the steel processes as batch raw materials. Chromium is added directly to the furnace melt as ferrochromium or it can be a component of scrap steel that is fed to the melting furnace. The majority of chromium consumed by the steel industry is used to manufacture stainless

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TABLE 2-5. CHROMIUM EMISSIONS DATA FOR MUNICIPAL REFUSE
AND SEWAGE SLUDGE INCINERATORS[52-56]

Incinerator Type	Chromium Emissions Data[a,b]
Sewage Sludge	7,700 µg/g
	9,400 µg/g
	2,800 µg/g
	3,300 µg/g
	1,000 µg/g[c]
	800 µg/g
Average	3,714 µg/g
Municipal Refuse	1,330 µg/g
	780 µg/g
	1,600 µg/g
Average	1,237 µg/g

[a] All values are controlled chromium emissions.

[b] Emissions data are in terms of µg of chromium per g of particulate matter emitted.

[c] Two separate tests had emission factor values of 1,000 µg/g.

TABLE 2-5. LOCATIONS OF MUNICIPAL REFUSE INCINERATORS[47,49,58]

State, City (no. of incinerators if more than 1)	Total Number of Incinerators per State
Alabama	0
Alaska	0
Arizona	0
Arkansas	29
Atkins	
Augusta	
Bentonville (2)	
Blytheville (4)	
Hope (2)	
Hot Springs (8)	
Kensett	
North Little Rock (4)	
Osceola (2)	
Siloam Springs (2)	
Stuttgart (2)	
California	0
Colorado	0
Connecticut	4
Ansonia	
East Hartford	
New Canaan	
Stamford	
Delaware	0
District of Columbia	1
Florida	16
Orlando (9)	
Pahokee (2)	
Port Orange (4)	
Dade County	
Georgia	0

TABLE 2-6 (CONTINUED). LOCATIONS OF MUNICIPAL REFUSE INCINERATORS[47,49,58]

State, City (no. of incinerators if more than 1)	Total Number of Incinerators per State
Hawaii Honolulu	1
Idaho	0
Illinois Chicago	1
Indiana East Chicago	1
Iowa	0
Kansas	0
Kentucky Louisville	1

Louisiana
    Donaldsonville
    Plaquemine (2)
    Rayne (2)
    Shreveport
	6

Maine
    Harpswell
    Kittery (2)
	3

Maryland Baltimore (2)	2

Massachusetts
    Braintree
    Bridgewater
    Fall River
    Framingham
    Saugus
	5

Michigan	0
Minnesota	0

State, City (no. of incinerators if more than 1)	Total Number of Incinerators per State
Mississippi	0
Missouri	2
St. Louis (2)	
Montana	0
Nebraska	0
Nevada	0
New Hampshire	11
Auburn	
Candia	
Bridgewater	
Litchfield	
Meredith (2)	
Pittsfield	
Wilton	
Wolfeboro	
Nottingham	
Canterbury	
New Jersey	1
Red Bank	
New Mexico	0
New York	7
South Brooklyn	
Hempstead	
Huntington	
Lachawanna	
Oyster Bay	
Skaneateles	
Tonawanda	
North Carolina	2
Wrightsville Beach (2)	

State, City (no. of incinerators if more than 1)	Total Number of Incinerators per State
North Dakota	0
Ohio Lakewood	1

Oklahoma
    Cleveland
    Tahlequah (4)
	5

Oregon Coos County (2)	2

Pennsylvania
    Harrisburg
    Philadelphia (2)
    Shippensburg
	4

Rhode Island	0
South Carolina	0
South Dakota	0

Tennessee
    Crossville (2)
    Nashville
	3

Texas
    Refugio
    Terrell (3)
	4

Utah	0
Vermont	0

Virginia
    Newport News
    Norfolk
    Portsmouth
    Salem (4)
	7

State, City (no. of incinerators if more than 1)	Total Number of Incinerators per State
Washington	8
Bellingham (8)	
West Virginia	0
Wisconsin	2
Sheboygan	
Waukesha	
Wyoming	0

TABLE 2-7. LOCATIONS OF SEWAGE SLUDGE INCINERATORS [31,46,47,57-64]

State, City (no. of incinerators if more than 1)	Total Number of Incinerators per State
Alabama	0

Alaska
    Anchorage
    Petersburg
    Wrangell
	3

Arizona	0
Arkansas	0
California Riverside	1
Colorado	0

Connecticut
    Cromwell
    Hartford
    Lake Arrowhead
    New Haven
    Waterbury
	5

Delaware	0
District of Columbia	0

Florida
    Duval County
    Pensacola (2)
	3

Georgia
    Decatur
    Jonesboro
    Maretta
    Savannah (2)
	5

Hawaii	0
Idaho	0

TABLE 2-7 (CONT.). LOCATIONS OF SEWAGE SLUDGE INCINERATORS[31,46,47,57-64]

State, City (no. of incinerators if more than 1)	Total Number of Incinerators per State
Illinois	1
Granite City	
Indiana	8
Indianapolis (8)	
Iowa	2
Cedar Rapids	
Davenport	
Kansas	3
Kansas City	
Mission	
Olathe	
Kentucky	7
Covington	
Cynthiana	
Erlanger (2)	
Louisville (3)	
Louisiana	0
Maine	0
Maryland	0
Massachusetts	8
Chicopee (2)	
Fall River	
Fitchburg	
New Bedford	
Worcester (3)	
Michigan	20
Ann Arbor	
Bay City	
Detroit (10)	
East Lansing	
Flint	
Grand Rapids	

TABLE 2-7 (CONT.). LOCATIONS OF SEWAGE SLUDGE INCINERATORS[31,46,47,57-64]

State, City (no. of incinerators if more than 1)	Total Number of Incinerators per State
Kalamazoo	
Saginaw	
Trenton	
Wyandotte	
Wyoming	
Minnesota	10
St. Paul (10)	
Mississippi	0
Missouri	1
Independence	
Montana	0
Nebraska	1
Bellevue	
Nevada	2
Carson City	
Douglas City	
New Hampshire	4
Manchester (2)	
Merrimack (2)	
New Jersey	6
Atlantic City	
Gloucester County	
Mercer City (2)	
Ocean City (2)	
New Mexico	0
New York	5
Amherst (2)	
Hamburg (2)	
N. Tonawanda	

State, City (no. of incinerators if more than 1)	Total Number of Incinerators per State
North Carolina Greensboro	1
North Dakota	0
Ohio Akron Cincinnati (3) Cuyahoga County (4) Hamilton County (5) Trumbull County	13
Oklahoma Lawton	1
Oregon	0
Pennsylvania Chester (2) Erie (2) Luzerne (2) Morrisville Tyrone Westmoreland County Willow Grove	10
Rhode Island Cranston Providence	2
South Carolina	0
South Dakota	0
Tennessee Maryville Nashville-Davidson Newport	3
Texas Fort Worth Plano (2) Richardson	4

State, City (no. of incinerators if more than 1)	Total Number of Incinerators per State
Utah	0
Virginia	4
Arlington	
Blacksburg	
Fairfax	
Hopewell	
Vermont	0
Washington	3
Longview (2)	
Vancouver	
West Virginia	1
Charleston	
Wisconsin	4
Green Bay (2)	
Menasha	
Milwaukee	
Wyoming	0

and alloy steels. In 1981 approximately 93 percent of steel industry chromium consumption was used for stainless and alloy steels.[65]

Because of the large percentage of chromium consumption associated with stainless and alloy steel production and the chromium emissions potential represented by this consumption, the modelling/exposure analysis concentrated on facilities producing stainless and alloy steels. The types of steel production facilities that produce chromium stainless and alloy steels and that were addressed in this study are electric arc furnaces (EAFs) and basic oxygen process furnaces (BOPFs).[66] In addition to these two types of steel furnaces, there is another type known as an argon-oxygen decarburization (AOD) vessel that was addressed in the chromium modelling/exposure analysis for the steel industry because of their demonstrated potential to emit chromium.[66,67,68] Argon-oxygen decarburization vessels are refining furnaces that are used in conjunction with EAFs; however, not all EAF steel plants have AOD refining vessels. High quality alloy steel produced by an EAF is often further refined by remelting it an AOD.

A typical EAF used to produce stainless and alloy steel is shown in Figure 2-9.[69] Chromium is emitted from an EAF as particulates during melting, refining, charging, and tapping operations. Melting refers to the initial melting of steel scrap and other raw materials in the high temperature environment of the furnace. Refining involves blowing oxygen into the molten steel bath for the purposes of speeding up the melting process, adjusting the chemistry of the steel, and superheating the steel bath. Oxygen blowing results in increased bath and gas temperatures, gas evolution, and generation of particulates. Charging refers to the operation of adding the raw materials into the EAF. Tapping operations involve removing the final molten product steel from the EAF by pouring it into a ladle. Melting and refining are generally viewed as process emission generating operations while charging and tapping are fugitive emission generating operations. Both process and fugitive emissions are generally collected and routed to a control device.

Chromium emissions from these four EAF operations have been found to contain both trivalent and hexavalent chromium.[70] Trivalent chromium occurs
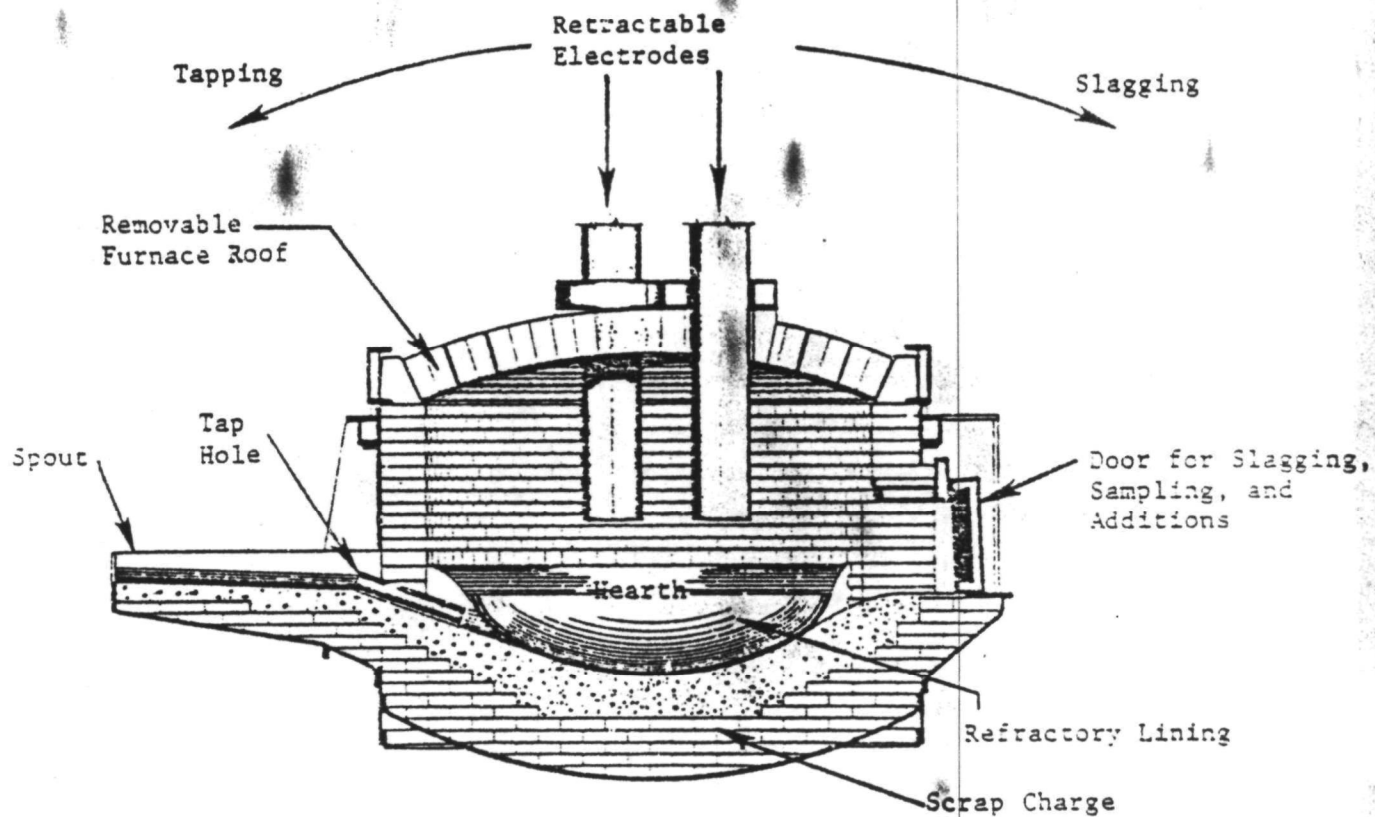
Figure 2-9. Typical electric arc steel furnace.[69]

as insoluble chromium oxide. Hexavalent chromium in EAF emissions is occurring as a result of the oxidizing environment inside the furnace. No information is available to determine the relative level of trivalent and hexavalent chromium present in total EAF chromium emissions.

The basic equipment configuration in a BOPF steel facility is illustrated in Figure 2-10.[71] For a typical steelmaking cycle that totals between 40 and 80 minutes the BOPF is first tilted towards the charging aisle and cold scrap metal is added. Hot metal from the blast furnace shop is then poured on top of the scrap charge. Following these activities the vessel is returned to the upright position and the oxygen lance is lowered into place in the BOPF. After blowing oxygen for about 10 to 15 minutes into the metal the steelmaking vessel is tilted towards the charging aisle for sampling (turndown). If the metal meets product specifications, tapping of the BOPF begins. If sampling shows that the metal is yet to specification the vessel is returned to an upright position and more oxygen is blown (reblowing). The metal is sampled after each reblow until product specification metal is produced. For tapping or removing product metal from the BOPF, the vessel it tilted away from the charging aisle and toward the teeming aisle located on the opposite side of the BOPF. The molten hot product metal is poured into teeming ladles which empty into molds located in the teeming aisle. Following tapping, the vessel is tilted back towards the charging aisle and slag is emptied into slagging pots. At this point the BOFF is ready for another steelmaking cycle.[72]

In non-chromium steels chromium that is present in the hot metal and scrap charges is only there as a contaminant. Consequently, for non-chromium steelmaking operations potential sources of chromium emissions include oxygen blowing (process emissions) and fugitive emissions from all th other process operations previously described. It is universal practice to capture emissions from oxygen blowing followed by removal in a wet scrubber or ESP. Some steelmaking shops also capture some of the fugitive emissions generated by charging, turndown, tapping, and slagging and route them to fabric filters, wet scrubbers, or ESPs. All of these general

2-42
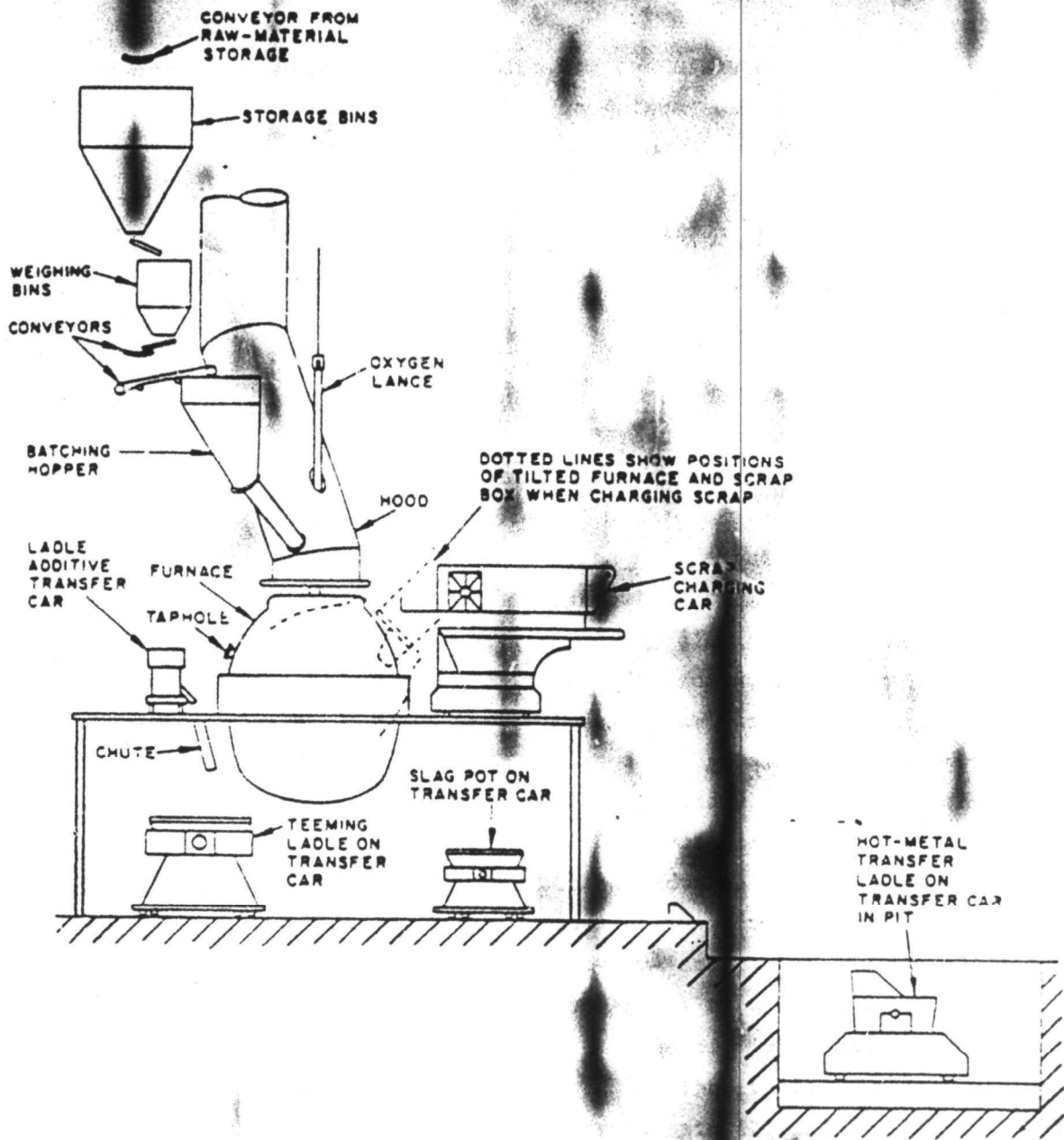
Figure 2-10. Schematic cross section of a top blown basic oxygen process furnace steel shop. 71

particulate control techniques are effective at reducing chromium emissions from steelmaking.

For chromium stainless and alloy steels, chromium is added either immediately prior to tapping or directly into the teeming ladle. Consequently, chromium emissions are most likely to occur during tapping and slagging (from residual chromium) operations, hot metal addition to the teeming ladle, and during teeming (pouring hot metal into molds). The majority of chromium emissions from stainless and alloy steel production are therefore fugitive in nature. Capture and control equipment are used to varying extents across the industry to control these fugitive emissions sources. As with non-chromium steel production operations, any control measures undertaken to reduce overall particulate emissions are generally effective in reducing chromium emissions.

Chromium emissions from BOPFs do not appear from the literature to have been as well characterized as EAF chromium emissions. All chromium emission factors reported in the literature for BOPFs are expressed as elemental chromium.[73,74] No information is provided on the occurrence of trivalent or hexavalent chromium compounds. It is anticipated, however, that because similar chromium raw materials are used by EAFs and BOPFs and both have high temperature oxidizing environments, chromium emissions from BCPFs should contain trivalent (chromium oxide) and hexavalent chromium compounds similar to EAF chromium emissions.

Argon-oxygen decarburization vessels such as that shown in Figure 2-11 are used to refine steel that has previously been melted in an EAF.[75] Chromium emissions from AOD vessels occur because of chromium contained in the molten steel bath (received from the EAF) and because chromium is sometimes added to molten steel in the AOD vessel as an alloying agent for specialty steel products. Chromium particulate emissions from an AOD are greatest during the argon-oxygen blowing or refining periods. Emissions from charging, tapping, and turndown operations are minimal for a variety of reasons that are specifically related to the design of an AOD vessel.[74] Available information indicates that chromium emissions from AOD vessels are predominantly in the form of trivalent chromium oxide.[74] No hexavalent

VESSEL TOP

TUYERE
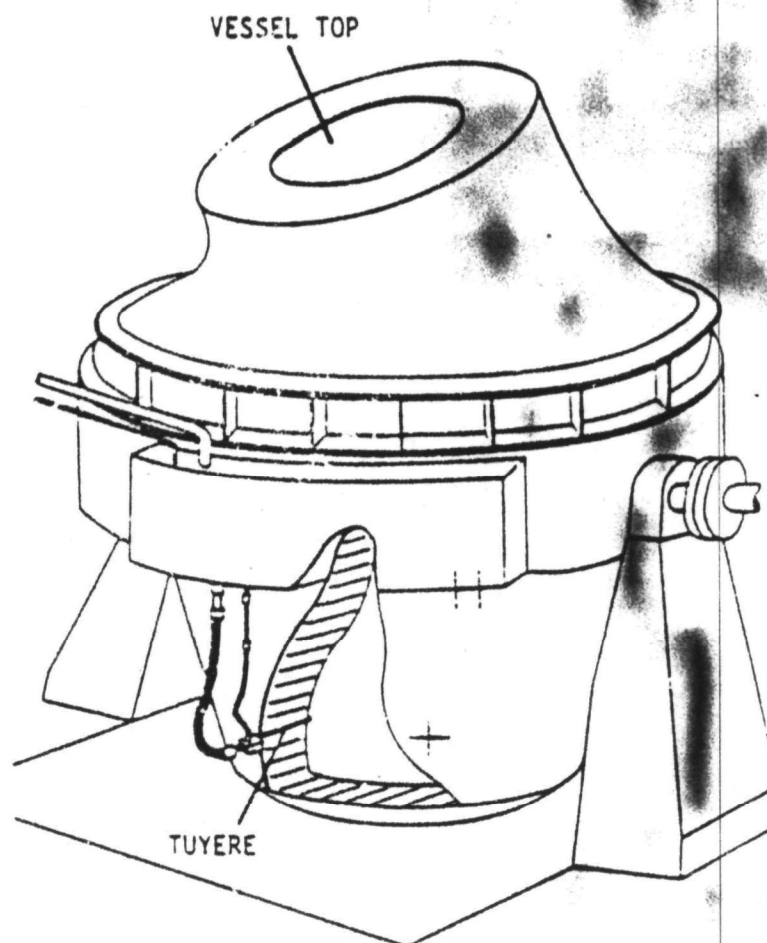
Figure 2-11.   Argon-oxygen decarburization vessel.[75]

chromium emissions have been identified in AOD vessel emissions, however, it is expected that they are present because chromium in the trivalent form is known to be oxidized at certain phases of the decarburization process.[75] Attempts are made to control the amount of chromium oxidation taking place by carefully controlling AOD vessel gas flows, gas mixtures, and temperature.

Chromium emissions estimates for the purposes of the modelling/exposure analysis were prepared for each EAF, BOPF, and AOD vessel known to be making stainless and alloy steel. Uncontrolled particulate and chromium emission factors, expressed in terms of production, for EAFs and AOD vessels were available in Reference 66 for melting, refining, charging, and tapping operations. Using these data chromium emission factors were calculated for EAFs and AOD vessels. These factors, 0.80 kg/Mg (1.59 lb/ton) for EAFs and 0.43 kg/Mg (0.87 lb/ton) for AOD vessels, were applied to estimated stainless and alloy steel production capacities at the domestic EAF and AOD vessel sites to determine potential uncontrolled chromium emissions. Based on estimated control equipment and control efficiencies for EAF and AOD vessel emissions given in Reference 76, an average control percentage of 97 percent was applied to the uncontrolled chromium emissions totals. Stack geometry data for EAFs and AOD vessels were taken from two U. S. EPA reports involving these sources in which dispersion modelling and exposure assessments were made.[77,78] The stack data used for EAFs and AOD vessels in this study are presented in Table 2-8. Geographic coordinate locations for all EAFs and AOD vessels identified were obtained from NEDS information.

Chromium emissions estimates for BOPFs were prepared in a similar manner to that used for EAFs and AOD vessels. The one uncontrolled chromium emission factor available for BOPFs had been determined for charging operation emissions only; however, for the purposes of this modelling/exposure analysis the factor was assumed to be applicable to the chromium emissions of all BOPF operations.[73] The uncontrolled emission factor was multiplied by the amount of BOPF production capacity manufacturing stainless and alloy steels to determine the rate of uncontrolled chromium emissions at each plant.[72,79] From Reference 76, the

TABLE 2-8. STACK GEOMETRY DATA USED FOR ELECTRIC ARC FURNACES
AND ARGON-OXYGEN DECARBURIZATION VESSELS[77,78]

Source	Production Capacity Mg (tons)/hr	Stack Height m (ft)	Stack Diameter m (ft)	Gas Temperature K (°F)	Gas Flow Rate m^3/min (acfm)
EAF	< 90.7 (100)	30.5 (100)	2.4 (8)	394 (250)	3,538 (125,000)
EAF	≥ 90.7 (100)	30.5 (100)	3.7 (12)	394 (250)	10,896 (385,000)
AOD Vessel	< 90.7 (100)	30.5 (100)	2.4 (8)	394 (250)	3,679 (130,000)
AOD Vessel	≥ 90.7 (100)	30.5 (100)	3.7 (12)	394 (250)	14,858 (525,000)

TABLE 2-9. STACK GEOMETRY DATA USED FOR BASIC OXYGEN PROCESS FURNACES[80]

BOPF Type	Primary Hood Type	Control Device	Gas Flow Rate m^3/min (acfm)		Gas Temperature K (°F)
272 Mg (300 ton) top blown	Open	Wet Scrubber	16,860	(596,000)	355 (180)
272 Mg (300 ton) top blown	Open	ESP	27,660	(977,000)	477 (400)
272 Mg (300 ton) top blown	Closed	Wet Scrubber	4,896	(173,000)	355 (180)
272 Mg (300 ton) bottom blown	Closed	Wet Scrubber	5,496	(194,000)	355 (180)
272 Mg (300 ton) bottom blown	Open	ESP	31,020	(1,096,000)	477 (400)
136 Mg (150 ton) top blown	Closed	Wet Scrubber	2,436	(86,000)	355 (180)

TABLE 2-10. NUMBER AND LOCATIONS OF ELECTRIC ARC FURNACES
IDENTIFIED TO BE EMITTING CHROMIUM[66]

Plant Location (State/City)	Number of Furnaces
Alabama	
Birmingham	4
Gadsden	2
Arizona	
Tempe	3
Arkansas	
Newport	2
California	
Etiwanda	1
Torrance	2
Los Angeles	2
Emeryville	1
Colorado	
Pueblo	2
Connecticut	
Bridgeport	2
Delaware	
Claymont	2
Hawaii	
Ewa	1
Illinois	
Chicago	3
Chicago Heights	4
Alton	2
Morton Grove	2
South Chicago	6

TABLE 2-10 (CONTINUED). NUMBER AND LOCATIONS OF ELECTRIC ARC FURNACES IDENTIFIED TO BE EMITTING CHROMIUM[66]

Plant Location (State/City)	Number of Furnaces
Indiana	
Kokomo	4
New Castle	4
East Chicago	2
Fort Wayne	3
Kentucky	
Owensboro	2
Ashland	2
Newport	3
Maryland	
Baltimore	3
Michigan	
Dearborn	2
Warren	5
Trenton	2
Ecorse	2
Monroe	1
Jackson	2
Minnesota	
St. Paul	2
Missouri	
Kansas City	6
Nebrasks	
Norfolk	5
New Jersey	
Sayerville	2
Perth Amboy	1
New York	
Watervliet	2
Syracuse	3
Lockport	3
Dunkirk	3

Plant Location (State/City)	Number of Furnaces
Ohio	
Warren	5
Mansfield	2
Cleveland	2
Canton	15
Oregon	
Portland	2
Pennsylvania	
Brackenridge	5
Butler	3
Beaver Falls	9
Reading	6
Lower Burrell	2
Johnstown	5
Steelton	3
Bethlehem	6
Midland	7
Bridgeville	3
Oakmont	1
Oil City	1
Washington	3
Pittsburgh	2
Irvine	2
Erie	3
Coatsville	4
Houston	2
Duquesne	5
Burgettstown	1
Latrobe	4
Fairless Hills	2
Burnham	4
Sharon	2
South Caroilna	
Darlington	5
Tennessee	
Harriman	3

TABLE 2-10 (CONTINUED). NUMBER AND LOCATIONS OF ELECTRIC ARC FURNACES
IDENTIFIED TO BE EMITTING CHROMIUM[66]

Plant Location (State/City)	Number of Furnaces
Texas	
Houston	8
El Paso	2
Midlothian	2
Longview	2
Pampa	1
Jewett	5
Fort Worth	4
Baytown	4
Utah	
Plymouth	2
Virginia	
Roanoke	3
Washington	
Seattle	4
Kent	2
West Virginia	
Huntington	2

TABLE 2-11. LOCATIONS OF ARGON-OXYGEN DECARBURIZATION VESSELS
IN THE UNITED STATES IN 1981.[66]

Plant Location (State/City)	Number of Vessels
Connecticut	
Bridgport	1
Illinois	
Chicago	1
Indiana	
Kokomo	2
New Castle	1
Fort Wayne	1
Maryland	
Baltimore	2
Michigan	
Warren	1
New York	
Syracuse	1
Watervliet	2
Ohio	
Mansfield	1
Canton	1
Pennsylvania	
Brackenridge	1
Butler	1
Beaver Falls	1
Reading	2
Midland	1
Bridgeville	1
Houston	1
Burnham	1
Washington	1
Oil City	2
Washington	
Seattle	1

TABLE 2-12.   LOCATIONS AND NUMBER OF BASIC OXYGEN PROCESS FURNACES
             IN THE UNITED STATES IN 1981

Plant Location (State/City)	Number of Furnaces
Alabama	
Gadsden	2
Fairfield	3
California	
Fontana	2
Colorado	
Pueblo	2
Illinois	
South Chicago	5
Chicago	2
Granite City	2
Indiana	
Gary	6
East Chicago	6
Burns Harbor	3
Kentucky	
Ashland	2
Maryland	
Sparrows Point	2
Michigan	
Dearborn	2
Trenton	5
Ecorse	4
New York	
Lackawanna	3
Buffalo	2
Ohio	
Middletown	2
Cleveland	4
Warren	2
Lorain	2
Steubenville	2

TABLE 2-12 (CONTINUED). LOCATIONS AND NUMBER OF BASIC OXYGEN PROCESS
FURNACES IN THE UNITED STATES IN 1981[2]

Plant Location (State/City)	Number of Furnaces
Pennsylvania	
Natrona	2
Bethlehem	2
Aliquippa	3
Farrell	3
Duquesne	2
Braddock	2
Monessen	2
West Virginia	
Weirton	2

Chromite Ore
(and Other Raw Material Ores)

```
┌──────────────┐     ┌──────────┐     ┌──────────┐     ┌──────────────┐
│ Ore Unloading│     │   Ore    │     │   Ore    │     │   Smelting   │
│     and      │ ──▶ │  Drying  │ ──▶ │ Crushing │ ─ ▶ │   Furnace    │
│  Storage   ▲ │     │        ▲ │     │        ▲ │     │            ▲ │
└──────────────┘     └──────────┘     └──────────┘     └──────────────┘
                                                                │
                                                                ▼
┌──────────────┐     ┌──────────────┐     ┌──────────────┐
│  Ferrochrome │     │  Ferrochrome │     │  Ferrochrome │
│  Screening ▲ │ ◀── │  Crushing  ▲ │ ◀── │  Casting   ▲ │
└──────────────┘     └──────────────┘     └──────────────┘
       │
       ▼
┌──────────────┐     ┌──────────────┐
│  Ferrochrome │     │  Ferrochrome │        FINAL FERROCHROMIUM
│   Storage    │ ──▶ │  Packaging ▲ │ ──▶        PRODUCT
└──────────────┘     └──────────────┘
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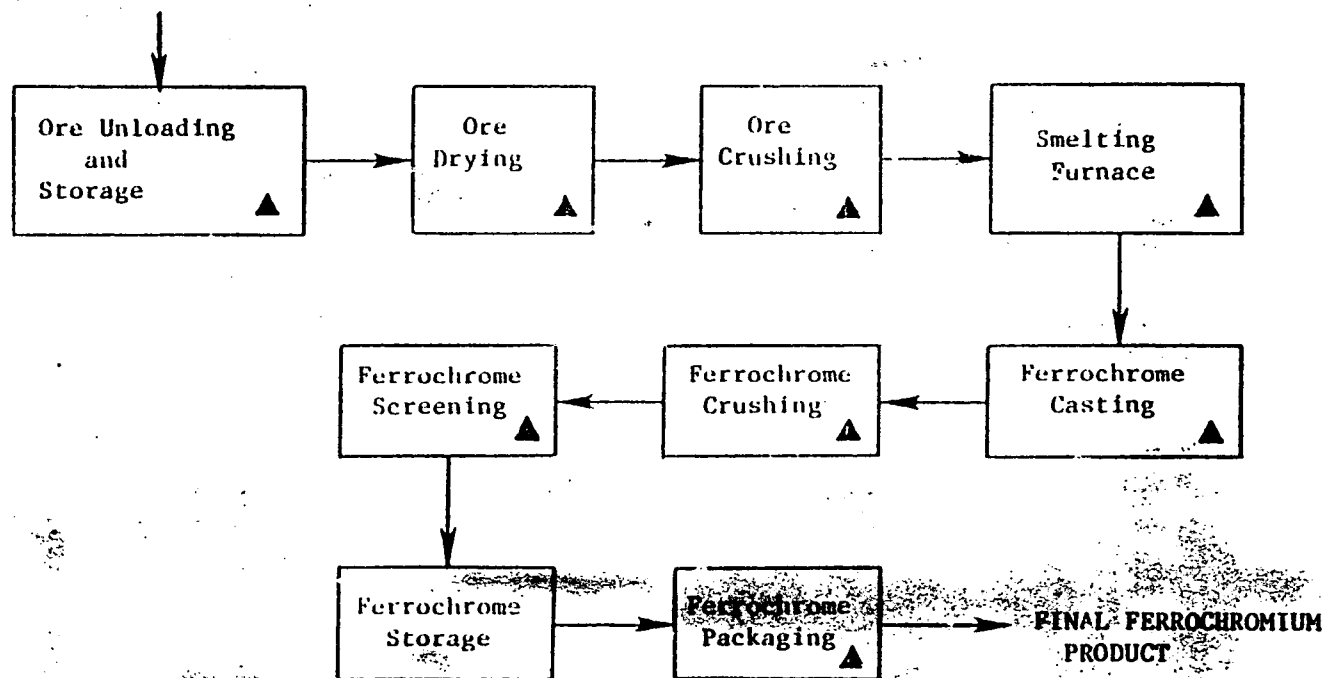
▲ Primary Chromium Emission Points

Figure 2-12.   Generalized flow diagram for the production of ferrochromium alloys.[83]

ferrochromium process.[83] Secondary sources of chromium emissions that are included in the operation of the smelting furnace are tapping operations in which molten ferrochromium or slag is removed from the furnace and ladle reaction operations in which metals or alloys are added to the tapped molten ferrochromium to obtain a specific final product composition.

Following the smelting process, the molten ferrochromium is cast into molds and allowed to cool. Fumes and dusts generated during the casting process can contain chromium. The operations performed in the ferrochromium process after casting are dependent on the required size of the final ferrochromium product. Ferrochromium products are marketed in sizes ranging from large chunks weighing 33.8 kg (75 lb) to fine powders. To produce the required size the cast ferrochromium is crushed and then screened. Both crushing and screening operations generate chromium emissions in the form of ferrochromium particulates.[83,84] Crushed and screened ferrochromium is shipped to consumers in bulk form or is packaged in containers. Ferrochromium dusts are generated during the bulk loading and packaging of crushed and screened ferrochromium.[84]

All available chromium emissions data and emission factors for chromium from ferrochromium facilities express emissions in terms of total chromium or chromium oxide. Chromium emissions from all potential point sources in the ferrochromium process (shown in Figure 2-12) appear to contain only trivalent chromium in the form of insoluble chromium oxide.[85,86,87] No indication of the presence of hexavalent chromium in ferrochromium process emissions was found or theorized in the available literature.

In 1980 there were eight facilities in the United States producing ferrochromium.[88] In 1983 the Ferroalloy Association indicated that only one facility, Interlake, Inc. in Beverly, Ohio, was still in operation producing ferrochromium.[89] The reasons behind the demise of the domestic ferro-chromium industry are explained in Section 1.2 of Chapter 1. As a result of the information provided by the Ferroalloy Association, only the Interlake Inc. facility was included in the chromium modelling/exposure analysis.

All chromium emitted from ferrochromium manufacturing is in a particulate form. Chromium emissions estimates for the Interlake plant were

prepared using available chromium emission factors given in Reference 85 and point source particulate emissions data provided by the NEDS. Stack geometry and geographic coordinate location data for the modelling/exposure analysis were taken directly from the NEDS.

2.10 COOLING TOWERS*

Cooling towers can be sources of atmospheric chromium emissions because chromium-containing compounds are sometimes added to cooling tower water as a corrosion inhibiting agent.[90,91,92] Chromium corrosion inhibitors are primarily added to protect the heat exchanger and piping in the tower.[93] Although chromium corrosion inhibitors are used in towers of all size applications including electric utilities, industrial plants, and commercial/institutional sites, use is greatest in the industrial sector, particularly in petroleum refineries and petrochemical plants.[93-96] Utilities generally locate near sources of once-through cooling water so towers are not needed or they construct the necessary towers with corrosion resistant materials. The majority of commercial/institutional towers rely on non-chromium water treatments such as maintenance of high pH or alternative phosphate or zinc treatment chemicals.[93-96]

Chromium corrosion inhibitors that are added to cooling tower water contain chromium in the form of chromates (Cr^{+6}). Chromium concentrations in cooling tower water are generally maintained at 15 to 20 wt ppm for corrosion inhibiting purposes.[90,91,92] Cooling tower chromium emissions occur as a dissolved component of cooling tower drift. Drift is essentially entrained water droplets that have been mechanically formed in the tower and are carried out of the tower by the system air flow. Chromium concentrations in cooling tower drift are approximately equal to the concentrations of 15 to 20 wt ppm found in the recirculating tower cooling water.[90,91,92] Cooling tower drift and consequently tower atmospheric chromium emissions are a function of primarily the quantity of heat rejected in a tower, tower air flow, tower design, and ambient meteorological conditions.[90,91,92,97]

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*Subsequent to the finalization of this report in October 1983, additional information was gathered and chromium emission estimates prepared for the cooling tower source category. The new information for cooling towers is presented in the July 1984 addendum to this report.

Tower design can be important because most towers are specifically
constructed to have a certain percentage of the recirculating water be
emitted as drift. Baffles and other mechanical obstructions are used to
attain a specified drift rate. For cooling towers at electric utilities
that were built pre-1970 drift losses of from 0.1 to 0.2 percent are common.
New utility cooling towers have designed drift losses on the order of 0.002
to 0.005 percent.[97]

The general mechanism of chromium emissions from cooling tower drift is
shown in Figure 2-13. Dissolved chromium is carried out of the tower as a
constituent of drift. Because the drift is cooler and denser than the
ambient air it will begin to fall to the ground due to the influence of
gravity. As the drift falls to the ground evaporation of the water droplets
begins to occur. Because of the gravity influence the situation becomes a
trajectory or ballistics problem complexed by evaporation. At some varying
height, which is dependent on site-specific meteorological conditions, the
moisture is evaporated leaving a chromium-containing dust. Once these
particles reach a certain size they will come under the influence of
atmospheric currents and thereby get dispersed. The form of chromium in the
dust is predominantly hexavalent; however, trivalent chromium could be
emitted if hexavalent chromates are reduced in the tower as a result of
performing their corrosion inhibiting function.

The deposition of chromium around cooling towers has been demonstrated
to generally be a localized effect because of the physical processes just
described.[90,91,92] Test work on several utility cooling towers has
confirmed the localized chromium emissions phenomenon. The results of one
such test are illustrated in Figure 2-14.[91] As shown in the figure,
chromium concentration in air decreases exponentially with distance from the
cooling tower. The concentrations in Figure 2-14 represent the average of
4 days of testing.

Several efforts have been made to model the behavior of cooling tower
drift taking into consideration results of the type shown in Figure 2-14.
The conclusions of these efforts have shown that it is possible to model
cooling tower drift; however, a complex droplet trajectory model,
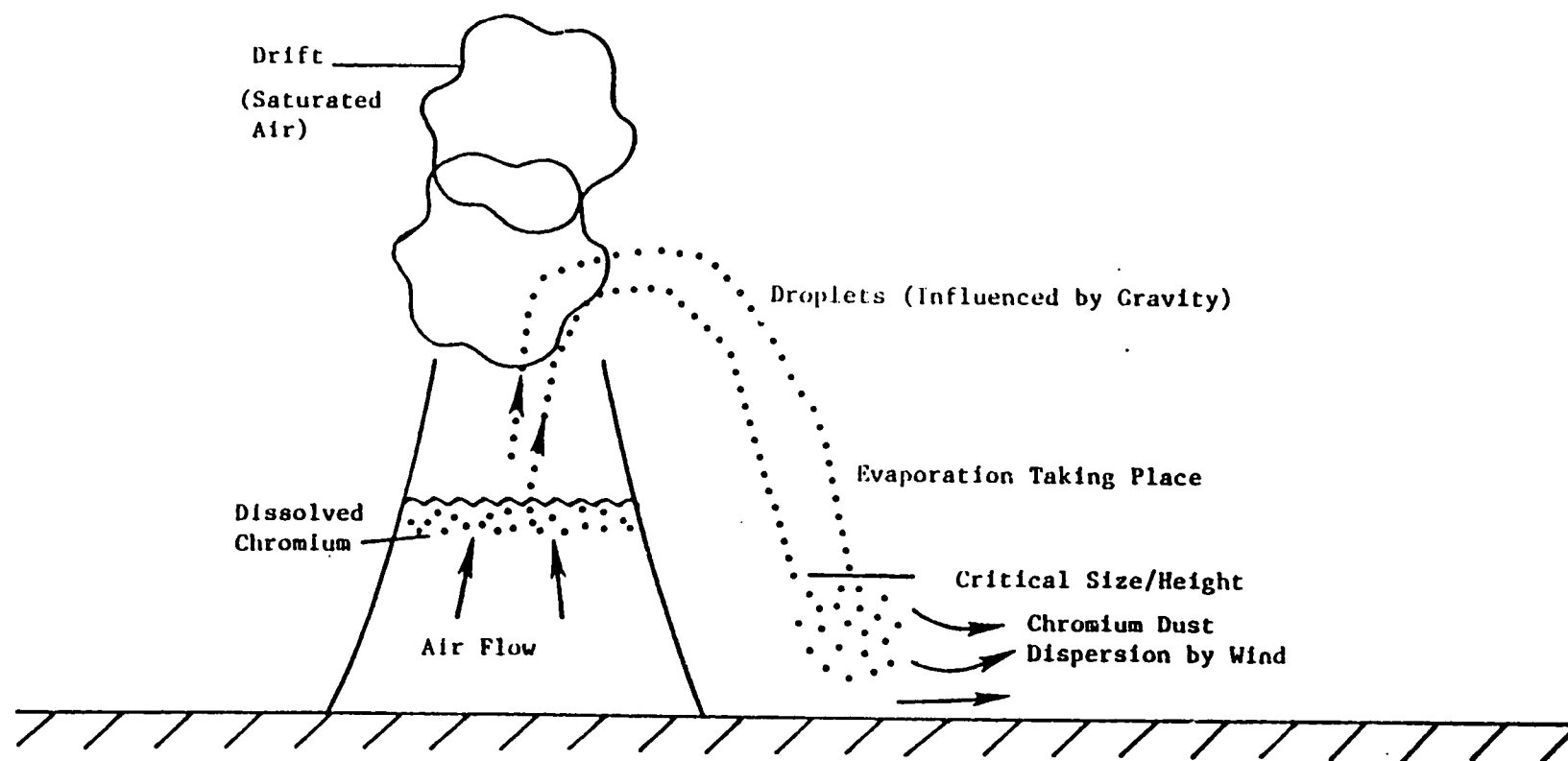
Figure 2-13. General mechanism of chromium emissions from cooling tower drift.
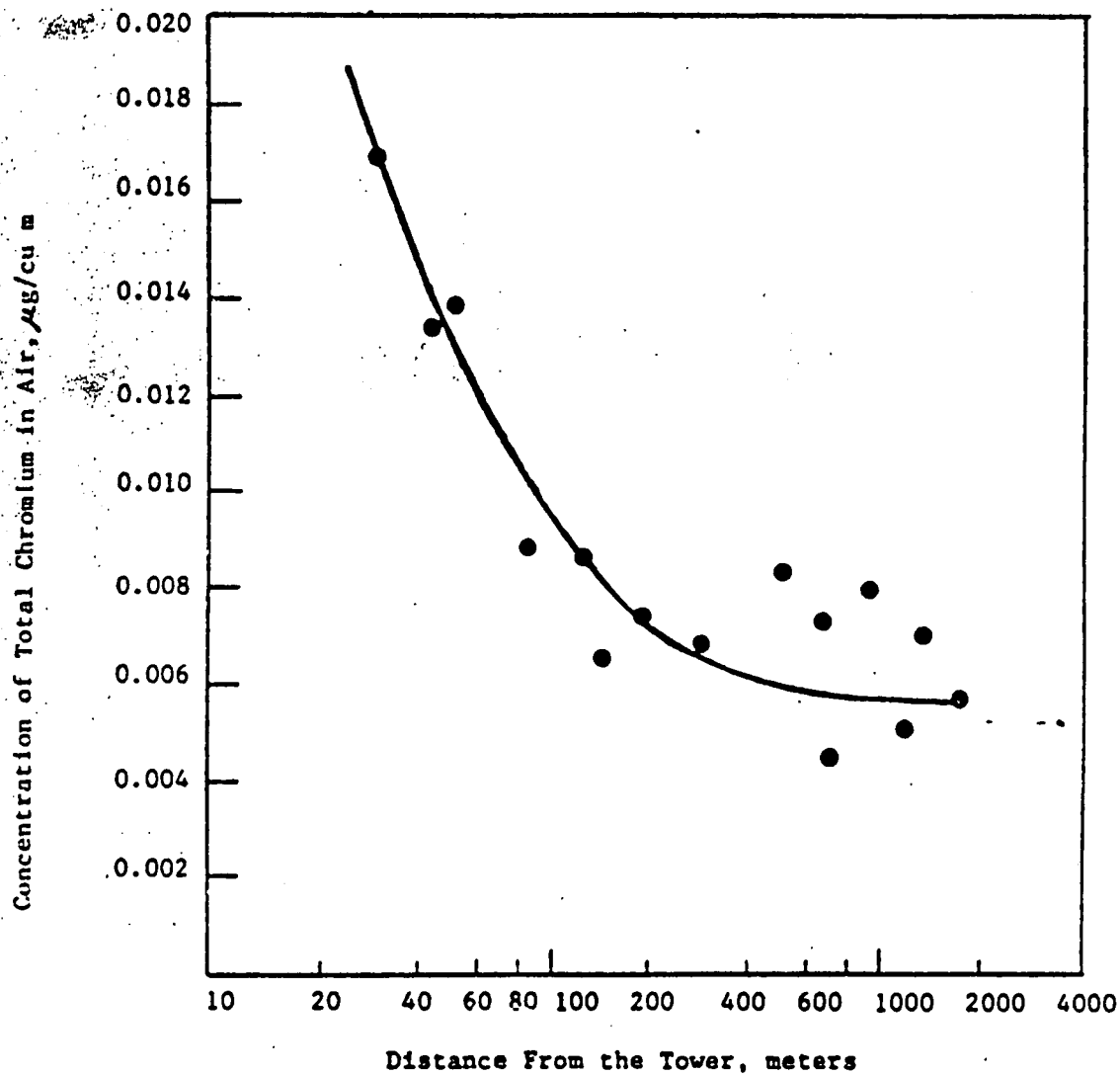
Figure 2-14. Concentration of chromium in air as a function of distance from the cooling tower.[91]

incorporating specific tower characteristics and local meteorological conditions, would be required for such a task.[90] These factors suggest that the use of the HEM to model cooling tower chromium emissions may not be adequate.

The number of cooling towers using chromium corrosion inhibitors, their national size distribution, and their locations are unknown factors in attempting to conduct a modelling/exposure analysis of this source category. The only available chromium emissions information for this source category applies only to utility cooling towers, which are not the major consumer of chromium corrosion inhibitors. No emissions or emission factor information is available on industrial or commercial/institutional towers. For these reasons, any attempt to characterize the level of chromium emissions from domestic cooling towers would be highly speculative and unreliable. The inability to characterize national cooling tower chromium emissions directly impacts the process of conducting a modelling/exposure analysis for this source category. These source category characterization problems combined with the modelling uncertainties discussed previously indicate that the national impact of cooling tower chromium emissions on ambient air quality cannot adequately be determined using the methodology adopted for this study.

2.11 COAL AND OIL COMBUSTION

2.11.1 Background

Chromium is a trace element component of coal and oil. Of the many trace elements in coal and oil chromium is considered to be minor in abundance.[98] Tables 2-13 and 2-14 present data that summarize the chromium content of domestic coals by coal type and coal source.[98,99] Testing of 11 samples of residual fuel oil indicated an average chromium concentration of 0.90 wt ppm, with the range of chromium among the samples being 0.09 to 1.9 wt ppm.[99] The chromium concentration in crude oils has been reported to range from 0.0023 to 0.640 wt ppm.[98] More information on the characteristics of chromium in coal and oil fuels is provided in references 98 and 99.

TABLE 2-13. CHROMIUM CONTENT OF DOMESTIC COALS BY TYPE[99]

Coal Type	Mean Chromium Content, wt ppm	Standard Deviation, wt ppm	Number of Samples
Bituminous	25.9	2.0	130
North Dakota Lignite	7.5	3.7	10
Texas Lignite	20.4	1.5	29
Anthracite	35.6	7.3	53

TABLE 2-14. CHROMIUM CONTENT OF DOMESTIC COALS BY SOURCE[98]

Coal Type	Mean Chromium Content, wt ppm	Standard Deviation, wt ppm	Number of Samples
Eastern U. S. (Appalachia)	20	16	23
Midwestern U. S. (Illinois Basin)	18	9.7	113
Western U. S.	9.0	4.2	29

When coal and oil are combusted in boilers and furnaces, the tra
chromium components they contain are released. The amount of chromium
released to the atmosphere is dependent primarily on the following factors:

- the chromium content of the fuel,
- the type of boiler used and its firing configuration,
- the partitioning of chromium between fly ash and bottom ash,
- the degree of chromium enrichment on fine fly ash, and
- the chromium removal efficiency of any controls that may be present.

The effect of each of these factors is described in the following
paragraphs.

The concentration of chromium in the feed coal or oil has been
determined to be the major factor affecting uncontrolled chromium emissions
from combustion sources.[100] The greater the chromium concentration in the
fuel, the higher the uncontrolled rate of chromium emissions. For the
combustion of coal, the type of boiler used and its firing configuration
affect chromium emissions by affecting the amount of coal ash that ends up
as bottom ash. The bottom ash contains some concentration of chromium that
is not emitted to the atmosphere. The combustion of oil produces
essentially no bottom ash, therefore, boiler type and firing configuration
do not affect the level of chromium emissions from oil fuels.

The emission of chromium from coal or oil combustion is generally
explained by the volatilization/condensation mechanism (VCM) theory. The
theory basically states that in the firebox of a boiler or furnace peak
temperatures of approximately 1,650°C (3,000°F) volatilize fuel trace
element species such as chromium. The hot flue gases from the combustion
process then undergo cooling through convective heat transfer and other
mechanisms such that the volatilized species condense. A trace element such
as chromium may condense or adsorb onto existing particles in the stream
according to the available surface area, or it may condense homogeneously
and form fine chromium particles.[101] Through this procedure the chromium
concentration in the bottom ash is depleted, while the concentration in the
fly ash is enriched. This phenomenon occurs because the fly ash has more

relative surface area than the bottom ash for condensation and the bottom ash does not come in contact with the volatilized chromium long enough for it to condense.[101,102] As an example, in a recent analysis of three coal-fired utility boilers the average chromium partitioning was reported to be 23 percent in the bottom ash and 77 percent in the fly ash.[103]

The degree of chromium partitioning and small particle enrichment that goes on during the VCM has been studied by several researchers, especially for coal combustion. These researchers have devised several classification schemes to describe the partitioning and enrichment behavior of many trace elements, including chromium. One of the more simplistic, but effective classification systems is given below:[101,102]

- Class 1. Elements which are approximately equally distributed between fly ash and bottom ash, or show little or no small particle enrichment.
- Class 2. Elements which are enriched in fly ash relative to bottom ash, or show increasing enrichment with decreasing particle size.
- Class 3. Elements which are intermediate between Clases 1 and 2.
- Class 4. Elements which are emitted entirely in the gas phase.

Chromium emissions from coal combustion have been shown to demonstrate the behavior of Classes 1, 2, and 3, and are usually categorized under Class 3. Class 3 elements such as chromium are apparently not totally volatilized during the coal combustion process, and, therefore, exhibit a capability for bottom ash or fly ash deposition. Chromium emissions from oil combustion generally demonstrate the behavior of Class 2 elements, primarily because little bottom ash is present in the combustion system.

The majority of chromium emissions from coal and oil combustion show preferential enrichment on fine fly ash particles.[102,104] Because of this enrichment factor, the type of control device used plays an important role in determining how much chromium is removed from the flue gas exhaust. Control devices not designed to remove fine particulates do not perform as well on chromium emissions as devices which are so designed. A summary of the collection efficiencies for chromium that have been determined for ESPs,

fabric filters, and wet scrubbers is given in Tables 2-15 to 2-17. In
addition to control devices, fuel cleaning has also been shown to be an
effective method of reducing chromium and other trace element emissions from
combustion processes. Physical coal cleaning has been shown to remove from
27 to 65 percent of· the chromium in coal depending on the source of the
coal. Physical cleaning is 50 to 65 percent efficient on eastern and
midwestern coals, but is only 27 percent efficient on western coals. Oil
fuels have successfully been cleaned of trace metals by hydrotreating
processes, but no specific removal data for chromium are available. Removal
efficiencies of greater than 95 percent have been achieved for nickel which
should be a good indicator of potential chromium removal levels because both
nickel and chromium exhibit Class 3 enrichment behavior.[105]

2.11.2 Estimation of National Impacts

National chromium exposure impacts as estimated by the HEM were not
determined for coal and oil combustion sources such as electric utility
boilers, industrial boilers, commercial/institutional boilers, and
residential heating units. The reasons combustion sources were not included
in the analysis are twofold. The first reason concerns the inability to
adequately characterize the hundreds and thousands of individual sources
within each coal and oil combustion source category. Characterization of
the sources involves many factors including emissions quantification, stack
geometry specification, and source location specification by
longitude/latitude coordinates. For combustion sources representative
emissions quantification is difficult due to the wide variability of the
factors affecting emissions, primarily chromium content of the fuel and
degree of emissions control. The sheer number of sources prohibits accurate
specification of stack geometry data and longitude/latitude coordinates.
However, precise longitude/latitude coordinates are required in the HEM to
determine population distributions so that source exposure impacts will not
be signifcantly misrepresented.

The second reason combustion sources were not included in the analysis
of national chromium impacts is that the ambient chromium concentrations
predicted by the HEM to occur from a specifically located, model combustion

TABLE 2-15. CHROMIUM COLLECTION EFFICIENCIES FOR ELECTROSTATIC PRECIPITATORS[105,106]

Source Identification	Fuel	Percent Collection Efficiency
Power Plant A	Coal	99.8
Power Plant B	Coal	98.8
Power Plant C	Coal	99.8
Power Plant D	Coal	98.7
Power Plant E	Coal	97
Power Plant F	Coal	97.6
Power Plant G	Coal	99.2
Power Plant H	Coal	65.6
Power Plant I	Coal	96.2

TABLE 2-16. CHROMIUM COLLECTION EFFICIENCIES FOR FABRIC FILTERS[105,106]

Source Identification	Fuel	Percent Collection Efficiency
Power Plant A	Coal	99.8
Steel Mill	--	99.9

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TABLE 2-14. CHROMIUM COLLECTION EFFICIENCIES FOR WET SCRUBBERS

Source Identifier	Fuel	Percent Collection Efficiency
Power Plant A	Coal	96.1[a]
Power Plant B	Coal	88.9[a]
Industrial Boiler A	Coal	95[b]
Industrial Boiler A	Oil	90[b]
Power Plant C	Coal	97[c]

[a]Controlled by a venturi scrubber.

[b]Scrubber was designed primarily for SO_2 control.

[c]The scrubber is preceeded by an ESP.

source are relatively very minor compared to the concentrations estimated to
be attributable to other chromium sources such as a chromium chemical or
ferrochromium plant. The relative level of ambient chromium concentration
attributable to a combustion source was assessed by developing and
characterizing the emissions of a typical coal burning electric utility
plant located at specific longitude/latitude coordinates. For the
combustion source category as a whole (utility, industrial,
commercial/institutional, and residential sources) the selection of a
typical coal-fired utility boiler (600 MW size) represents the upper end of
the potential chromium emissions range because coal has a higher chromium
content than oil and the overall mass emission of particulates is greater
than that from other types of combustion sources.

For the purposes of analysis the model facility was assumed to be
located in Indianapolis, Indiana. This site was used because Department of
Energy (DOE) coal use data show that Indiana is a large coal consuming state
for electric power generation and a plant of this type (600 MW coal burner)
is located in the Indianapolis area. The specific plant parameters used in
the HEM are given below.

    Cr emission rate: 715 kg (1,573 lb)/yr
    Stack height: 175 m (574 ft)
    Stack diameter: 6.1 m (20 ft)
    Exit velocity: 20 m/sec (65.6 ft/sec)
    Exit temperature: 400 K (261 F)
    Bldg. cross sectional area: 500 m^2 (5,382 ft^2)
    Source type: urban
    Coordinates: 39° 30' 00" latitude
                  87° 25' 00" longitude

The HEM analysis for this plant predicted that ambient chromium
concentrations could range from 10^{-17} µg/m^3 to 10^{-5} µg/m^3. The highest
chromium level to which any person was estimated to be exposed to was
0.000047 µg/m^3. In comparision for a ferrochromium plant, ambient chromium
levels are predicted by the HEM to range from 10^{-3} µg/m^3 to almost 3 µg/m^3.

The minimum concentration to which any person was estimated to be exposed to from the ferrochromium plant is two orders of magnitude higher than the maximum exposure level from the model power plant. The same comparison exists for a chromium chemical plant assessed in this study. The predicted ambient chromium exposure level ranges from 10^{-3} µg/m^3 to 2 ug/m^3 such that the minimum exposure from a chromium chemical plant is also two orders of magnitude higher than the maximum exposure from the model power plant. In view of the inability to adequately characterize the combustion source category on a national basis and the relatively minor chromium exposure potential presented by the model combustion source, national chromium exposure impacts from coal and oil combustion sources were not determined in this study.

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CHAPTER 3

CHROMIUM DISPERSION MODELLING AND POPULATION EXPOSURE ANALYSIS

3.0 INTRODUCTION

As discussed in Chapter 1, the objective of this study is to estimate the ambient chromium concentrations attributable to chromium emission source categories and determine the level of population exposure to these concentrations using the U. S. EPA's HEM. The primary purpose of Chapter 3 is to present the chromium concentration dispersion modelling and population exposure results generated by the HEM. To better understand what the results mean it is useful to have a knowledge of how the HEM is structured and how its outputs are determined. Appendix A provides a general description of the HEM and of the methodology it contains to estimate the level of population exposure to any pollutant under consideration.

The summary HEM results for the chrome ore refining, chromium chemicals, refractory, cement, steel, municipal and sewage sludge incineration, and ferrochromium source categories are presented in the following sections. Any assumptions or source assessment methodologies used that might have a significant impact on the modelling/exposure results are discussed for each source category. A qualitative evaluation of the emissions, stack geometry, and location data (of each source category) used in the HEM analysis is presented in Appendix B.

3.1 CHROMIUM ORE REFINING

As stated in Chapter 2, only one chromium ore refining plant was identified and modelled in this study. The exposure results of the HEM for the single chromium ore refining plant are given in Table 3-1. Approximately 365,000 people are estimated to be exposed to an atmospheric chromium concentration of 0.0000133 $\mu g/m^3$ or greater. The maximum

TABLE 3-1. PUBLIC EXPOSURE TO CHROMIUM FROM CHROMIUM ORE REFINING PLANTS AS PRODUCED BY THE HUMAN EXPOSURE MODEL

Concentration Level ($\mu g/m^3$)	Population Exposed[a] (Persons)	Public Exposure[b] (Persons-$\mu g/m^3$)
0.0118	0	< 1
0.01	0	0.000169
0.0050	0	0.00135
0.0025	1	0.00336
0.001	60	0.106
0.0005	708	0.540
0.00025	5,393	3
0.0001	32,819	7
0.00005	90,509	10
0.000025	280,991	17
0.00001	364,726	19
0.00000951	364,726	19

[a]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.

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

concentration to which any person is exposed is 0.0118 $\mu g/m^3$, although there is only a fraction of a person exposed to this concentration.

3.2 CHROMIUM CHEMICALS MANUFACTURE

Three chromium chemical plants were included in the HEM analysis for chromium chemicals manufacture. Table 3-2 presents, for each specific chromium chemical plant, a breakdown of the total chromium exposure level and the number of people exposed as projected by the HEM. The national public exposure to chromium emissions from the three facilities studied is given in Table 3-3. Approximately 1.85 million people are estimated by the HEM to be exposed to a total chromium concentration in air of 0.000233 $\mu g/m^3$ or greater. The maximum concentration to which anyone is potentially exposed is 1.89 $\mu g/m^3$ of total chromium.

3.3 REFRACTORY MANUFACTURE

Sixteen refractory manufacturing plants using chromium were included in the HEM analysis for this source category. As shown in Table 2-2 of Chapter 2, however, a total of 35 plants have been identified to be manufacturing chromium refractory products and therefore assumed to be chromium emitters. The reason that only 16 plants were included in the modelling/exposure analysis was that no chromium emissions or plant characterization information was available on the other 19 sources. However, despite the number of uncharacterized plants, the 16 that were included in the HEM analysis constitute the major chromium consuming and chromium emitting plants in the refractory source category.[1,2] Although the uncharacterized plants would add to the national level of population exposure from chromium refractory plants, the additional exposure is projected to be minor in comparison due to the smaller size of the facilities and their geographic locations.

Human exposure model results for total chromium exposure and number of people exposed on a per plant basis are presented for all 16 refractory plants in Table 3-4. The national population exposure results calculated by the HEM for chromium emissions from refractory plants are given in

TABLE 3-2. TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE
EXPOSED FROM CHROMIUM CHEMICALS MANUFACTURE[a]

Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Diamond Shamrock, Castle Hayne, NC	98,792	1,200
American Chrome & Chemical, Corpus Christi, TX	227,757	2,740
Allied Chemical, Baltimore, MD	1,523,433	41,400

[a]A 20 km (12.4 miles) radius was used for the analysis of chromium
chemical plants.

TABLE 3-3. PUBLIC EXPOSURE TO CHROMIUM FROM THREE MAJOR
CHROMIUM CHEMICAL MANUFACTURING PLANTS AS
PRODUCED BY THE HUMAN EXPOSURE MODEL

Concentration Level ($\mu g/m^3$)	Population Exposed[a] (Persons)	Public Exposure[b] (Persons-$\mu g/m^3$)
1.89	1	2
1.0	6	9
0.5	3,865	2,510
0.25	19,370	7,770
0.1	65,463	14,600
0.05	180,502	22,400
0.025	411,501	30,400
0.01	1,062,928	40,400
0.005	1,598,515	44,400
0.0025	1,808,106	45,200
0.001	1,838,288	45,300
0.0005	1,839,699	45,300
0.00025	1,849,992	45,300
0.000233	1,849,992	45,300

[a]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.

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

TABLE 3-4. TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE
EXPOSED FROM CHROMIUM REFRACTORY MANUFACTURE[a]

Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Corhart Refractories, Buckhannon, WV	26,322	4,330
General Refractories, Lehi, UT	172,162	279
A. P. Green Refractories, Tarentum, PA	392,369	2,800
Lava Crucible Refractories, Zelienople, PA	187,737	60
Kaiser Refractories, Plymouth Meeting, PA	2,154,957	3,170
Gunning Refractories, South Webster, OH	38,379	119
Resco Products, Norristown, PA	1,745,057	543
Basic Refractories, Maple Grove, OH	88,893	207
Kaiser Refractories, Columbiana, OH	89,937	570
Wellsville Fire Brick Co., Wellsville, MO	10,598	43
Corhart Refractories, Pascagoula, MS	85,439	597
Didier Taylor Refractories, South Shore, KY	83,697	231
Harbison-Walker Refractories, Baltimore, MD	1,424,411	3,320

TABLE 3-4 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM CHROMIUM REFRACTORY MANUFACTURE[a]

Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Gunning Refractories, Crown Point, IN	386,894	134
Harbison-Walker Refractories, Hammond, IN	1,193,663	26,700
Kaiser Refractories, Moss Landing, CA	161,321	569

[a] A 20 km (12.4 miles) radius was used for the analysis of chromium refractory plants.

Table 3-5. The maximum concentration to which any person is potentially exposed is 13.5 ug/m^3 of total chromium although only a fraction of a person is exposed at this level.

In evaluating the HEM results for refractory plants data base deficiencies involving chromium emissions information and refractory plant longitude/latitude location coordinates should be considered. No emissions test data were available to characterize chromium emissions from refractory production processes. Chromium emissions estimates used in the HEM analysis were prepared using general particulate emissions data and estimated levels of chromium in the particulate emissions. The particulate chromium levels were estimated using process information from the published literature and State air quality permits. The estimates used in the HEM analysis were reasonable; however, they probably represent the upper end of the potential emission range. The development of a better chromium emissions data base for this source category is a definite recommendation prior to initiating future exposure analysis efforts.

A second factor to be considered for this source category is that precise longitude/latitude location coordinates were not available for all plant sites. For these five plants without locations data longitude/latitude coordinates were estimated from atlases such that the obtained coordinates represented the geographic center of the city location and not the exact plant location. In these cases it is possible that the density of the population distribution around the plant may have been overstated or understated. Therefore, the total public exposure to chromium from refractory plants predicted by the HEM may be biased slightly high or low. It should be noted that the combination of potentially upper end chromium emissions (the first consideration) and an overstatement of the population exposed would produce an HEM exposure result that is biased high for the refractory source category. With the information available it is not possible to indicate the degree to which such a bias may or may not have been produced.

TABLE 3-5. PUBLIC EXPOSURE TO CHROMIUM FROM CHROMIUM REFRACTORY PLANTS AS PRODUCED BY THE HUMAN EXPOSURE MODEL

Concentration Level ($\mu g/m^3$)	Population Exposed[a] (Persons)	Public Exposure[b] (Persons-$\mu g/m^3$)
13.5	0	1
10	0	4
5	1	11
2.5	24	73
1	509	719
0.5	4,976	3,820
0.25	15,205	7,600
0.1	59,921	14,300
0.05	129,876	18,900
0.025	272,685	23,700
0.01	777,461	31,500
0.005	1,442,270	36,500
0.0025	2,072,713	38,700
0.001	4,048,332	41,800
0.0005	5,971,919	43,200
0.00025	6,481,292	43,400
0.0001	7,997,769	43,700
0.00005	8,229,068	43,700
0.0000368	8,242,165	43,700

[a]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.

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

3.4 MUNICIPAL REFUSE AND SEWAGE SLUDGE INCINERATION

As stated in Section 2.7 of Chapter 2, 129 municipal refuse incinerators were identified in this study and included in the HEM analysis. However, because several sites have multiple incinerators ducted to one control system, the number of distinct site entries given in the summary tables below does not equal 129. This same principle also holds true for the 141 sewage sludge incinerators. Table 3-6 presents the summary HEM results for the total number of people exposed and the total chromium exposure at each municipal refuse incinerator site examined. The national public exposure to chromium from municipal refuse incinerators, as determined by the HEM, is given in Table 3-7. Approximately 45 million people are estimated to be exposed to chromium concentrations of 0.00000012 $\mu g/m^3$ or greater as a result of municipal refuse incinerator operations. The highest ambient chromium concentration predicted by the HEM to be encountered in the vicinity of municipal refuse incinerators is 0.0245 $\mu g/m^3$. Table 3-7 indicates that only a fraction of a person is actually exposed to the highest predicted concentration.

Table 3-8 presents the summary HEM results for the total number of people exposed and the total chromium exposure at each sewage sludge incinerator studied. The national public exposure to chromium from sewage sludge incinerators is presented in Table 3-9. Approximately 45 million people are projected to be exposed to chromium concentrations of 0.0000005 $\mu g/m^3$ or greater as a result of sewage sludge incinerator operations. The highest ambient chromium concentration estimated by the HEM to be encountered in the area of sewage sludge incinerators is 0.0838 $\mu g/m^3$. However, the HEM also predicts that only a fraction of a person is exposed to this maximum concentration.

To appropriately evaluate the exposure results given in Tables 3-6 to 3-9, certain factors in the municipal refuse and sewage sludge incinerator data bases should be noted. The first factor involves the great variability of the chromium levels found in municipal refuse and sewage sludge, which in turn affects the levels of chromium emitted. As discussed in Section 2.7 of

TABLE 3-6. TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE
EXPOSED FROM MUNICIPAL REFUSE INCINERATORS[a]

Incinerator, Location	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Augusta, AR	9,032	0.04
Bentonville, AR	59,276	0.5
Blytheville, AR	42,318	0.8
Hope, AR	17,689	0.09
Hot Springs, AR	66,960	4
Kensett, AR	31,271	0.06
Atkins, AR	37,281	0.07
North Little Rock, AR	305,901	13
Osceola, AR	24,994	0.3
Siloam Springs, AR	24,951	0.3
Stuttgart, AR	15,247	0.2
Orlando, FL	474,557	18
Pahokee, FL	47,926	0.4
Port Orange, FL	146,855	2
Donaldsonville, LA	37,459	0.2
Plaquemine, LA	85,476	0.7
Rayne, LA	81,604	0.5
Harpswell, ME	53,494	0.02
Kittery, ME	137,793	1
Auburn, NH	184,597	0.03

TABLE 3-6 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM MUNICIPAL REFUSE INCINERATORS[a]

Incinerator Location	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Bridgewater, NH	19,159	0.04
Candia, NH	166,425	0.2
Canterbury, NH	69,276	0.1
Litchfield, NH	262,891	0.8
Meredith, NH	39,505	0.1
Nottingham, NH	46,587	0.07
Pittsfield, NH	42,863	0.09
Wilton, NH	53,995	0.2
Wolfeboro, NH	40,044	0.07
Skaneateles, NY	73,188	0.3
Wrightsville Beach, NC	100,654	0.9
Cleveland, OK	15,530	0.06
Tahlequah, OK	25,573	0.6
Coos County, OR	41,160	0.2
Crossville, TN	24,255	0.2
Refugio, TX	5,250	0.005
Terrell, TX	13,812	0.03
Salem, VA	201,407	4
Bellingham, WA	67,926	0.6
Ansonia, CT	690,812	133

TABLE 3-6 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE
EXPOSED FROM MUNICIPAL REFUSE INCINERATORS[a]

Incinerator Location	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
East Hartford, CT	652,253	140
New Canaan, CT	407,498	41
Stamford, CT	438,057	47
Washington, DC	1,985,386	1,950
Chicago, IL	2,240,530	673
East Chicago, IN	1,440,154	122
Louisville, KY	781,871	2,620
Shreveport, LA	14,120	2
Baltimore, MD	1,411,705	21
Baltimore, MD	1,517,384	604
Braintree, MA	1,419,658	953
Bridgewater, MA	86,350	27
Fall River, MA	327,388	23
Framingham, MA	606,935	331
Saugus, MA	1,398,135	248
St. Louis, MO	1,484,720	141
St. Louis, MO	1,338,049	206
Red Bank, NJ	448,355	116
Harrisburg, PA	312,305	155
Huntington, NY	1,023,122	557

TABLE 3-6 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM MUNICIPAL REFUSE INCINERATORS[a]

Incinerator Location	Total Number of Persons Exposed	Total Exposure (Persons-µg/m^3)
Lackawanna, NY	885,000	259
Oyster Bay, NY	1,056,654	1,190
Tonawanda, NY	876,795	151
Lakewood, OH	1,258,571	419
Philadelphia, PA	2,696,321	778
Philadelphia, PA	2,908,879	895
Shippensburg, PA	2,153,465	411
Nashville, TN	450,589	158
Newport News, VA	12,523	1
Norfolk, VA	788,288	81
Portsmouth, VA	674,382	199
Sheboygan, WI	83,589	149
Waukesha, WI	491,324	37
Honolulu, HA	627,857	159
Dade County, FL	1,385,689	169
Orlando, FL	318,726	7
South Brooklyn, NY	5,056,145	1,200

[a] A 20 km (12.4 miles) radius was used for the analysis of municipal waste incinerators.

TABLE 3-7. PUBLIC EXPOSURE TO CHROMIUM FROM MUNICIPAL REFUSE
INCINERATORS AS PRODUCED BY THE HUMAN EXPOSURE MODEL

Concentration Level $(\mu g/m^3)$	Population Exposed[a] (Persons)	Public Exposure[b] (Persons-$\mu g/m^3$)
0.0245	0	< 1
0.01	42,551	604
0.005	267,058	2,080
0.0025	817,966	3,930
0.001	3,081,821	7,370
0.0005	6,674,389	9,870
0.00025	13,815,227	12,400
0.0001	28,113,506	14,700
0.00005	35,814,533	15,200
0.000025	39,267,454	15,400
0.00001	41,998,744	15,400
0.000005	43,171,894	15,400
0.0000025	43,854,513	15,400
0.000001	44,614,448	15,400
0.0000005	44,881,518	15,400
0.00000025	44,896,673	15,400
0.00000012	44,944,086	15,400

[a]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.

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

TABLE 3-8. TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE
EXPOSED FROM SEWAGE SLUDGE INCINERATORS[a]

Incinerator, Location	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Alaska Village Electric Co-op, Anchorage, AK	21	0.0C006
Wrangell, AK	893	0.0002
City of Riverside Incinerator, Riverside, CA	454,483	3
Mattabassett District Incinerator, Cromwell, CT	503,569	5
Hartford Sewage Treatment Plant, Hartford, CT	666,991	115
Lake Arrowhead, CA Incinerator	159,643	0.1
City of New Haven Incinerator, New Haven, CT	504,326	43
Waterbury Sludge Incinerator, Waterbury, CT	382,993	18
Buckman Sewage Treatment Plant, Duval County, FL	513,758	77
Pensacola Incinerator, Pensacola, FL	214,215	3
DeKalb County Snapfinger Water Pollution Control, Decatur, GA	691,793	2
Jonesboro, GA Incinerator	257,425	4
Marietta, GA Incinerator	497,857	10
Savannah, GA Incinerator	184,373	11
Granite City, IL Incinerator	1,292,493	12

TABLE 3-8 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM SEWAGE SLUDGE INCINERATORS[a]

Incinerator, Location	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Indianapolis Sludge Incinerators, Indianapolis, IN	804,229	24
Cedar Rapids, IA	75,752	0.7
Davenport Sewage Treatment Plant, Davenport, IA	309,024	1
Kansas City Wastewater Treatment Plant Kansas City, KS	943,145	3
Mission, KS Incinerator	902,376	10
Johnson City Unified Sewage Plant, Olathe, KS	230,782	5
Covington, KY Incinerator	984,937	25
City of Cynthiana Incinerator, Cynthiana, KY	21,357	0.2
Sanitation District 1 of Camdry Creek, Erlanger, KY	949,940	5
Sanitation District 1 of Camdry Creek, Erlanger KY	782,255	7
Metropolitan Sewer District, Louisville, KY	732,475	478
Chicopee Wastewater Treatment Plant, Chicopee, MA	528,726	7
Fall River, MA Incinerator	381,771	6

TABLE 3-8 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE
EXPOSED FROM SEWAGE SLUDGE INCINERATORS[a]

Incinerator, Location	Total Number of Persons Exposed	Total Exposure (Persons-μg/m³)
E. Fitchburg Wastewater Treatment Plant, Fitchburg, MA	176,631	3
New Bedford Sewage Treatment Plant, New Bedford, MA	182,852	1
Upper Blackstone Treatment Plant, Worcester, MA	356,541	11
Ann Arbor Wastewater Treatment Plant, Ann Arbor, MI	250,452	7
Bay City Wastewater Treatment Plant, Bay City, MI	241,264	4
Sewerage Treatment Plant, Detroit, MI	1,992,075	1,480
East Lansing Wastewater Treatment Plant, East Lansing, MI	318,129	14
Flintwater Pollution Control, Flint, MI	410,359	48
Grand Rapids Wastewater Treatment Plant, Grand Rapids, MI	421,649	18
Kalamazoo Wastewater Treatment Plant, Kalamazoo, MI	192,934	4
Saginaw Wastewater Treatment, Saginaw, MI	223,825	31
Trenton Wastewater Plant, Trenton, MI	431,750	5

TABLE 3-8 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE
EXPOSED FROM SEWAGE SLUDGE INCINERATORS[a]

Incinerator, Location	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Wyandotte Wastewater Plant, Wyandotte, MI	838,272	28
Wyoming Wastewater Treatment Plant, Wyoming, MI	317,771	10
Metropolitan Wastewater Plant, St. Paul, MN	936,022	90
Metropolitan Waste Control, St. Paul, MN	1,000,366	9
Independence, MO Incinerator	868,541	20
Paplo Wastewater Treatment Plant, Bellevue, NE	472,366	10
Carson City Sewerage Treatment Plant, Carson City, NV	58,425	0.5
Douglas City Sewer Impoundment District, Douglas City, NV	57,983	0.6
Manchester, NH Incinerator	192,449	8
Merrimack, NH Incinerator	172,913	7
Atlantic City Sewer Authority, Atlantic City, NJ	164,940	11
Gloucester County Sewerage Authority, Gloucester County, NJ	1,995,527	12
Stony Brook Regional Sewerage Authority, Mercer City, NJ	381,292	4

TABLE 3-8 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE
EXPOSED FROM SEWAGE SLUDGE INCINERATORS[a]

Incinerator, Location	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Ocean City Utilities Authority, Ocean City, NJ	159,764	2
Amherst, NY Incinerators	978,078	43
Hamburg, NY Incinerators	238,460	3
North Tonawanda, NY Incinerator	899,324	7
N. Buffalo Waste Treatment Plant, Greensboro, NC	234,568	6
Akron Water Pollution Control, Akron, OH	573,868	54
Cincinnati, OH Incinerators	,044,863	116
Southerly Wastewater Treatment, Cuyahoga County, OH	1,?36,504	496
Mill Creek Treatment Plant, Hamilton City, OH	51,933	2
Warren Wastewater Treatment Plant, Trumbull City, OH	366,846	13
Lawton, OK Incinerator	116,921	0.7
Delaware City Regional Water Authority, Chester, PA	945,208	57
Erie Sewer Authority, Erie, PA	216,366	20
Greater Hazelton Sewer Authority, Luzerne County, PA	110,746	15
Wyoming Valley Sanitary Authority, Luzerne County, PA	257,264	11

TABLE 3-8 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE
EXPOSED FROM SEWAGE SLUDGE INCINERATORS[a]

Incinerator, Location	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Morrisville, PA Incinerator	855,671	4
Tyrone Borough Sewer Authority, Tyrone, PA	15,399	0.03
Kiski Valley Water Pollution Control Authority, Westmoreland County, PA	182,053	0.9
Upper Moreland Incinerator, Willow Grove, PA	1,602,913	160
Cranston, RI Incinerator	727,978	25
Providence, RI Incinerator	760,968	17
Maryville, TN Incinerator	147,593	0.6
Central Wastewater Plant, Nashville-Davidson, TN	471,788	20
Newport Utilities Board Wastewater Plant, Newport, TN	35,604	0.9
Carswell Air Force Base, Ft. Worth, TX	549,046	0.3
Plano, TX Incinerator	217,578	0.5
Richardson, TX Incinerator	357,831	2
Arlington County Incinerator, Arlington, VA	2,057,854	18
Blacksburg-VPI Sanitation Authority, Blacksburg, VA	85,923	1
Lower Potomac Pollution Control, Fairfax, VA	659,260	35

TABLE 3-8 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM SEWAGE SLUDGE INCINERATORS[a]

Incinerator, Location	Total Number of Persons Exposed	Total Exposure (Persons-μg/m^3)
Hopewell, VA Incinerator	157,739	6
Longview, WA Incinerator	73,521	0.6
Cowlitz County Sewage Authority, Longview, WA	75,576	2
Vancouver, WA Incinerator	691,171	4
Charleston, WV Incinerator	247,045	27
Green Bay Metro Sewerage District, Green Bay, WI	171,229	29
Neenah-Menasha Sewage Authority, Menasha, WI	54,658	0.3
Milwaukee Sewage Authority, Milwaukee, WI	1,110,952	16

[a]A 20 km (12.4 miles) radius was used for the analysis of sewage sludge incinerators.

TABLE 3-9. PUBLIC EXPOSURE TO CHROMIUM FROM SEWAGE SLUDGE
INCINERATORS AS PRODUCED BY THE HUMAN EXPOSURE MODEL

Concentration Level ($\mu g/m^3$)	Population Exposed[a] (Persons)	Public Exposure[b] (Persons-$\mu g/m^3$)
0.0838	0	< 1
0.05	17	1
0.025	688	22
0.01	10,876	163
0.005	45,149	398
0.0025	125,366	669
0.001	501,197	1,230
0.0005	1,565,732	1,960
0.00025	3,743,096	2,720
0.0001	7,087,313	3,260
0.00005	11,026,504	3,530
0.000025	16,552,800	3,730
0.00001	25,142,816	3,870
0.000005	33,399,161	3,930
0.0000025	40,222,586	3,950
0.000001	44,001,675	3,960
0.0000005	44,827,827	3,960

[a]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.

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

Chapter 2, chromium contents in various refuse and sludge streams can vary from one to three orders of magnitude, thereby potentially exerting a significant impact on chromium air emissions. The variability in the chromium content of particulate emissions from both types of incinerators has been illustrated in Table 2-5. The average chromium values in Table 2-5 were used to calculate chromium emissions from the purposes of the HEM analysis. Holding all other factors constant, it is easy to see that if the upper or lower values in the chromium data given in Table 2-5 had been used for the HEM analysis, a different exposure picture than that shown in Tables 3-6 to 3-9 potentially would have resulted.

The second factor to be considered in evaluating the HEM results involves only municipal refuse incinerators. Precise longitude/latitude location coordinates for all municipal refuse incinerators were not available, particularly for several of the small package incinerators located in relatively small towns. Location coordinates for these sites were estimated from atlases such that the coordinates used in the HEM were for the geographic center of the town and not the incinerator site. By doing this the density of the population distribution may have been overstated or understated, thereby directly affecting the size of the exposed population. The effect this factor had on the total public exposure to chromium given in Table 3-7 is anticipated to be minor because the unlocated incinerators are small size/low chromium emission units located in relatively low density population areas.

The third factor to be considered in evaluating the HEM results involves only the sewage sludge incinerator source category. The facet of the sewage sludge category that has a bearing on the exposure analysis concerns differences in published estimates of the number of sewage sludge incinerators currently operating in the United States. The list of the 141 sewage sludge incinerators included in the HEM analysis was generated from the NEDS and from contacts with U.S. EPA regional offices. A recent study estimated the number of sewage sludge incinerators operating in the United States to be more than twice the 141 analyzed in this report; however, an individualized listing of these incinerators was not provided.[3]

It is highly probable that there may be more than 141 sewage sludge incinerators in the United States, but to determine the exact number more is not possible with currently available data. Obviously a larger population of sewage sludge incinerators would mean a potentially larger public exposure to chromium than that shown in Table 3-9.

3.5 FERROCHROMIUM PRODUCTION

As explained in Chapters 1 and 2, only one ferrochromium production plant is in operation in the United States. The public exposure to chromium presented by this plant, as estimated by the HEM, is given in Table 3-10. Approximately 22,132 people are projected to be exposed to a total atmospheric chromium concentration of 0.00142 ug/m^3 or greater. The maximum concentration to which a person could potentially be exposed is 2.87 ug/m^3; however, there is only a fraction of a person actually exposed to this level. The maximum concentration to which any people are actually exposed is 0.0195 ug/m^3. There are 914 people exposed at the 0.0195 ug/m^3 concentration level.

3.6 STEEL MANUFACTURING

In section 2.8 of Chapter 2 various steel producing sources such as EAFs, BOPFs, and AOD vessels were discussed separately. However, many plants contain both EAFs and BOPFs or EAFs/AOD vessels and BOPFs. In the HEM analysis EAFs, BOPFs, and AOD vessels were not treated individually, but rather they were combined into a single steel plant where applicable. In other words a separate HEM analysis was not conducted for plant A's EAF chromium emissions and plant A's BOPF chromium emissions. One HEM analysis was conducted for plant A's total chromium emissions. Table 3-11 presents the summary HEM results for the total number of people exposed and the total chromium exposure at each steel plant studied. The national public exposure to chromium from steel manufacturing plants is presented in Table 3-12. Approximately 69.3 million people are projected to be exposed to chromium concentrations of 0.0000025 ug/m^3 or greater as a result of steel plant chromium emissions. The maximum chromium concentration to which any person is potentially exposed from steel manufacturing is 0.0877 ug/m^3; however, only a fraction of a person is actually exposed at this level.

TABLE 3-10. PUBLIC EXPOSURE TO CHROMIUM FROM FERROCHROMIUM
PLANTS AS PRODUCED BY THE HUMAN EXPOSURE MODEL

Concentration Level (μg/m³)	Population Exposed[a] (Persons)	Public Exposure[b] (Persons-μg/m³)
2.87	0	< 1
2.5	0	< 1
1.0	0	< 1
0.5	0	< 1
0.25	0	< 1
0.1	0	< 1
0.05	0	< 1
0.025	0	< 1
0.0195	914	18
0.01	1,487	27
0.005	6,045	62
0.0025	13,473	87
0.00142	22,132	102

[a]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.

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

TABLE 3-11. TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE
EXPOSED FROM STEEL MANUFACTURING PLANTS[a]

Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Bethlehem Steel, Burns Harbor, IN	246,370	8
Kaiser Steel, Fontana, CA	431,659	6
Bethlehem Steel, Sparrows Piont, MD	1,044,566	16
U. S. Steel, Gary, IN	605,300	13
National Steel, Granite City, IL	1,210,516	11
Armco, Middletown, OH	267,881	5
U. S. Steel, Lorain, OH	305,376	7
U. S. Steel, Braddock, PA	1,057,969	16
Jones & Laughlin, Aliquippa, PA	317,888	4
Bethlehem Steel, Lackawanna, NY	885,000	17
Republic Steel, Buffalo, NY	982,397	15
U. S. Steel, Fairfield, AL	567,363	11
Whelling-Pittsburgh Steel, Monessen, PA	215,154	2

TABLE 3-11 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE
EXPOSED FROM STEEL MANUFACTURING PLANTS[a]

Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Cyclops Corp., Bridgeville, PA	860,763	1,340
Cyclops Corp., Mansfield, OH	151,754	193
Electralloy Corp., Oil City, PA	51,613	128
Crucible, Inc., Syracuse, NY	242,138	90
Crucible, Inc. Midland, PA	268,815	546
CF & I Steel, Pueblo, CO	117,916	174
Cabot Corp., Kokomo, IN	97,793	131
Carpenter Technology Corp., Reading, PA	262,290	339
Carpenter Technology Corp., Bridgeport, CT	482,962	495
Bethlehem Steel, Steelton, PA	344,245	324
Babcock & Wilcox, Beaver Falls, PA	228,890	377
Armco, Inc. Butler, PA	103,272	185
Copperweld Steel, Warren, OH	290,560	189

TABLE 3-11 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM STEEL MANUFACTURING PLANTS[a]

Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Republic Steel, Warren, OH	331,535	7
Bethlehem Steel, Bethlehem, PA	481,509	181
National Steel, Weirton, WV	147,265	2
Sharon Steel, Farrell, PA	297,315	2
Republic Steel, Cleveland, OH	1,405,552	33
Interlake, Chicago, IL	2,142,814	40
Jones & Laughlin, East Chicago, IN	1,408,553	17
Simonds Steel, Lockport, NY	109,095	8
Roblin Steel, Dunkirk, NY	49,319	25
Republic Steel, Gadsden, AL	91,844	151
Nucor Corp., Norfolk, NE	28,024	57
Nucor Corp., Jewett, TX	4,684	2
Nucor Corp., Darlington, SC	89,814	26

TABLE 3-11 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE
EXPOSED FROM STEEL MANUFACTURING PLANTS[a]

Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Northwest Steel Rolling, Kent, WA	418,364	94
New Jersey Steel & Structure, Sayerville, NJ	870,047	217
National Forge Co., Erie, PA	221,786	363
McLouth Steel, Trenton, MI	453,179	391
Marathon Le Tourneau, Longview, TX	95,819	28
Laclede Steel Co., Alton, IL	412,604	374
Judson Steel Corp. Emeryville, CA	1,566,989	353
Jessup Steel Corp., Washington, PA	116,599	38
Jones & Laughlin Steel, Warren, MI	2,278,195	3,400
Josyln Stainless Steels, Ft. Wayne, IN	278,382	529
ITT Harper, Morton Grove, IL	2,613,703	495
Ingersol Rand, Pampa, TX	23,367	64
Ingersoll Johnson Steel, New Castle, IN	59,947	21

TABLE 3-11 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM STEEL MANUFACTURING PLANTS[a]

Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Kentucky Electric Steel, Ashland, KY	112,440	21
Al Tech Specialty Steel, Watervliet, NY	524,509	497
Marathon Steel, Tempe, AZ	678,143	49
Phoenix Steel Corp., Claymont, DE	740,981	483
North Star Steel, St. Paul, MN	684,776	179
Oregon Steel Mills, Portland, OR	628,517	168
Connors Steel Co., Huntington, WV	177,365	63
Connors Steel Co., Birmingham, AL	538,505	176
Hawaiian Western Steel, Ewa, HA	162,207	12
Roanoke Electric Steel, Roanoke, VA	206,676	40
Rariton River Steel, Perth Amboy, NJ	1,365,555	651
Nucor Corp., Plymouth, UT	7,692	2
Washington Steel Co., Houston, PA	268,815	315

TABLE 3-11 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM STEEL MANUFACTURING PLANTS[a]

Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
U. S. Steel, Baytown, TX	172,077	500
U. S. Steel, Duquesne, PA	1,168,152	806
U. S. Steel, Fairless Hills, PA	40,367	29
Texas Steel, Ft. Worth, TX	7,344	3
Tennessee Forging Steel, Newport, AR	19,920	5
Tennessee Forging Steel, Harriman, TN	50,430	8
Teledyne Vasco, Latrobe, PA	153,970	13
Finkle & Sons, Chicago, IL	3,583,504	1,230
Republic Steel, South Chicago, IL	2,143,893	1,840
Camulet Steel Co., Chicago Heights, IL	835,317	100
Columbia Tool Steel, Chicago Heights, IL	758,850	130
U. S. Steel, South Chicago, IL	2,193,165	3,410
Ameron Steel and Wire, Ltiwanda, CA	553,528	346

TABLE 3-11 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE
EXPOSED FROM STEEL MANUFACTURING PLANTS[a]

Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Armco, Inc., Torrance, CA	2,286,634	297
Bethlehem Steel, Los Angeles, CA	1,246,493	363
National Steel, Ecorse, MI	232,986	400
Ford Motor Co., Dearborn, MI	2,197,829	1,860
Armco, Inc., Baltimore, MD	1,492,025	3,630
Eastern Stainless Steel, Baltimore, MD	1,401,892	1,260
Armco, Inc., Houston, TX	1,113,868	1,220
Cameron Iron Works, Houston, TX	378,397	48
Border Steel Mills, El Paso, TX	438,614	56
Bethlehem Steel, Seattle, WA	939,739	582
E. M. Jorgensen Co., Seattle, WA	886,161	448
Jones & Laughlin Steel, Pittsburgh, PA	1,333,793	1,200
Newport Steel, Newport, KY	983,703	413

TABLE 3-11 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM STEEL MANUFACTURING PLANTS[a]

Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Armco, Inc., Ashland, KY	191,858	2
Edgewater Steel, Oakmont, PA	1,067,892	162
Allegheny Ludlum Steel, Brackenridge, PA	331,844	1,040
Braeburn Alloy Steel Div., Braeburn, PA	378,737	40
Quantex Corp., Jackson, MI	138,491	58
North Star Steel, Monroe, MI	89,662	107
Chaparral Steel Corp., Midlothian, TX	230,434	188
Jessup Steel Co., Oweusboro, KY	84,743	23
The Ceco Corp., Birmingham, AL	494,659	40
Armco, Inc., Kansas City, MO	523,346	582
California Steel Co., Chicago, IL	2,554,174	596
Union Electric Steel, Burgettstown, PA	125,826	12
Lukens Steel Co., Coatsville, PA	164,120	248

TABLE 3-11 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM STEEL MANUFACTURING PLANTS[a]

Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
National Forge Co., Irvine, PA	38,085	15
Standard Steel Div. of Timet, Burnham, PA	47,337	66
Timken Co., Latrobe, PA	135,716	88
U. S. Steel, Johnstown, PA	156,620	57
Republic Steel, Canton, OH	316,582	691
Timken Co., Canton, OH	325,629	746
Jones & Laughlin Steel, Cleveland, OH	1,404,665	1,340
Inland Steel, East Chicago, IN	1,297,852	575

[a] A 20 km (12.4 miles) radius was used for the analysis of steel manufacturing plants.

TABLE 3-12. PUBLIC EXPOSURE TO CHROMIUM FROM STEEL MANUFACTURING
PLANTS AS PRODUCED BY THE HUMAN EXPOSURE MODEL

Concentration Level ($\mu g/m^3$)	Population Exposed[a] (Persons)	Public Exposure[b] (Persons-$\mu g/m^3$)
0.0877	0	< 1
0.05	455	28
0.025	5,733	202
0.01	105,745	1,520
0.005	655,234	5,190
0.0025	2,675,640	12,000
0.001	11,227,637	24,900
0.0005	23,709,980	33,800
0.00025	36,074,774	38,300
0.0001	48,658,204	40,400
0.00005	54,116,157	40,800
0.000025	57,971,330	40,900
0.0C001	65,884,712	41,000
0.000005	69,425,323	41,100
0.0000025	70,304,856	41,100

[a]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.

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

Due to present economic conditions the domestic steel industry is in a period of production cutbacks and total plant closures. Both of these conditions directly affect potential chromium emissions from the steel industry. It is possible that the national public exposure levels to chromium from steel production shown in Table 3-12 and the individual plant levels shown in Table 3-11 are overstated because of plant cutbacks and plant closures that are unable to be accounted for.

Other factors to be considered in evaluating the steel production HEM results are that only one chromium emission factor was available for BOPFs, no actual plant stack geometry data were available, and emission control efficiencies were assumed to be equal for similar sources at all plants in the industry. Because only one chromium factor was available for BOPF emissions, variability in chromium levels could not be taken into consideration. The single factor available may not be representative of all BOPF chromium emissions or of long-term BOPF chromium emissions.

Stack geometry data for all types of facilities (EAFs, BOPFs, and AODs) were estimated from model plants used to develop new source performance standards. While these values are representative of the steel operations in general, they may not be equivalent to actual plant values such that emissions dispersion as estimated by the HEM may be imprecise. The effect of this potential imprecision on the overall HEM analysis for steel plants is estimated to be negligible.

Emissions collection and control efficiencies for every steel plant in the United States are not available, therefore assumptions had to be made on the chromium emission removal efficiency at each plant. The control efficiencies used to estimate chromium emissions from the HEM analysis were taken from a recent U. S. EPA report that included an investigation of steel plant particulate control efficiencies.[4] In the HEM analysis efficiencies for each type of source, for example EAFs, were assumed to be equal at every plant. Because all facilities do not have identical control efficiencies bias was introduced into the analysis. It is anticipated that total chromium emission control efficiencies may be slightly overstated in the HEM analysis because of uncertainties involving the control of fugitive

emissions.[5] Contacts with U. S. EPA regional offices have indicated that fugitive emissions are not highly controlled at all plants.[6,7,8] The impact of this situation on the overall source category HEM analysis is difficult to predict in view of the potential variabilities in the chromium emission estimates.

3.7 CEMENT MANUFACTURING

A total of 163 portland cement plants were included in the HEM analysis of the cement manufacturing source category. Table 3-13 presents the summary HEM results for the total number of people exposed and the total chromium exposure at each of the 163 plants. The range of cement plant total chromium exposure predicted by the HEM is large, 0.005 persons-ug/m^3 to 103 persons-ug/m^3. This range indicates significant differences in plant sizes and emissions, degree of emissions control, and population density around the sources.

The national public exposure to chromium from cement manufacturing plants is presented in Table 3-14. Approximately 50.4 million people are estimated to be exposed to chromium concentrations of 0.000000025 ug/m^3 or greater as a result of cement plant chromium emissions. The maximum chromium concentration to which any person is potentially exposed from cement manufacturing is 0.0469 ug/m^3; however, only a fraction of a person is actually exposed at this level.

In evaluating the HEM results for cement plants a data base deficiency involving the determination of chromium emissions should be considered. The majority of plant chromium emissions estimates were prepared using chromium emission factors (lb Cr/ton particulate emitted) and particulate emissions data from the NEDS information base. The use of NEDS information could cause chromium emission estimates to be inaccurate because NEDS emission numbers are not always reliable or current. Often NEDS numbers are themselves estimates based on assumptions, and therefore can be inaccurate to various degrees. Also because of a failure to keep NEDS information updated, emissions can be overestimated (if better controls have been installed since the last update). It is not possible to judge the quality

TABLE 3-13. TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE
EXPOSED FROM CEMENT MANUFACTURING PLANTS[a]

Cement Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Citadel Cement, Birmingham, AL	541,808	8
Alpha Portland Co., Birmingham, AL	532,613	23
Martin Marietta, Birmingham, AL	568,179	16
Martin Marietta, Calera, AL	46,292	3
Citadel Cement, Demopolis, AL	16,602	0.5
Universal Atlas, Leeds, AL	152,907	5
National Cement, Ragland, AL	21,525	2
Phoenix Cement Co., Clarkdale, AZ	8,538	0.8
Arizona Portland Cement, Pima County, AZ	695	0.005
Arkansas Cement Corp., Foreman, AR	8,094	2
Ideal Cement, Okay, AR	8,000	0.3
California Portland Cement, Colton, CA	647,310	12
Lone Star Industrial Cement, Davenport, CA	82,805	5

TABLE 3-13 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE
EXPOSED FROM CEMENT MANUFACTURING PLANTS[a]

Cement Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
General Portland, Inc., Lebec, CA	1,452	0.05
Kaiser Cement, Lucerne Valley, CA	3,046	0.3
California Portland Cement, Mojave, CA	11,904	1
Monolith Portland Cement, Monolith, CA	9,311	0.08
Flintkote Co., Redding, CA	49,522	1
Flintkote Co., San Andreas, CA	9,443	0.9
Ideal Cement Co., San Juan Bautista, CA	97,799	1
Southwestern Portland Cement, Victorville, CA	21,046	0.2
Martin Marietta, Boulder County, CO	77,769	2
Ideal Basic Industries, Florence, CO	17,040	0.5
Ideal Cement Co., Laporte, CO	88,840	1
Ideal Basic Industries, Portland, CO	9,354	0.07
Florida Mining Materials, Brooksville, FL	35,946	0.3

TABLE 3-13 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM CEMENT MANUFACTURING PLANTS[a]

Cement Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Lehigh Portland Cement, Dade County, FL	700,939	6
Lone Star Florida, Dade County, FL	1,010,444	3
General Portland Cement, Dade County, FL	295,406	5
Maule Industries, Hialeah, FL	1,501,202	39
General Portland Cement, Tampa, FL	519,463	0.3
Martin Marietta, Atlanta, GA	1,010,892	13
Medusa Cement Co., Clinchfield, GA	26,775	0.8
Marquette Cement Co., Rockmont, GA	38,142	2
Cyprus-Hawaiian Cement, Honolulu County, HA	148,945	3
Kaiser Cement & Gypsum, Nanakuli, HA	0	0
Idaho Portland Cement, Inkom, ID	49,297	1
Medusa Corp., Dixon, IL	47,680	12
Missouri Portland Cement, Joppa, IL	22,777	0.3

Cement Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Illinois Cement Co., LaSalle, IL	60,325	3
Marquette Cement, Oglesby, IL	65,089	2
Lehigh Portland Cement, Buffington, IN	668,911	9
Universal Atlas Cement, Buffington, IN	668,911	8
Louisville Cement, Logansport, IN	39,603	12
Lehigh Portland Cement, Mitchell, IN	45,471	1
Louisville Cement, Speed, IN	307,439	19
Martin Marietta, Buffalo, IA	260,085	7
Marquette Cement, Des Moines, IA	298,199	13
Penn-Dixie Cement, W. Des Moines, IA	295,091	18
Northwest State Portland Cement, Mason City, IA	48,007	2
Lehigh Portland Cement, Mason City, IA	48,381	9
Lone Star Industries, Bonner Springs, KS	271,369	12

TABLE 3-13 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM CEMENT MANUFACTURING PLANTS[a]

Cement Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Ash Grove Cement, Chanute, KS	18,973	1
General Portland Cement, Fredonia, KS	9,952	0.1
Monarch Cement Co., Humboldt, KS	23,650	0.5
Lehigh Portland Cement, Independence, KS	22,801	1
Flintkote Co., Kosmosdale, KY	157,179	2
Kosmos Cement Co., Louisville, KY	219,280	3
Louisiana Cement, New Orleans, LA	438,827	27
Lone Star Cement, New Orleans, LA	1,003,515	28
Lone Star Industries, New Orleans, LA	1,000,186	6
Dundee Cement Co., Detroit, MI	52,400	1
Martin Marietta, Thomaston, ME	33,032	4
Marquette Cement, Hagerstown, MD	135,195	5
Alpha Portland Cement, Lime Kiln, MD	86,047	2

TABLE 3-13 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM CEMENT MANUFACTURING PLANTS[a]

Cement Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Lehigh Portland Cement, Union Bridge, MD	72,671	5
Huron Cement Co., Alpena, MI	20,000	0.5
Medusa Cement Co., Charlevoix, MI	11,245	0.4
Peerless Cement Co., Detroit, MI	2,003,053	31
Peerless Cement Co., Detroit, MI	2,042,932	36
Aetna Portland Cement, Essexville, MI	116,828	3
Martin Marietta, Essexville, MI	109,405	3
Jefferson Marine Terminal Monroe County, MI	335,632	0.3
Penn-Dixie Industries, Petroskey, MI	26,014	2
Peerless Cement, Port Huron, MI	87,403	1
Wyandotte Cement Co., Wyandotte, MI	1,166,409	0.4
United Cement Co., Artesia, MS	24,171	0.3
Marquette Cement, Cape Girardeau, MO	59,759	3

TABLE 3-13 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM CEMENT MANUFACTURING PLANTS[a]

Cement Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Dundee Cement Co., Clarksville, MO	15,622	0.05
Alpha Portland Cement, St. Louis, MO	1,134,744	37
Missouri Portland Cement, St. Louis, MO	1,400,165	71
Missouri Portland Cement, Sugar Creek, MO	638,974	3
Kaiser Cement, Jefferson County, MT	35,858	0.04
Ideal Basic Industries, Trident, MT	4,275	0.08
Ash Grove Cement, Louisville, NE	16,332	0.3
Ideal Cement Co., Superior, NE	4,372	0.2
Nevada Cement Co., Fernley, NV	2,191	2
Ideal Cement, Tijeras, NM	202,223	3
Alpha Portland Cement, Cementon, NY	81,052	12
Lehigh Portland Cement, Cementon, NY	76,177	19
Flintkote Co., Glen Falls, NY	47,914	0.8

TABLE 3-13 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM CEMENT MANUFACTURING PLANTS[a]

Cement Plant	Total Number of Persons Exposed	Total Exposure (Persons-μg/m^3)
Penn-Dixie Cement Howes Cave, NY	28,978	0.2
Atlantic Cement Co., Ravena, NY	195,640	9
Ideal Cement Co., Castle Hayne, NC	70,950	2
Southwestern Portland Cement Fairborn, OH	534,034	41
Southwestern Portland Cement, Greene County, OH	491,237	?6
General Portland Cement, Paulding, OH	28,870	1
Southwestern Portland Cement, Greene County, OH	412,631	4
Marquette Cement Co.. Superior, OH	103,930	0.9
Columbia Cement Co., Zanesville, OH	86,155	0.5
Medusa Cement Co., Toledo, OH	457,419	10
Ideal Cement Co., Ada, OK	28,591	0.6
Oklahoma Cement Co., Pryor, OK	26,294	1
Martin Marietta, Tulsa, OK	432,437	44

Cement Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Oregon Portland Cement, Huntington, OR	1,576	0.006
Oregon Portland Cement, Lake Oswego, OR	840,683	9
Bessemer Cement Co., Bessemer, PA	280,733	9
Copley Cement, Cementon, PA	373,491	7
National Gypsum Co., Evansville, PA	233,673	8
White Hall Cement, Lehigh County, PA	391,466	9
Lone Star Industries, Nazareth, PA	362,808	15
Penn-Dixie Industries, Nazareth, PA	382,408	4
Marquette Cement Mfg., Neville Island, PA	1,108,708	6
Lehigh Portland Cement, Northampton, PA	403,452	8
Hercules Cement, Inc., Northampton, PA	301,908	1
Martin Marietta, Northampton, PA	391,075	10
Keystone Portland Cement, Northampton County, PA	441,979	7

TABLE 3-13 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM CEMENT MANUFACTURING PLANTS[a]

Cement Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Penn-Dixie Industries, Northampton County, PA	382,217	8
Marquette Cement Co., Pittsburgh, PA	1,108,798	10
Medusa Cement Co., Wampum, PA	191,011	28
Penn-Dixie Industries, West Winfield, PA	123,613	3
Medusa Cement Co., York, PA	213,683	23
Giant Portland Cement, Harleyville, SC	29,129	3
Gifford-Hill Portland Cement, Harleyville, SC	29,129	4
Santee Portland Cement, Holly Hill, SC	29,854	3
Pete Lien & Sons Lime, Rapid City, SD	76,193	0.1
South Dakota Cement, Rapid City, SD	76,502	32
Signal Mountain Cement, Chattanooga, TN	291,874	14
Marquette Cement Co., Cowan, TN	25,724	3
Marquette Cement Co., Nashville, TN	468,500	26

TABLE 3-13 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE
EXPOSED FROM CEMENT MANUFACTURING PLANTS[a]

Cement Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Southwestern Portland Cement Amarillo, TX	59,916	2
Centex-Austin Cement, Buda, TX	406,504	10
Centrex Cement, Corpus Christi, TX	233,033	25
General Portland, Inc., Dallas, TX	1,137,909	29
Southwestern Portland Cement, El Paso, TX	433,184	23
Trinity Division, Ft. Worth, TX	611,178	50
Ideal Basic Industries, Galena Park, TX	1,419,737	33
Gulf Coast Portland, Houston, TX	1,783,009	16
TEX Industries, Midlothian, TX	37,043	4
Gifford-Hill Portland Cement, Midlothian, TX	53,169	2
Southwestern Portland Cement, Odessa, TX	34,935	0.6
Alpha Portland Cement, Orange, TX	65,904	14
Penn-Dixie Cement Corp., Richard City, TN	30,288	1

TABLE 3-13 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM CEMENT MANUFACTURING PLANTS[a]

Cement Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Kaiser Cement, San Antonio, TX	608,747	47
Capital Cement, San Antonio, TX	638,039	13
San Antonio Portland Cement, San Antonio, TX	940,917	103
Lone Star Industries, Sweetwater, TX	1,232	0.1
Eagelite Aggregate Co., Waco, TX	141,052	2
Universal Atlas Cement, Waco, TX	141,052	15
Ideal Cement Co., Morgan, UT	6,730	0.8
Portland Cement Co., Salt Lake City, UT	605,780	4
Lone Star Cement, Botetourt, VA	72,178	1
Lone Star Industries, Chesapeake, VA	674,934	11
Columbia Cement, Bellingham, WA	77,278	15
Lehigh Portland Cement, Metaline Falls, WA	2,802	0.8
Lone Star Industries, Seattle, WA	929,567	47

TABLE 3-13 (CONTINUED). TOTAL CHROMIUM EXPOSURE AND NUMBER OF PEOPLE EXPOSED FROM CEMENT MANUFACTURING PLANTS[a]

Cement Plant	Total Number of Persons Exposed	Total Exposure (Persons-$\mu g/m^3$)
Ideal Basic Industries, Seattle, WA	915,425	11
Martin Marietta Cement, Martinsburg, WV	62,170	3
Medusa Cement Co., Manitowoc, WI	66,466	0.4
Universal Atlas Cement, Milwaukee, WI	1,084,650	24
Marquette Cement Co., Milwaukee, WI	1,084,650	92
National Gypsum Co., Superior, WI	152,881	3
Monolith Portland Cement, Laramie, WY	27,654	5

[a] A 20 km (12.4 miles) radius was used for the analysis of cement manufacturing plants.

TABLE 3-14. PUBLIC EXPOSURE TO CHROMIUM FROM CEMENT MANUFACTURING
PLANTS AS PRODUCED BY THE HUMAN EXPOSURE MODEL

Concentration Level ($\mu g/m^3$)	Population Exposed[a] (Persons)	Public Exposure[b] (Persons-$\mu g/m^3$)
0.0469	0	< 1
0.025	11	0.333
0.01	289	4
0.005	1,389	11
0.0025	9,189	37
0.001	46,668	93
0.0005	193,365	194
0.00025	696,089	363
0.0001	2,584,447	647
0.00005	7,082,615	953
0.000025	15,312,102	1,240
0.00001	31,739,998	1,510
0.000005	40,991,487	1,580
0.0000025	46,477,640	1,600
0.000001	48,588,177	1,600
0.0000005	48,932,801	1,600
0.00000025	49,285,477	1,600
0.0000001	50,111,798	1,600
0.00000005	50,447,547	1,600
0.000000025	50,450,530	1,600

[a]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.

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

of the NEDS information for cement plants. However, during the chromium emission estimating process NEDS particulate emissions that were greatly inconsistent with other similar plants in the source category were not used to estimate chromium emissions. Instead alternative emissions estimating procedures were adopted in these cases. Overall, it is anticipated that the NEDS information for cement plants overstates to some degree particulate (and consequently chromium) emissions for this source category because of improvements in the status of emissions control.

3.8 MEASURED AMBIENT CHROMIUM CONCENTRATIONS

Actual measured ambient chromium concentrations have been determined for many areas of the United States through sampling programs conducted by the U. S. EPA and State air quality agencies. Selected chromium results for the period of 1977 to 1980 are presented in Appendix C. The values in Appendix C were selected as reliable because they meet U. S. EPA data validity requirements concerning number of samples (representativeness) and use of appropriate analytical techniques. All the values given in Appendix C are in the National Aerometric Data Bank which is maintained by the Monitoring and Data Analysis Division of the U. S. EPA located in Research Triangle Park, North Carolina.

The ambient chromium concentrations in Appendix C are useful as a comparison tool to gain some perspective on the ambient chromium levels predicted to occur by the HEM. The data in Appendix C are not intended to represent the concentrations attributable to any specific point source. The locations of the sampled points are not known. However, it is possible that a measured ambient chromium concentration can be indirectly correlated to chromium sources or source categories examined in this study. As an example consider the data in Appendix C for Baltimore, Maryland. The 1977 Baltimore chromium concentration maximum of 2.4870 ug/m^3 is the highest in the entire data set. As a correlation to why this level may have occurred consider that in the Baltimore area there is a major chromium chemical producer, a major chromium refractory producer, five steel manufacturing furnaces, and two refuse incinerators.

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3.9 REFERENCES

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APPENDIX A

DESCRIPTION OF THE HUMAN EXPOSURE MODEL (HEM)

A.1 GENERAL

The U. S. EPA's Human Exposure Model is a general model capable of producing quantitative expressions of public exposure to ambient air concentrations of pollutants emitted from stationary sources. The HEM contains (1) an atmospheric dispersion model, with included meteorological data, and (2) a population distribution estimate based on Bureau of Census data. The only input data needed to operate this model are source data, e.g., plant location, height of the emission release point, and temperature of the off-gases. Based on the source data, the model estimates the magnitude and distribution of ambient air concentrations of the pollutant in the vicinity of the source. The model is programmed to estimate these concentrations within a radial distance of 20 km (12.4 miles) from the source. If other radial distances are preferred, an over-ride feature allows the user to select the distance desired. The selection of 20 km (12.4 miles) as the programmed distance is based on modelling considerations, not on health effects criteria or U. S. EPA policy. The dispersion model contained in HEM is felt to be reasonably accurate within 20 km (12.4 miles). If the user wishes to use a dispersion model other than the one contained in HEM to estimate ambient air concentrations in the vicinity of a source, HEM can accept the concentrations if they are put into an appropriate format.

Based on the radial distance specified, HEM combines numerically the distributions of pollutant concentrations and people to produce quantitative expressions of public exposure to the pollutant.

A.2 POLLUTANT CONCENTRATIONS NEAR A SOURCE

The dispersion model within the HEM is a gaussian diffusion model that uses the same basic dispersion algorithm as the U. S. EPA's Climatological Dispersion Model.[1] The algorithm has been simplified to improve computational efficiency.[2] The algorithm is evaluated for a representative set of input values as well as actual plant data, and the concentrations input into the exposure algorithm are arrived at by interpolation. Stability array (STAR) summaries are the principal meteorological input to the HEM disperion model. The STAR data are standard climatological frequency-of-occurrence summaries formulated for use in U. S. EPA models and are available for major U. S. meteorological monitoring sites from the National Climatic Center, Asheville, N. C. A STAR summary is a joint frequency-of-occurrence of wind speed, atmospheric stability, and wind direction, classified according to Pasquill's categories. The STAR summaries in HEM usually reflect 5 years of meteorological data for each of 309 sites nationwide. The model produces polar coordinate receptor grid points consisting of 10 downwind distances located along each of 16 radials which represent wind directions. Concentrations are estimated by the dispersion model for each of the 160 receptors located on this grid. The radials are separated by 22.5-degree intervals beginning with 0.0 degrees and proceeding clockwise to 337.5 degrees. The 10 downwind distances for each radial are 0.2, 0.3, 0.5, 0.7, 1.0, 2.0, 5.0, 10.0, 15.0, and 20.0 kilometers. The center of the receptor grid for each plant is assumed to be the plant center.

A.3 THE POPULATION LIVING NEAR AN EMISSION SOURCE

To estimate the number and distribution of people residing within 20 km (12.4 miles) of each plant, the model contains a slightly modified version of the Master Enumeration District List—Extended (MED-X) data base. The data base is broken down into enumeration district/block group (ED/BG) values. It contains the population centroid coordinates (latitude and longitude) and the 1970 population of each ED/BG in the United States (50 States plus the District of Columbia). For human exposure estimates, MED-X has been reduced from its complete form (including descriptive and

summary data) to produce a computer file of the data necessary for the
estimation. A separate file of county-level growth factors, based on 1978
estimates of the 1970 to 1980 growth factor at the county level, has been
used to estimate the 1980 population for each ED/BG. The HEM identifies the
population around each plant by using the geographical coordinates of the
plant. The HEM identifies, selects, and stores for later use those ED/BGs
with coordinates falling within 20 km (12.4 miles) of plant center.

A.4 POPULATION EXPOSURE DETERMINATIONS

The HEM uses the estimated ground level concentrations of a pollutant
together with population data to calculate public exposure. For each of
160 receptors located around a plant, the concentration of the pollutant and
the number of people estimated by the HEM to be exposed to that particular
concentration are identified. The HEM multiplies these two numbers to
produce exposure estimates and sums these products for each plant.

A two-level scheme has been adopted in order to pair concentrations and
populations prior to the computation of exposure. The two level approach is
used because the concentrations are defined on a radius-azimuth (polar) grid
pattern with non-uniform spacing. At small radii, the grid cells are
usually smaller than ED/BG's; at large radii, the grid cells are usually
larger than ED/BG's. The area surrounding the source is divided into two
regions, and each ED/BG is classified by the region in which its centroid
lies. Population exposure is calculated differently for the ED/BG's located
within each region. For ED/BG centroids located between 0.1 km (0.06 miles)
and 2.8 km (1.7 miles) from the emission source, populations are divided
between neighboring concentration grid points. There are 96 (6 x 16) polar
grid points within this range. Each grid point has a polar sector defined
by two concentric arcs and two wind direction.radials. Each of these grid
points and respective concentrations are assigned to the nearest ED/BG
centroid identified from MED-X. Each ED/BG can be paired with one or many
concentration points. The population associated with the ED/BG centroid is
then divided among all concentration grid points assigned to it. The land
area within each polar sector is considered in the apportionment.

For population centroids between 2.8 km (1.7 miles) and 20 km (12.4 miles) from the source, a concentration grid cell, the area approximating a rectangular shape bounded by four receptors, is much larger than the area of a typical ED/BG. Since there is an approximate linear relationship between the logarithm of concentration and the logarithm of distance for receptors more than 2 km from the source, the entire population of the ED/BG is assumed to be exposed to the concentration that is logarithmically interpolated radially and arithmetically interpolated azimuthally from the four receptors bounding the grid cell.

Concentration estimates for 80 (5 x 16) grid cell receptors at 2.0, 5.0, 10.0, 15.0, and 20.0 km from the source along each of 16 wind directions are used as reference points for this interpolation.

In summary, two approaches are used to arrive at coincident concentration/population data points. For the 96 concentration points within 2.8 km (1.7 miles) of the source, the pairing occurs at the polar grid points using an apportionment of ED/BG population by land area. For the remaining portions of the grid, pairing occurs at the ED/BG centroids themselves through the use of log-log and linear interpolation. For a more detailed discussion of the model used to estimate exposure, see reference 2.

A.5 REFERENCES

1. Busse, A. D. and J. R. Zimmerman. User's Guide for the Climatological Dispersion Model. EPA-R4-73-024. December 1973.

2. Systems Applications, Inc. Human Exposure to Atmospheric Concentrations of Selected Chemicals, Volumes I and II. EPA-2/250-1 and EPA-1/250-2.

APPENDIX B

QUALITATIVE EVALUATION OF THE SOURCE CATEGORY
DATA USED IN THE HEM ANALYSIS

The purpose of this appendix, principally Table B-1, is to indicate the
relative quality of the input chromium source category data used in the HEM
analysis. Table B-1 should be viewed as an aid to evaluating the exposure
results given in Chapter 3. The ratings assigned to various source
categories in Table B-1 were developed specifically to describe the data
used in the HEM analysis and are not a part of any establ...ir d or published
ratings or guidelines system.

TABLE B-1. QUALITATIVE EVALUATION OF THE SOURCE CATEGORY DATA USED IN THE HEM ANALYSIS

Source Category	Chromium Emissions Data[a]	Stack Geometry Data	Location Data	Overall Category Rating[b]
Chromium Ore Refining	C,B	Known	Estimated	2
Chromium Chemicals Manufacturing	C,B,A	Known	Known	2
Refractory Manufacturing	C,D	Known and Estimated	Known and Estimated	3
Municipal Refuse Incineration	D	Estimated	Known	3
Sewage Sludge Incineration	D	Known	Known	3
Ferrochromium Manufacturing	D,A	Known	Known	2
Steel Manufacturing	D,A	Estimated	Known	3
Cement Manufacturing	D	Known and Estimated	Known and Estimated	4

[a] A - Emissions estimates determined from source tests.
B - Emissions estimates determined from material balances.
C - Emissions estimates determined from company engineering estimates.
D - Emissions estimates determined from gross particulate emissions levels and measured chromium levels in particulates.
The most prevalently used technique is listed first followed by other succeeding techniques used.

B-2

[b] 1 = **Excellent** source category characterization. Emissions, stack geometry, and location data are all based on measurements and are reliable.

2 = **Good** source category characterization. Generally stack geometry and location data are known. Emissions data are based on material balances and sound estimating methods.

3 = **Fair** source category characterization. Emissions, stack geometry, and location data are known for a portion of the source category. Chromium emissions estimates are less reliable due to a lack of particulate and/or chromium data.

4 = **Poor** or variable source category characterization. Emissions, stack geometry, and location data were estimated from available information. Chromium emissions data were missing or highly variable for several plants or several processes within the source category.

APPENDIX C

TOTAL CHROMIUM CONCENTRATIONS MEASURED IN THE AMBIENT AIR OF THE UNITED STATES DURING 1977 - 1980[c]

Site	Year	Total Chromium Concentration, $\mu g/m^3$	
		Arithmetic Mean	Maximum Observed Value
Birmingham, AL	1977	0.0088	0.0384
Gadsden, AL	1977	0.0052	0.0052
Huntsville, AL	1977	0.0070	0.0419
	1980	0.0070	0.0428
Douglas, AZ	1978	0.0070	0.0133
	1979	0.0067	0.0287
Grand Canyon National Park, AZ[b]	1977	0.0058	0.0134
Tucson, AZ	1977	0.0061	0.0155
Anaheim, CA	1977	0.0073	0.0283
Berkely, CA	1977	0.0098	0.0729
Burbank, CA	1977	0.0104	0.0236
Fresno, CA	1977	0.0122	0.0324
Long Beach, CA	1977	0.0175	0.0410
Los Angeles, CA	1977	0.0188	0.0666
Oakland, CA	1977	0.0186	0.0603
Ontario, CA	1977	0.0181	0.0342
Pasadena, CA	1977	0.0134	0.0328
Sacramento, CA	1977	0.0098	0.0236
San Bernadino, CA	1977	0.0330	0.1033
San Diego, CA	1977	0.0109	0.0236
San Francisco, CA	1977	0.0063	0.0148
San Jose, CA	1977	0.0138	0.0291
Santa Ana, CA	1977	0.0100	0.0209
Torrance, CA	1977	0.0306	0.3153
Waterbury, CT	1978	0.0342	0.2178
	1979	0.0326	0.1396
Kent County, DE[b]	1977	0.0058	0.0117
Newark, DE	1977	0.0110	0.0543
Wilmington, DE	1977	0.0267	0.0572
Davie, FL	1980	0.0052	0.0052
Jacksonville, FL	1977	0.0071	0.0212
St. Petersburg, FL	1980	0.0052	0.0052
Atlanta, GA	1977	0.0089	0.0441
	1980	0.0062	0.0191
Columbus, GA	1977	0.0054	0.0117
Hawaii County, HA[b]	1977	0.0063	0.0216
Honolulu, HA	1977	0.0063	0.0132
	1979	0.0127	0.2155
	1980	0.0068	0.0941

C-1

TOTAL CHROMIUM CONCENTRATIONS MEASURED IN THE AMBIENT AIR OF THE UNITED STATES DURING 1977 – 1980[c]

Site	Year	Total Chromium Concentration, $\mu g/m^3$ Arithmetic Mean[a]	Maximum Observed Value
Boise City, ID	1977	0.0088	0.0724
Indianapolis, IN	1977	0.0076	0.0198
Cedar Rapids, IA	1977	0.0067	0.0155
Waterloo, IA	1977	0.0089	0.0151
Kansas City, KS	1977	0.0167	0.0413
	1978	0.0276	0.0724
	1980	0.0191	0.0358
Bowling Green, KY	1977	0.0067	0.0276
Covington, KY	1977	0.0065	0.0169
Louisville, KY	1977	0.0118	0.0806
Baton Rouge, LA	1977	0.0083	0.0518
Iberville Parish, LA	1977	0.0063	0.0159
	1978	0.0059	0.0128
	1980	0.0052	0.0052
New Orleans, LA	1977	0.0059	0.0233
Acadia National Park, ME[b]	1977	0.0052	0.0052
Portland, ME	1977	0.0102	0.0248
Baltimore, MD	1977	0.1568	2.4870
	1979	0.0935	0.4589
Calvert County, MD[b]	1977	0.0081	0.0274
Dorchester, MA	1977	0.0063	0.0167
	1978	0.0099	0.0239
	1979	0.0067	0.0166
Saginaw, MI	1977	0.0080	0.0299
Minneapolis, MN	1977	0.0089	0.0490
	1978	0.0116	0.0259
Duluth, MN	1980	0.0067	0.0149
Jackson, MS	1977	0.0059	0.0125
St. Louis, MO	1977	0.0061	0.0146
Lincoln, NE	1977	0.0064	0.0189
Omaha, NE	1979	0.0077	0.0232
	1980	0.0057	0.0197
Las Vegas, NV	1977	0.0087	0.0215
White Pine County, NV[b]	1977	0.0052	0.0052
Bayonne, NJ	1977	0.0105	0.0253
	1978	0.0149	0.0324
	1980	0.0123	0.0508
Camden, NJ	1978	0.0307	0.1561
Elizabeth, NJ	1978	0.0163	0.0295

TOTAL CHROMIUM CONCENTRATIONS MEASURED IN THE AMBIENT AIR
OF THE UNITED STATES DURING 1977 - 1980[c]

Site	Year	Total Chromium Concentration, ug/m^3	
		Arithmetic Mean[a]	Maximum Observed Value
Glassboro, NJ	1978	0.0133	0.0231
Newark, NJ	1978	0.0181	0.0301
	1979	0.0129	0.0333
	1980	0.0091	0.0369
Perth Amboy, NJ	1977	0.0128	0.0329
	1978	0.0120	0.0333
Trenton, NJ	1978	0.0127	0.0311
Alberquerque, NM	1977	0.0140	0.0392
Niagara Falls, NY	1979	0.0389	0.5590
	1980	0.0144	0.0603
Rochester, NY	1980	0.0059	0.0132
Yonkers, NY	1980	0.0079	0.0265
Charlotte, NC	1977	0.0054	0.0115
Durham, NC	1977	0.0061	0.0181
Winston-Salem, NC	1977	0.0055	0.0132
Akron, OH	1977	0.0126	0.0610
	1978	0.0188	0.0528
	1979	0.0116	0.0389
	1980	0.0204	0.0710
Canton, OH	1979	0.0382	0.1999
Cincinnati, OH	1977	0.0083	0.0377
	1978	0.0116	0.0294
	1979	0.0451	0.4316
	1980	0.0150	0.0718
Cleveland, OH	1978	0.0198	0.0569
	1980	0.0144	0.0431
Columbus, OH	1977	0.0114	0.0594
	1980	0.0141	0.1080
Dayton, OH	1977	0.0102	0.0330
	1978	0.0108	0.0443
	1980	0.0116	0.0264
Portsmouth, OH	1977	0.0082	0.0316
Steubenville, OH	1978	0.0517	0.2602
	1979	0.1212	0.6839
Toledo, OH	1979	0.0081	0.0195
Youngstown, OH	1977	0.0168	0.0538
	1978	0.0215	0.0919
	1979	0.0270	0.1291

TOTAL CHROMIUM CONCENTRATIONS MEASURED IN THE AMBIENT AIR
OF THE UNITED STATES DURING 1977 – 1980[c]

Site	Year	Total Chromium Concentration, ug/m^3	
		Arithmetic Mean[a]	Maximum Observed Value
Oklahoma City, OK	1980	0.0086	0.0238
Curry County, OR[b]	1977	0.0052	0.0052
Portland, OR	1977	0.0284	0.1185
Allentown, PA	1977	0.0082	0.0223
Bethlehem, PA	1977	0.0131	0.0541
Erie, PA	1977	0.0172	0.2531
Harrisburg, PA	1977	0.0080	0.0278
Hazelton, PA	1977	0.0062	0.0252
Philadelphia, PA	1977	0.0168	0.0441
Reading, PA	1977	0.0149	0.0585
Scranton, PA	1977	0.0127	0.0362
West Chester, PA	1977	0.0132	0.0292
Wilkes-Barre, PA	1977	0.0100	0.0211
York, PA	1977	0.0071	0.0211
Greenville, SC	1977	0.0311	0.4031
Black Hills National Forest, SD[b]	1978	0.0090	0.0295
Chattanooga, TN	1977	0.0122	0.0453
	1978	0.0140	0.0463
	1979	0.0112	0.0760
	1980	0.0150	0.0705
Cumberland County, TN[b]	1977	0.0056	0.0177
Beaumont, TX	1977	0.0074	0.0159
Corpus Christi, TX	1977	0.0120	0.0402
Fort Worth, TX	1977	0.0094	0.0263
Tom Green County, TX[b]	1977	0.0052	0.0052
Wichita Falls, TX	1977	0.0076	0.0189
Ogden, UT	1978	0.0077	0.0252
Burlington, VT	1977	0.0055	0.0134
Danville, VA	1977	0.0069	0.0213
	1978	0.0064	0.0183
	1979	0.0056	0.0152
Hampton, VA	1977	0.0199	0.1018
Lynchburg, VA	1977	0.0066	0.0122
Norfolk, VA	1977	0.0067	0.0152
	1978	0.0069	0.0158
	1979	0.0083	0.0291
	1980	0.0119	0.1456
Portsmouth, VA	1977	0.0066	0.0142

TOTAL CHROMIUM CONCENTRATIONS MEASURED IN THE AMBIENT AIR OF THE UNITED STATES DURING 1977 - 1980[c]

Site	Year	Total Chromium Concentration, ug/m³	
		Arithmetic Mean[a]	Maximum Observed Value
Richmond, VA	1977	0.0074	0.0168
Roanoke, VA	1977	0.0073	0.0248
Shenandoah National Park, VA[b]	1977	0.0056	0.0130
Wythe County, VA[b]	1977	0.0060	0.0130
Seattle WA	1977	0.0097	0.0295
	1978	0.0135	0.0290
	1980	0.0190	0.0510
Tacoma, WA	1977	0.0099	0.0330
	1978	0.0249	0.1625
	1980	0.0104	0.0283
Charleston, WV	1977	0.0087	0.0270
South Charleston, WV	1977	0.0082	0.0349
Eau Claire, WI	1978	0.0074	0.0156
	1979	0.0064	0.0199
Kenosha, WI	1978	0.0095	0.0245
	1979	0.0061	0.0147
Madison, WI	1977	0.0052	0.0052
Milwaukee, WI	1977	0.0089	0.0266
Racine, WI	1977	0.0060	0.0137
Superior, WI	1977	0.0060	0.0172

[a] Values represent 24 hour averages.

[b] Background sites, all other sites are determined to be populated urban areas.

[c] Source: Unpublished data in the National Aerometric Data Bank maintained by the Monitoring and Data Analysis Division of EPA, Research Triangle Park, N.C.