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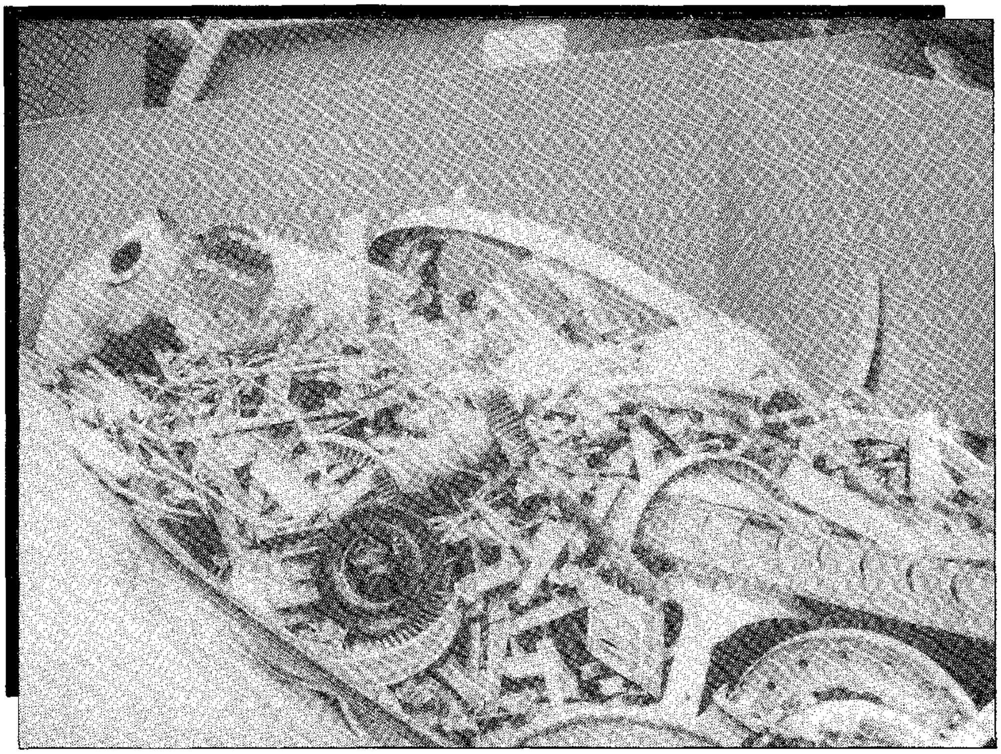
A Chromium Consumption and Recycling Flow Model

By Robert C. Gabler, Jr.



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Cover: Sorted aircraft engine parts ready for recycling of chrominum and other metals.

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World resources of chromium appear ample for the foreseeable future; however, political and economic events in the last two decades have caused concern over the availability and reliability of an uninterrupted supply. Because of this concern, the U.S. Congress requested that the U.S. Bureau of Mines initiate a study of the flow of strategic and critical materials (chromium, cobalt, manganese, and the platinum-group metals) in the U.S. economy that would delineate and quantify the production areas where the metal values are lost. As a result, the Bureau has developed a computerized commodity flow model for strategic and critical materials. Major attributes of this flow model are that it is generic and applicable to most commodities and that it is amenable to updating as supply, demand, and/or production data change. The original model, with slight modifications, was used to track the flow of chromium. This report follows the flow of chromium through its metallurgical, chemical, and refractory applications, and highlights areas where significant losses occur because of downgrading, export, or disposal. The study indicates that materials containing 451,760 mt of chromium were consumed, including 99,221 mt Cr from recycling. Chromium losses from all causes in 1989 were estimated to be 345,347 mt Cr from a variety of areas. These areas and their losses are as follows: processing losses, 38,825 mt Cr; processing-downgraded scrap, 18,227 mt Cr; manufacturing losses, 18,128 mt Cr; manufacturing-downgraded scrap, 56,595 mt Cr; prompt scrap exported, 1,531 mt Cr; obsolete scrap exported, 43,443 mt Cr; recovery losses, 155,529 mt Cr; and recycling losses, 13,069 mt Cr. Recycled chromium-containing material accounted for 22 pct of the apparent consumption of chromium in 1989.

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UNITED STATES DEPARTMENT OF THE INTERIOR
Bruce Babbitt, Secretary

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

lb	pound	st	short ton
mt	metric ton	st/yr	short ton per year
pct	percent	$/kg	dollar per kilogram

A CHROMIUM CONSUMPTION AND RECYCLING FLOW MODEL

By Robert C. Gabler, Jr.[1]

ABSTRACT

The U.S. Bureau of Mines (USBM) has developed a computerized commodity flow model for strategic and critical materials. This flow model is generic and applicable to most commodities and amenable to updating as supply, demand, and/or production data change. The original model, with slight modifications, was used to track the flow of chromium. This report follows the flow of chromium through its metallurgical, chemical, and refractory applications, and highlights areas where significant losses occur because of downgrading, export, or disposal. The study indicates that materials containing 451,769 mt of chromium were consumed, including 99,221 mt of chromium from recycling. Chromium losses from all causes in 1989 were estimated to be 345,347 mt from a variety of areas. These areas and their chromium losses are as follows: processing losses, 38,825 mt; processing-downgraded scrap, 18,227 mt; manufacturing losses, 18,128 mt; manufacturing-downgraded scrap, 56,595 mt; prompt scrap exported, 1,531 mt; obsolete scrap exported, 43,443 mt; recovery losses, 155,529 mt; and recycling losses, 13,069 mt. Recycled chromium-containing material accounted for 22 pct of the apparent consumption of chromium in 1989.

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INTRODUCTION

Chromium is an indispensable element in a variety of strategic and critical applications. It is used to produce steels, superalloys, refractory brick, and a variety of chemicals. There is no substitute for chromite ore in the production of chromium ferroalloys, chromium chemicals, or chromium refractories. There is no substitute for chromium in stainless and heat-resistant (SHR) steels—the major end use of chromium—nor for chromium in superalloys—the major strategic end use of chromium (*1*).[2] The United States currently is dependent on foreign supplies of virgin chromium, imported primarily as chromite ore or as chromium ferroalloys. Most of the U.S. chromium demand has been filled by the Republic of South Africa, along with Turkey, Zimbabwe, Yugoslavia, the Philippines, China, and several other nations (*1-2*) (see table 1). In the future, most new production of chromium is expected to come from the Republic of South Africa, where 95 pct of these resources are located (*1*).

Table 1.—Imports of chromium-containing materials by country of origin in 1989

Country	Contained Cr, mt	Pct of total	Type of material
Republic of South Africa	242,192	54.8	CO, FC, C
Turkey	71,085	16.1	CO, FC, C
Zimbabwe	33,953	7.7	FC, FCS
Yugoslavia	19,480	4.4	FC
Philippines	18,742	4.2	CO, FC
China	14,140	3.2	FC, M, C
All others	42,742	9.7	CO, FC, M, C
Total	442,334	100.0	

C Chemicals.
CO Chromite ore.
FC Ferrochromium.
FCS Ferrochromium-silicon.
M Metal.

World resources of chromium are ample for the foreseeable future (*1*), as are the resources of cobalt, manganese, and the platinum-group metals (PGM). However, past political and economic events have raised concern about the uninterrupted availability and reliability of supplies of these commodities. For this reason, and because of the essential nature of these commodities, the metals are considered strategic and critical materials. The risk of cobalt supply disruption was considered high around the time of the 1978 Katangese rebellion in Zaire (*3-4*). The price of cobalt rose from $11/kg in 1977 to $51/kg in 1979. Even though some of this price increase was due to sharply increased demand, the rapid changes in the cobalt market generated significant concern about future disruptions to the supply of cobalt, and also chromium, manganese, and PGM. For chromium, the lack of domestic supply, geographically concentrated foreign supply, and foreign supply from unfriendly sources (U.S.S.R at that time) or potentially politically unstable sources (Republic of South Africa) were the major causes of concern. This concern led to studies on the strategic importance, availability, and supply vulnerability of chromium and a number of other commodities (*4-12*). Most of these studies either are now out of date or do not supply information on losses of the strategic and critical commodities due to waste disposal, downgrading, and/or export. The lack of knowledge on these unknown losses makes conservation efforts difficult.

Industry officials in the production, manufacturing, and recycling of strategic and critical commodities are reluctant to discuss the quantities of materials that go to disposal, downgrading, and export. This information is often considered to be proprietary in nature.

Even when data are available, there is confusion between disposition of materials and recycling. For example, in a survey of seven scrap recyclers in 1987 (*13*), the following estimates were obtained for disposition of scrap from the superalloy industry:

	Range, pct
Domestic recycling	60-100
Exports	0- 40
Recycled scrap:	
Domestic remelting	75-100
Recycling to same superalloy	38- 90
Recycling to other high-value superalloy	5- 38
Downgrading	10- 25
Discarding	3- 5

These estimates are typical of the data on processing, manufacturing, disposal, downgrading, and recycling of strategic and critical materials. Therein lies the difficulty in determining the amounts of critical and strategic commodities that are discarded, downgraded, or exported. This study was conducted to ascertain how the United States is using and losing its strategic and critical materials.

In 1980, the U.S. Bureau of Mines (USBM) reported the results of contract studies by Inco Research and Development Center, Suffern, NY, and Arthur D. Little, Inc., Cambridge, MA, to assess the domestic availability of chromium in scrap metal and the amount of scrap being recycled (*14-15*). These reports contain data up to 1976 and 1978, respectively; no updates of these studies were conducted following their publication. In the 1970's and

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[2] Italic numbers in parentheses refer to items in the list of references preceding the appendix.

the early 1980's, the National Materials Advisory Board (NMAB) conducted a number of studies on the consumption of chromium, its strategic importance, and contingency plans for the future (*16-19*).

In May 1985, the U.S. Congress, Office of Technology Assessment (OTA), produced a study entitled "Strategic Materials: Technologies To Reduce U.S. Import Vulnerability" (*20*). Included in the study was a set of recommendations to the USBM to conduct a survey of recycling-related activities. OTA recommended a scrap recycling study to update the chromium scrap metal information contained in two USBM publications (*14-15*) and to expand the scope of the previous studies to include information on scrap generated by the cobalt, manganese, and PGM industries, as well as the wastes generated by all the various industrial and Department of Defense (DOD) users of these four commodities.

Acting on this recommendation, in 1987 the USBM initiated a study of the four commodities. The main objective of this study is to produce a commodity-oriented structural model tracing flow, recycling, and final disposition of the four identified commodities, which can be updated in subsequent years. A second objective of the study is to provide, in an understandable manner, an overview of the commodity flow that can be used by Congress and industry associations as a tool to help in the study of that commodity's vulnerability to political and availability factors outside the control of the United States. Another objective of the study is to highlight significant commodity loss areas where further research is required.

A hierarchical model for the commodity cobalt was developed (*21-22*). The model is generic and can be applied to other strategic and critical commodities. The model previously has been applied to PGM, as well as to cobalt (*21, 23*). To meet the stated objectives of this study, the model was applied to chromium with slight modification. (Note: The described flow model is a "snapshot" of a dynamically changing view of chromium consumption. Thus, the flow model is based on the best available data at the time of the snapshot. Recent data (obtained after 1990) show that consumption data for SHR steel scrap contain both the obsolete scrap and the prompt scrap. However, this will not be shown in the snapshot.)

DESCRIPTION OF FLOW MODEL

As stated in the introduction, the chromium flow model is based on the generic flow model developed for the commodities cobalt and PGM, with some minor modifications.

DEFINITIONS

Consumption

Apparent consumption.—Production plus net trade plus stock changes. Production is domestic mine production plus recycle. Net trade is imports minus exports. Stock change is beginning minus ending stocks (*24*). (Note that neither reported nor apparent consumption is actual consumption. However, apparent consumption is very close to actual consumption.) A more detailed definition and calculation of apparent consumption is in the appendix.

Consumption.—Apparent consumption, except where it is listed as reported consumption.

Reported consumption.—Those data reported to the USBM in response to the Bureau's industry consumption survey questionnaires. In addition, estimated data from nonrespondents often is included in USBM reported consumption tables.

Scrap

Home scrap.—Scrap generated during processing that is internally recycled within the generating company and that can be considered as being endlessly recirculated. It is some times referred to as "run-around scrap." It is not counted as part of consumption (*15*).

Obsolete scrap.—Scrap generated by users and recyclers when used products are overhauled or when the product has reached the end of its productive life cycle (*15*).

Prompt scrap.—Also called prompt industrial scrap or new scrap; consists of solids, turnings, grindings, sludges, and liquors generated during the manufacturing process when the primary product is fabricated into a finished product (*15*).

Run-around scrap.—Home scrap.

Downgraded scrap.—Scrap that is used for a lower grade alloy, such as superalloy scrap used for stainless steel or alloy steel scrap used for cast iron.

Recovery and Recycle

Recovery.—The practices of acquiring metals from obsolete material for recycle back into new products.

Recycle.—The processes of collecting, cleaning, assaying, and sorting materials for reuse in industry.

Losses.—Materials such as fume, spilled contaminated metal, scale, metal trapped in slag, material removed in pickling, plating wastes, grindings, etc.

Recovery loss.—Those obsolete materials that are never collected for recycling. An example is obsolete material that is used as landfill.

Recycling loss.—Those losses that occur in the recycling process. For example, a major loss area is downgraded scrap material that is recycled to lower quality metals, particularly where the metal in question is not needed but is acceptable.

Ferroalloys

Chromium ferroalloy and metal.—Ferrochromium plus ferrochromium-silicon plus chromium metal.

Chromium ferroalloy.—Ferrochromium plus ferrochromium-silicon.

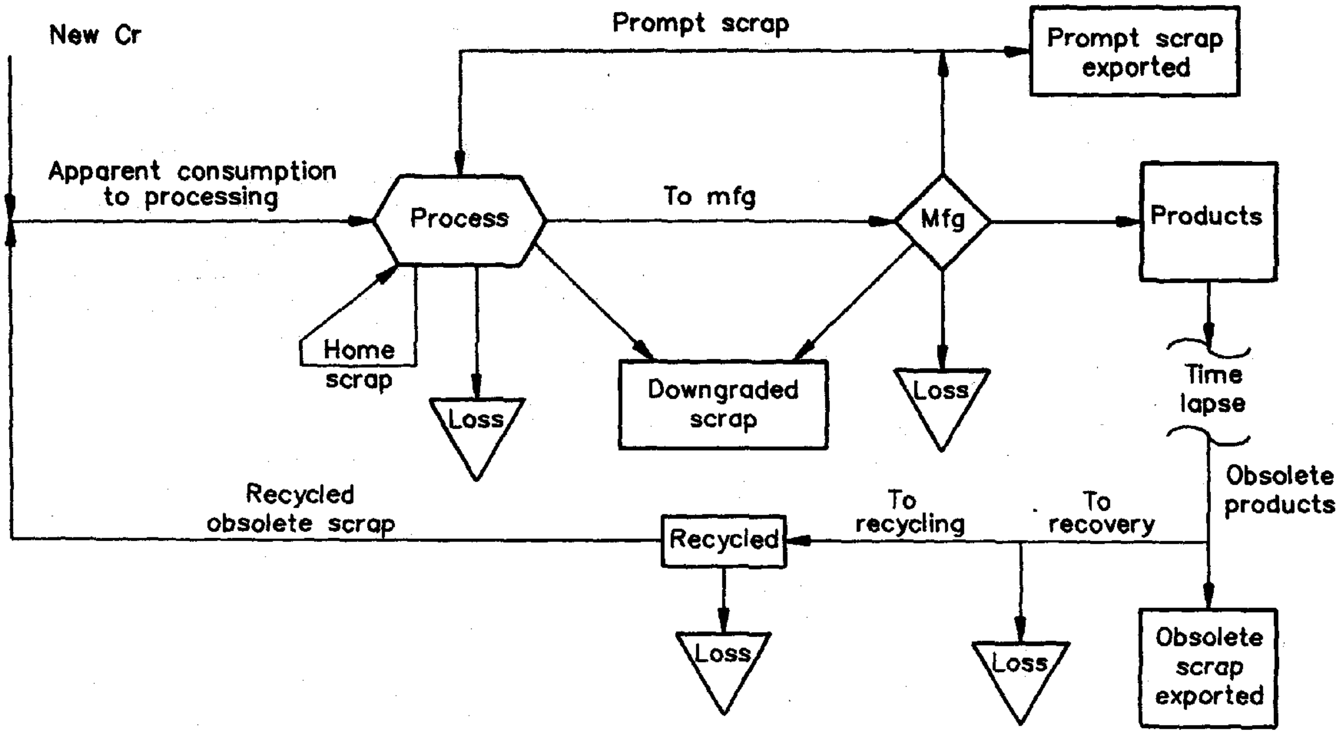
Ferrochromium.—High- plus low-carbon ferro-chromium.

Ferroalloys.—All ferroalloys, including ferrochromium, ferrochromium-silicon, ferromanganese, ferrosilicon, ferronickel, ferroboron, ferrovanadium, ferrotitanium, ferrotungsten, etc.

GENERAL CONFIGURATION

A typical chromium flow model is shown in figure 1. (Mathematical relationships in the chromium model are discussed in the appendix.) The supplies of chromium come from imports of chromite ore, chromium ferroalloys, chromium chemicals, and chromium metal, and secondary production (scrap). In any given year, fractions of this material go to exports, stocks, domestic processing, and manufacturing. During processing, about 28 pct of input reports as home scrap and is internally recycled. About 5 pct of input reports to processing losses, about 2.6 pct of input reports to downgraded material, and most of the chromium reports to manufacturing. Note that home scrap is not counted, as it is endlessly recycled, and counting it would be double counting. However, it is part of the recycling of the commodity. The processed material then goes to product manufacturing. During manufacturing, a small amount of chromium (about 4 pct) reports as losses and some as downgraded material (about 12 pct). The remainder goes to final products. Prompt scrap amounts to about 13 pct, of which 0.3 pct goes to export and the remainder to processing. After a normal use life, each product that is not in a dissipative end use winds up as obsolete scrap and waste. The estimated amount recycled, based on data reported to the USBM, was 99,221 mt of chromium (2). Much of this material (97,098 mt of chromium) was SHR steel and superalloy. Some additional material, nearly all metallurgical material, is

Figure 1



Typical flow model.

recycled, but not for its chromium content. There are currently no available published data on the percentages of contained chromium in these scrap materials.

PROPERTIES OF FLOW MODEL

The flow model described in IC 9252 (*21*) and IC 9303 (*23*) is generic in nature and thus capable of being used for a wide variety of commodities with only minor modifications. The model is easily updated, is generally understood by the public, and highlights areas where recycling research is needed. The model is hierarchical, with three levels: the entire chromium industry, the individual industry level, and the individual plant level. The data in this report cover the entire chromium industry and the individual industry level.

ASSUMPTIONS IN MODEL

In the development of the model, a number of assumptions had to be made. These are as follows:

1. Where data were found, the percentages reporting in each category were used. Where no current data were available, the data from NMAB-335 (*18*) and NMAB-406 (*4*) were used and assumed to be still valid.
2. The use lives of various products vary over a wide range. NMAB estimated the lifetimes of a number of products (*4*). Its estimation for the lifetimes of superalloys, welding and hardfacing materials, SHR steels, high-strength low-alloy (HSLA) steels, and tool steels was 5 years, and its estimation for other alloys (based on the high content of magnetic alloys in the "other alloys" category) was 10 years. The lifetimes of carbon steels and cast irons are based on the current life cycles of automobiles and light trucks because these items are high in consumption of carbon steels and cast irons. Currently, the life cycle of motor vehicles is about 10 years (*20*). The lifetimes of miscellaneous and unspecified materials is assumed to be 5 years, based on the most frequent lifetimes of metal products. Nearly all refractory materials, with the exception of glass furnace refractories, have lifetimes of less than 1 year. Chemical products are nearly all used in dissipative end uses and are not recycled.
3. Thus, it is assumed that obsolete scrap available for recycle in 1989 would come from 1979 consumption of carbon steels, cast irons, and other alloys; from 1984 consumption of superalloys, welding and hardfacing materials, SHR steels, alloy steels, HSLA steels, tool steels, and miscellaneous and unspecified metal products; and from 1989 refractory products.
4. Unless otherwise stated, all chromium quantities are metric tons of contained chromium. All values reported are the best estimates possible with currently available data.

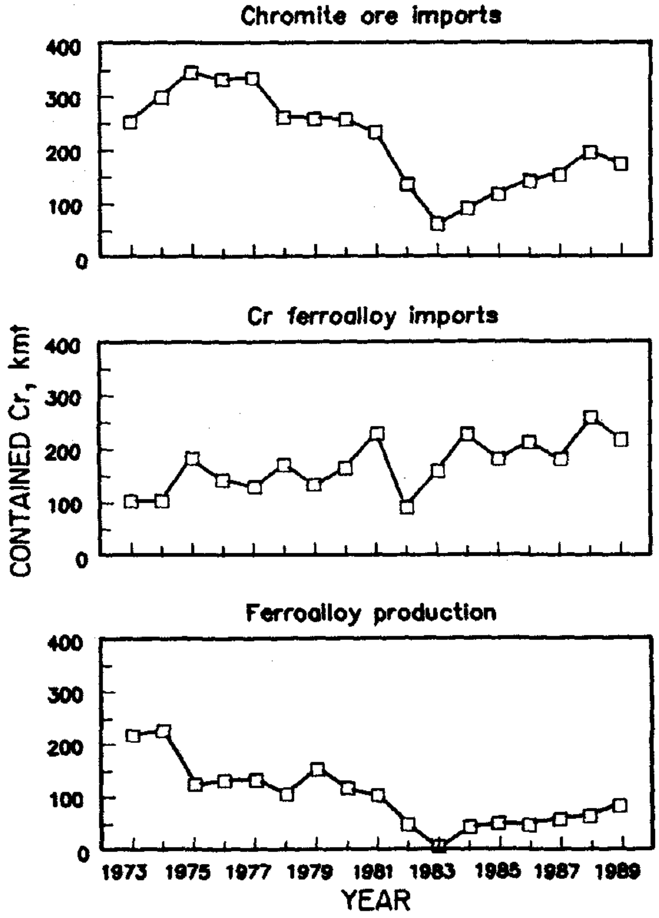
CHROMIUM INDUSTRY

Chromium is consumed by three major industries in the United States. In 1989, the metallurgical industry consumed about 84 pct, the chemical industry about 13 pct, and the refractory industry about 3 pct. The major overall end use is for SHR steels, which account for about 78 pct of metallurgical consumption, or about 65 pct of apparent consumption of chromium. In 1989, the United States imported about 78 pct of the chromium that it consumed. There has been a trend in chromite-producing countries to vertically integrate their chromium industries by developing their own ferrochromium production facilities. This has led to a significant change in the percentages of chromium imported as chromite ore versus chromium imported as ferrochromium. The data from 1973 to 1989 are shown in table 2. Ore imports have fallen from 72.9 pct of imports in 1973 to 44.1 pct in 1989, and ferrochromium imports have risen from 27.1 pct in 1973 to 55.9 pct in 1989. The trend in U.S. imports is shown in figure 2. This trend of producer nations toward their own production of chromium ferroalloys has caused a decline in U.S. chromium ferroalloy production.

Table 2.—U.S. production of chromium ferroalloy and importation of chromite and chromium ferroalloy for 1973-89, 1,000 mt of contained chromium (*25*)

Year	U.S. chromium ferroalloy production	Chromite imports	Chromium ferroalloy imports
1973	225	256	95
1974	234	299	93
1975	136	347	180
1976	143	331	136
1977	143	334	122
1978	119	258	165
1979	161	258	123
1980	129	254	157
1981	115	228	224
1982	63	130	77
1983	18	53	148
1984	54	83	220
1985	62	109	172
1986	59	133	203
1987	69	142	168
1988	73	185	252
1989	90	162	205

Figure 2



U.S. chromite ore and chromium ferroalloy imports, and U.S. chromium ferroalloy production from 1973 to 1989.

The breakdown of chromium consumption in the United States by end use industries in 1989 is shown in table 3, and an overview of the U.S. chromium industry is shown in figure 3. The flow model does not include domestic ferrochromium production losses (1,028 mt). In 1989, chromium input to the U.S. economy amounted to 428,376 mt distributed among various input materials as follows: chromite ore contained 162,113 mt of chromium; chromium ferroalloy, 208,152 mt; chromium metal, 4,202 mt; chromium chemicals, 4,688 mt; and recycled scrap, 99,221 mt. The distribution of this input material was as follows: exports of chromite ore and chromium ferroalloys, metal, and chemicals contained 24,801 mt of chromium; additions to industry stocks, 1,806 mt; materials consumed directly by industry, 360,668 mt; and chromite ore for chromium ferroalloy production, 91,101 mt. During processing to chromium ferroalloys, slag and particulates containing 1,028 mt of chromium reported as losses while chromium ferroalloys containing 90,073 mt of chromium reported to U.S. chromium-consuming industries.

Table 3.—U.S. apparent consumption of chromium in 1989

Industry	Contained Cr, mt	Pct of total
Metallurgical:		
SHR steels	294,423	65.2
Alloy steels	33,453	7.4
HSLA steels	13,049	2.9
Superalloys	12,251	2.7
Carbon steels	7,776	1.7
Cast irons	7,454	1.6
Tool steels	4,370	1.0
Other alloys	4,105	0.9
Welding materials	1,208	0.3
Domestic ferrochromium production losses	1,028	0.2
Miscellaneous and unspecified	611	0.1
Chemical	60,210	13.3
Refractory	11,832	2.6
Total[1]	451,769	100.0

[1] Data do not add to total shown due to independent rounding.

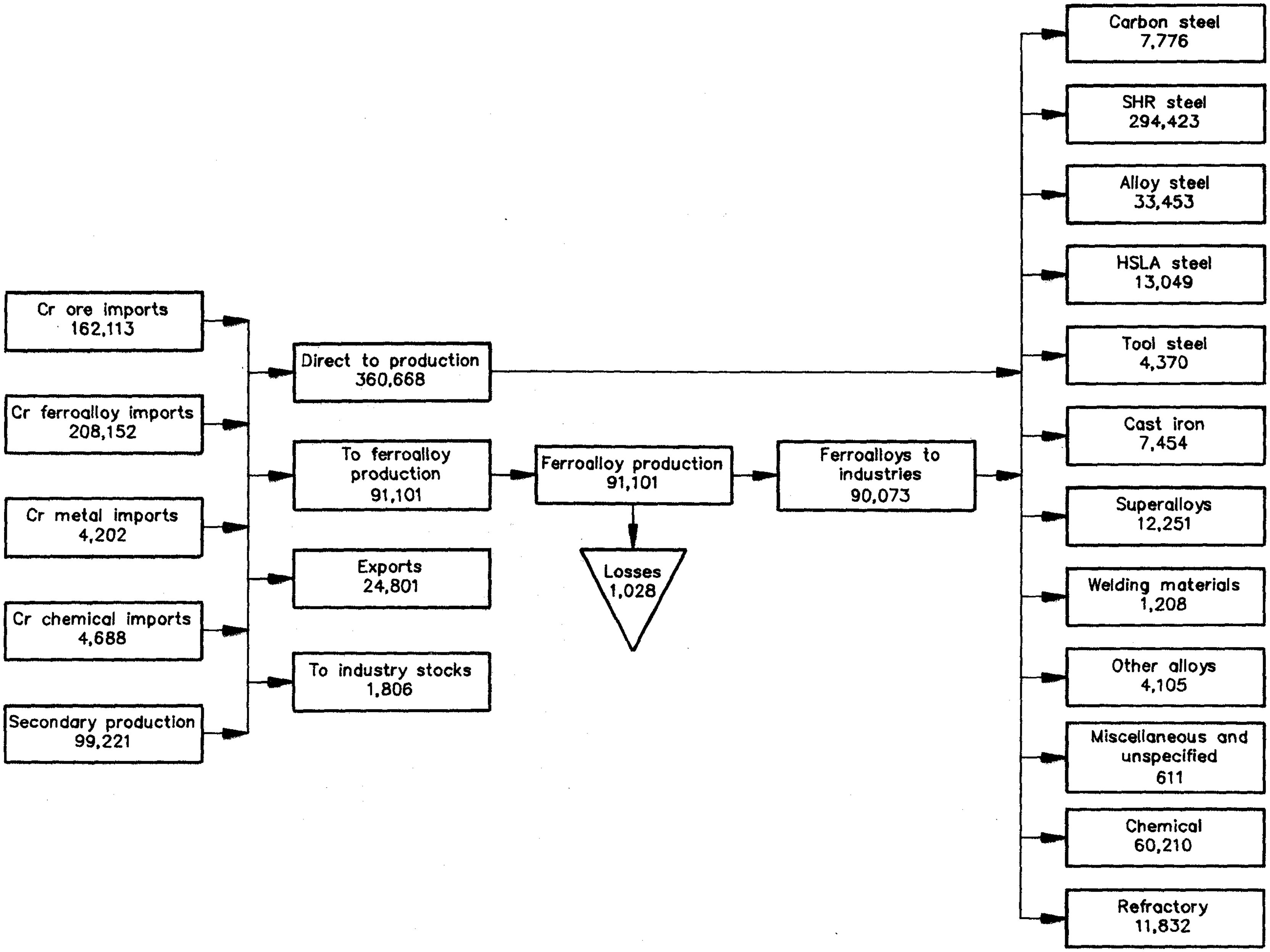
The metallurgical industries consumed materials containing 378,974 mt of chromium. The chromium chemical industries consumed material (mostly ore) containing 60,210 mt of chromium, and the refractory industry consumed ore containing 11,832 mt of chromium.

The only current domestic supply of chromium is recycled scrap. SHR steels and superalloys are recycled primarily for their nickel and chromium content. An electric furnace charge for SHR steels may consist of as much as 50 pct prompt and purchased SHR steel scrap (*2*). In many cases, mixed turnings and borings from superalloy product manufacturing are downgraded to stainless steel scrap. While this does not waste the nickel and chromium content, a higher value scrap is then sold as a lower value scrap, and valuable supplies of superalloys are lost to a lesser product. Most of the other steel and other alloys containing chromium may be recycled, but not specifically for their chromium content. Chromium chemicals generally are consumed in dissipative end uses and thus are not recycled. There is some recycling of chromium refractories, particularly foundry sands. However, there may be some recycling of chromium from waste materials in the future because of increasingly strict environmental standards and increasing disposal costs for wastes.

CARBON STEELS

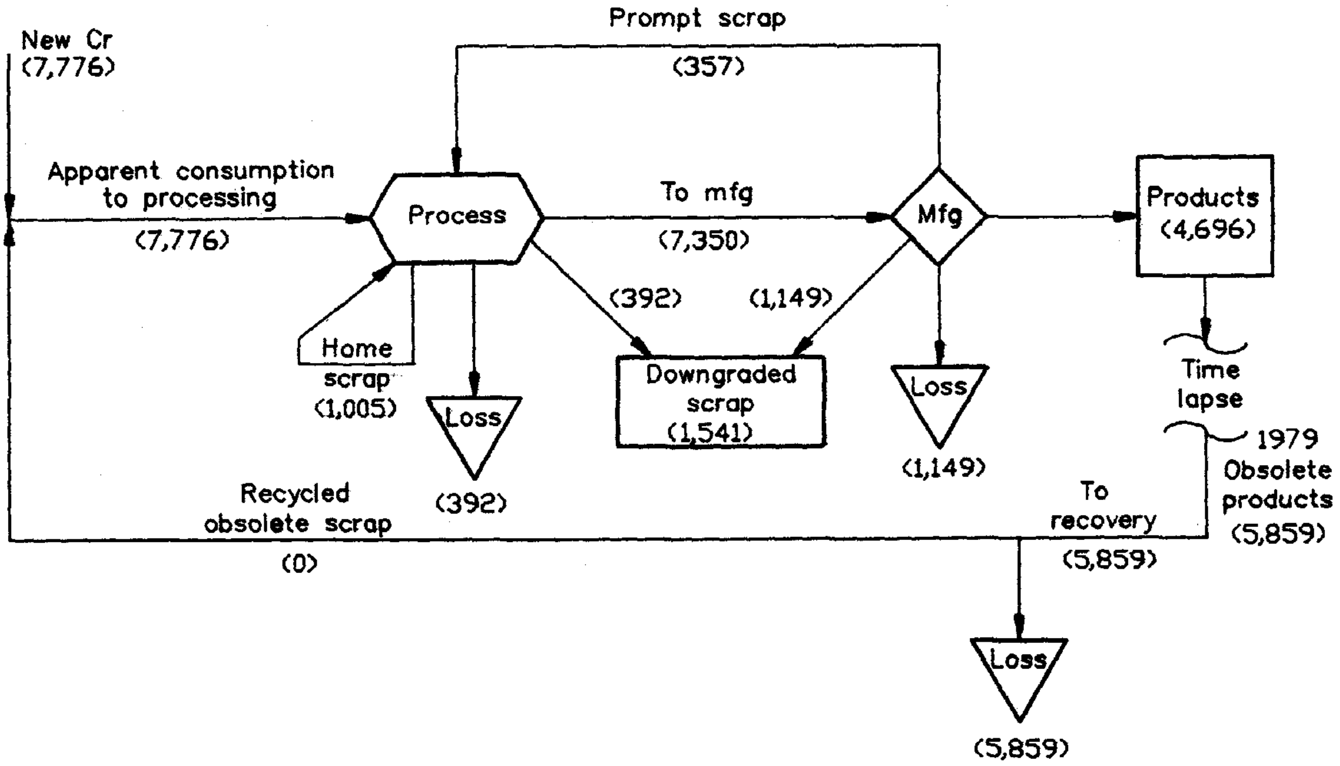
Carbon steels are consumed in the manufacture of automobiles, appliances, structural steels, and a wide variety of other products. During 1989, the carbon steel industry consumed 7,776 mt of chromium, mostly in the form of chromium ferroalloys. The flow model for chromium in carbon steels is shown in figure 4. An additional 357 mt of chromium in prompt scrap and 1,005 mt of

Figure 3



Overview of chromium industry in United States. Amounts are metric tons of contained chromium.

Figure 4



Carbon steels flow model. Amounts are metric tons of contained chromium.

chromium in home scrap were also consumed during processing. A quantity of material containing 392 mt of chromium reported to processing losses (slags, dusts, etc.). A quantity of material containing 392 mt of chromium was downgraded to lesser materials. The remaining material, containing 7,350 mt of chromium, reported to product manufacturing.

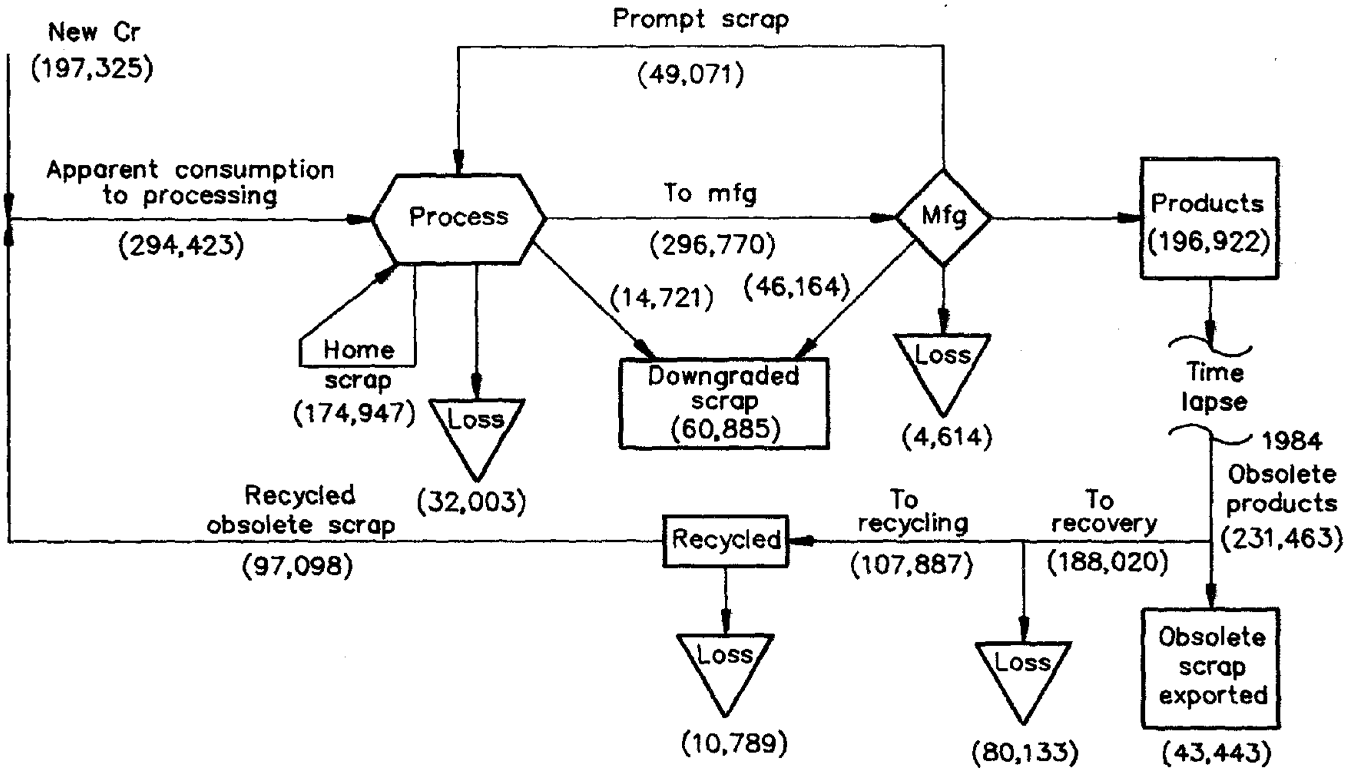
During manufacturing, material containing 357 mt of chromium was recycled to processing as prompt scrap, material containing 1,149 mt of chromium was downgraded to lesser metals, and material containing 1,149 mt of chromium reported to manufacturing losses (dusts, contaminated metal, grindings, etc.). Final products using carbon steels contained 4,696 mt of chromium.

Because carbon steel products are used heavily in automobiles and appliances, these products are estimated to have a 10-year life cycle (*20*). Material containing 5,859 mt of chromium from 1979 carbon steel industry consumption potentially was available for recycling. While considerable amounts of this material were recycled to various steel melts as part of the scrap charges to the furnaces, essentially none is recycled specifically for its chromium content. In many instances, the chromium-containing carbon steels are not identified as such and are, thus, recycled to other steels. There are no data available to indicate the success of recovering chromium-bearing carbon steels as such and recycling them back to chromium-containing carbon steels.

STAINLESS AND HEAT-RESISTANT STEELS

SHR steels are used in many environments where resistance to corrosion or heat is required. They also have end uses as varied as kitchen sinks or other sinks, counter tops, decorative components of automobiles and marine vessels, and jet engine parts. SHR steels are the largest consumers of chromium, accounting for 65 pct of 1989 apparent consumption of chromium. SHR steels also accounted for most of secondary or recycled chromium-bearing scrap by consuming 97,098 mt of this scrap. The flow model for SHR steels is shown in figure 5. The total feed to SHR steels included obsolete scrap containing 97,098 mt of chromium, prompt scrap containing 49,071 mt of chromium, home scrap containing 174,947 mt of chromium, and new material containing 197,325 mt of chromium. During processing, in addition to home scrap, 32,003 mt of chromium reported to processing losses, while 14,721 mt of chromium reported to downgraded scrap, and material containing 296,770 mt of chromium went as feed to manufacturing.

Figure 5



Stainless and heat-resistant steels flow model. Amounts are metric tons of contained chromium.

During manufacturing, material containing 46,164 mt of chromium reported to downgraded scrap, material containing 4,614 mt of chromium reported to manufacturing losses, and material containing 49,071 mt of chromium returned to processing as prompt scrap. The final products contained 196,922 mt of chromium.

Obsolete scrap for 1989 consumption of chromium in SHR steels came from 1984 production of these materials. From 1984 apparent consumption of chromium in SHR steels, material containing 231,463 mt of chromium potentially would be available for recycle. Available data indicate that SHR steel obsolete scrap containing 43,443 mt of chromium was exported in 1989 (*26*). This left scrap containing 188,020 mt of chromium available for recovery. Of this amount, scrap containing 80,133 mt of chromium was lost to unknown and unrecovered losses. The remaining scrap, containing 107,887 mt of chromium, was processed for recycling. During recycling, material containing 10,789 mt of chromium reported to recycling losses, and scrap containing 97,098 mt of chromium reported to 1989 SHR steel consumption. The recycling loss material probably includes major amounts of downgraded scrap.

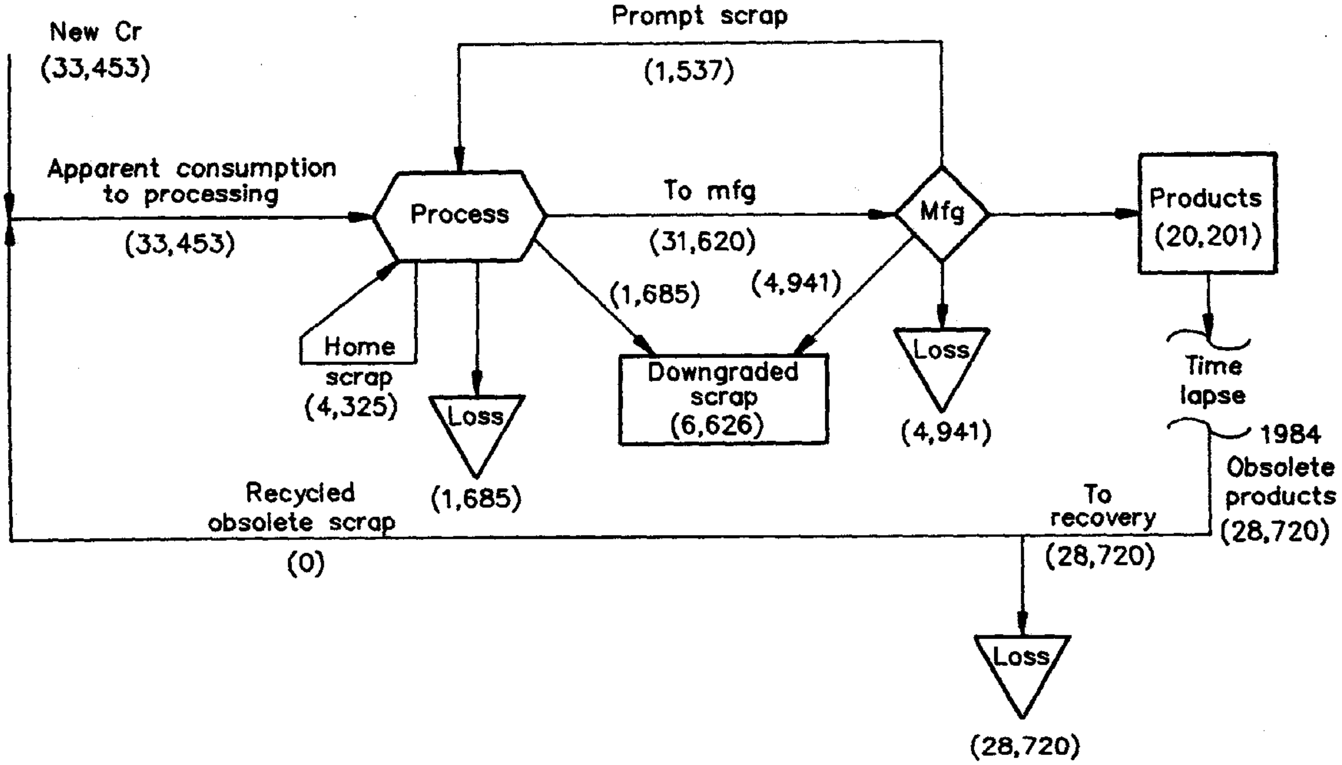
These export, unknown, unrecovered, and recycling losses of SHR steel scrap account for the largest losses of scrap that contains chromium. This amounts to a loss of material containing 134,365 mt of chromium. This lost material would amount to about 30 pct of 1989 total apparent consumption of chromium.

ALLOY STEELS

Special alloying constituents give alloy steels the strength necessary for their many end uses. These alloys are most frequently used in structural steel applications such as in bridges and buildings. These alloys may contain from 0.4 to 4.0 pct chromium. The flow model for alloy steels is shown in figure 6. New chromium material feed to processing contains 33,453 mt of chromium. Additional feed to processing is home scrap containing 4,325 mt of chromium and prompt scrap containing 1,537 mt of chromium. During processing, loss material containing 1,685 mt of chromium and downgraded material containing 1,685 mt of chromium are generated. Processing material feed to manufacturing contains 31,620 mt of chromium.

During manufacturing, in addition to prompt scrap, loss material containing 4,941 mt of chromium and downgraded material containing 4,941 mt of chromium are produced. Final products contain 20,201 mt of chromium.

Figure 6



Alloy steels flow model. Amounts are metric tons of contained chromium.

Potentially available material for recycling was provided by 1984 apparent consumption of chromium for alloy steels. This material contained 28,720 mt of chromium. Essentially none of this material was recycled for its chromium content, and thus, obsolete scrap containing 28,720 mt of chromium was lost in unknown and unrecovered materials. While almost all steel melts contain between 30 and 50 pct scrap material, none is known to be specifically recycled for its chromium content. Thus, there are no data on the amounts of chromium in this recycled steel that arrive in the new products. Any chromium that remains in the melted scrap is augmented by additions of chromium, mostly from ferrochromium.

HIGH-STRENGTH LOW-ALLOY STEELS

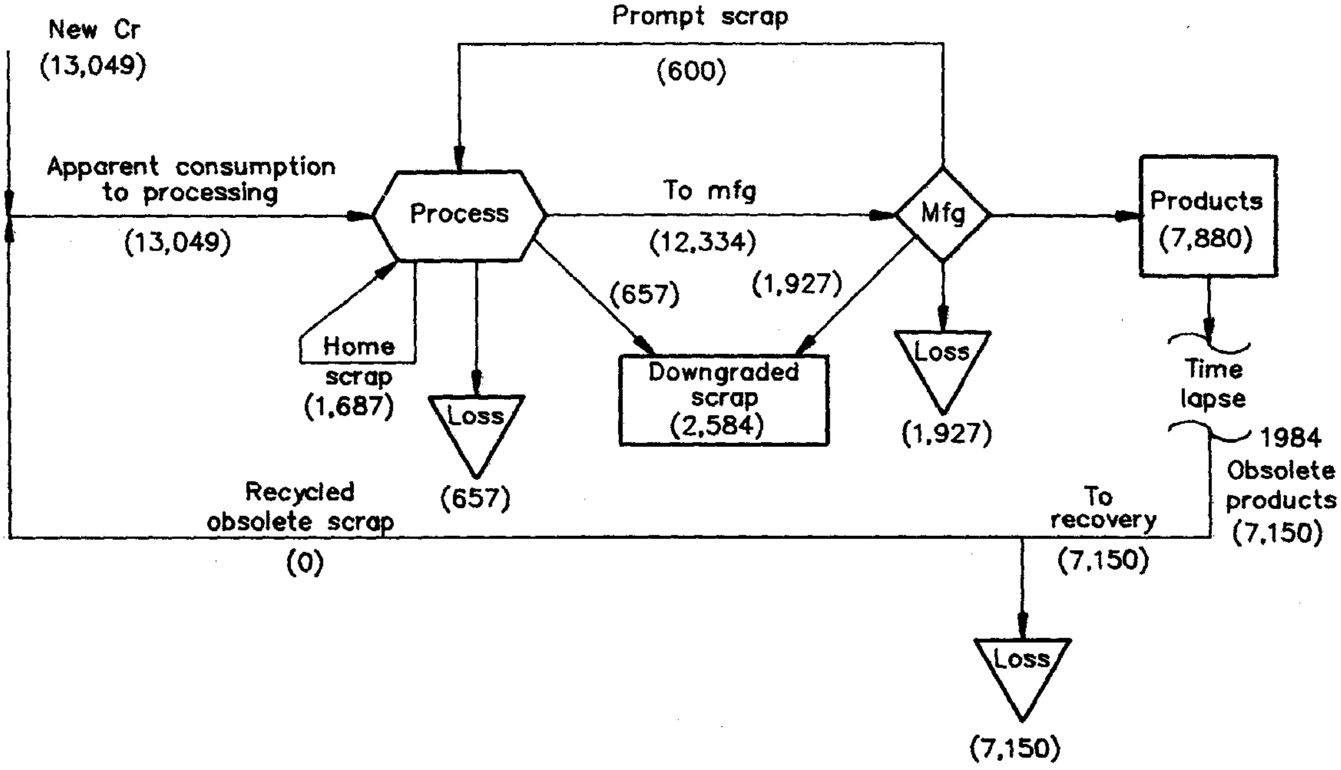
These alloys were originally developed for the Alaska Pipeline, where environmental conditions required unusually high strength materials (*27*). These steels are now used extensively as structural steels in automobiles, buildings, and bridges, and also have some uses where the properties of these steels provide protection against atmospheric corrosion. The flow model for HSLA steels is shown in figure 7. Feed to processing included new material containing 13,049 mt of chromium, prompt scrap containing 600 mt of chromium, and home scrap containing 1,687 mt of chromium. During processing, loss material containing 657 mt of chromium and downgraded material containing 657 mt of chromium were generated. The remaining material, containing 12,334 mt of chromium, went as feed to manufacturing.

During manufacturing, prompt scrap containing 600 mt of chromium, loss material containing 1,927 mt of chromium, and downgraded material containing 1,927 mt of chromium were produced. Final products contained 7,880 mt of chromium. From 1984 apparent consumption of chromium in HSLA steels, obsolete material containing 7,150 mt of chromium potentially was available for recycling. Essentially all of this material reported as unknown and unrecovered losses. As with alloy steels, almost all this material is not recycled for its chromium content. Thus, the entire 7,150 mt of contained chromium is lost to efficient recycle.

TOOL STEELS

Tool steels are designed for cutting, forming, or otherwise shaping a material. Typically these steels may contain

Figure 7



High-strength low-alloy steels flow model. Amounts are metric tons of contained chromium.

from 0.25 to 13.5 pct chromium (*27*). The flow model for tool steels is shown in figure 8. New material containing 4,370 mt of chromium, prompt scrap containing 201 mt of chromium, and home scrap containing 565 mt of chromium were the feed to processing. Loss material containing 220 mt of chromium and downgraded scrap containing 220 mt of chromium were produced during processing. Processed material containing 4,131 mt of chromium was sent as feed to manufacturing.

During manufacturing, prompt scrap containing 201 mt of chromium, downgraded scrap containing 645 mt of chromium, and loss material containing 645 mt of chromium were produced. The final products contained 2,639 mt of chromium.

Material containing 3,680 mt of chromium from 1984 apparent consumption of chromium in tool steels potentially was available for recovery and recycling. Virtually all this material reported to unknown and unrecovered losses. The reason none is shown to be recycled is that obsolete scrap from these types of end uses is not recycled for its chromium content. Thus, the fate of material containing this 3,680 mt of chromium is unknown.

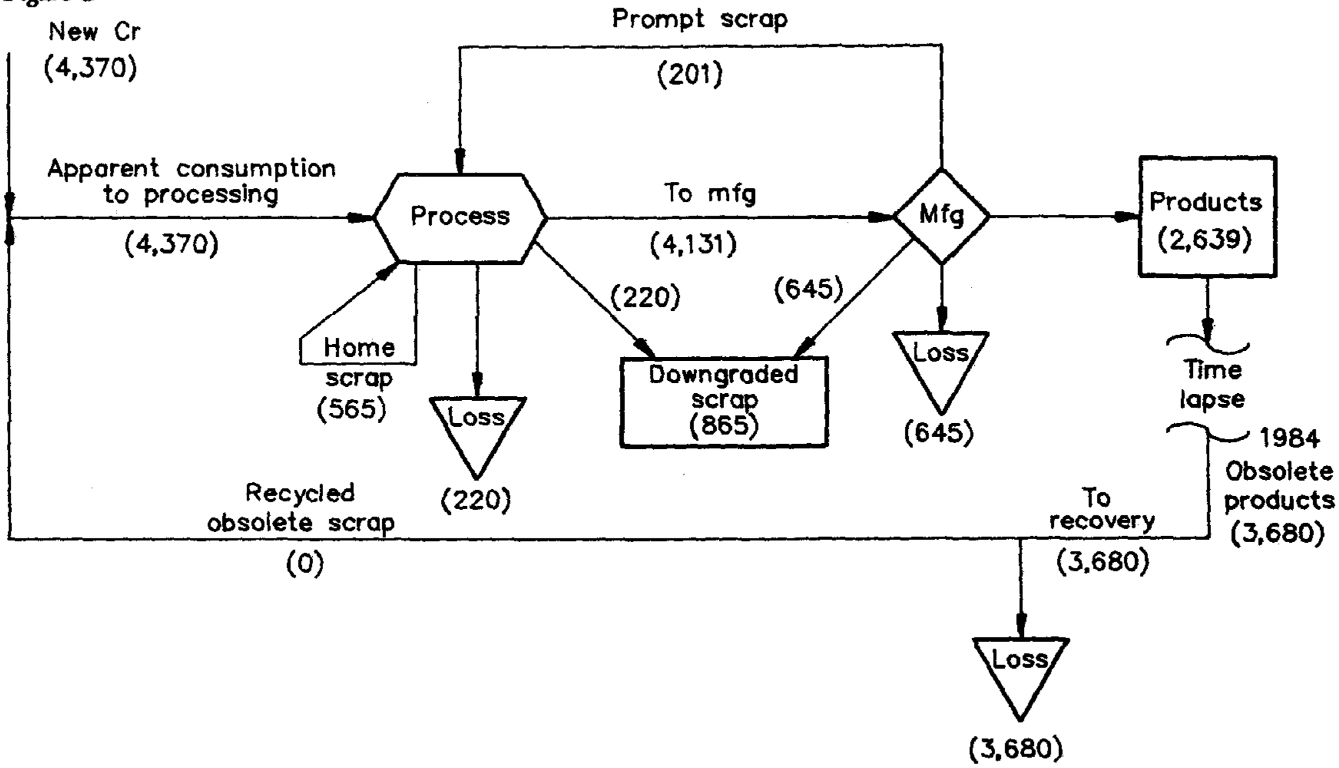
CAST IRONS

Cast irons have a variety of end uses. Some of the major ones are as engine blocks, some types of gears, and large pieces of many different types of machinery. Typically these cast irons may contain from 0.03 to 0.45 pct chromium (*27*). The flow model for cast irons is shown in figure 9. New feed material containing 7,454 mt of chromium went to processing. Prompt scrap containing 1,357 mt of chromium and home scrap containing 359 mt of chromium also were part of the feed to processing. During processing, material containing 373 mt of chromium reported to processing losses. Material containing 8,438 mt of chromium was feed to manufacturing.

During manufacturing, material containing 132 mt of chromium reported as manufacturing losses, and prompt scrap containing 1,357 mt of chromium was produced and recycled back to processing. Final products contained 6,949 mt of chromium.

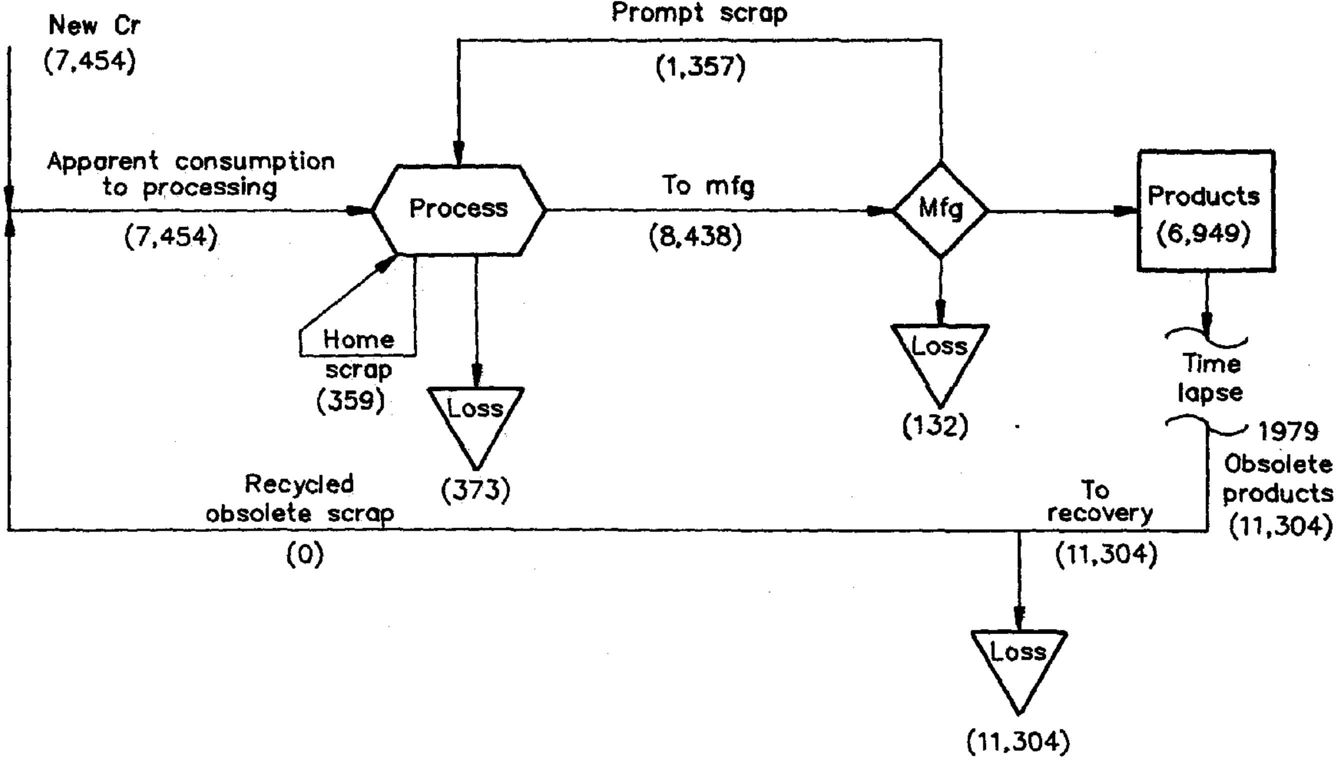
Typically, today's automobiles last an average of 10 years (*20*). Because automobile engine parts are the heaviest users of cast irons, a lifetime of 10 years is assumed.

Figure 8



Tool steels flow model. Amounts are metric tons of contained chromium.

Figure 9



Cast irons flow model. Amounts are metric tons of contained chromium.

Thus, potentially available obsolete scrap for 1989 production would come from 1979 apparent consumption of chromium in cast irons. Thus, obsolete scrap containing 11,304 mt of chromium potentially would be available for consumption in 1989. This material is not recycled for its chromium content, but for its iron content. A large percentage of cast iron scrap is recycled and remelted; however, because there were no data on amounts recycled for their chromium content, it is assumed that 1979 obsolete scrap reports to unknown and unrecovered losses.

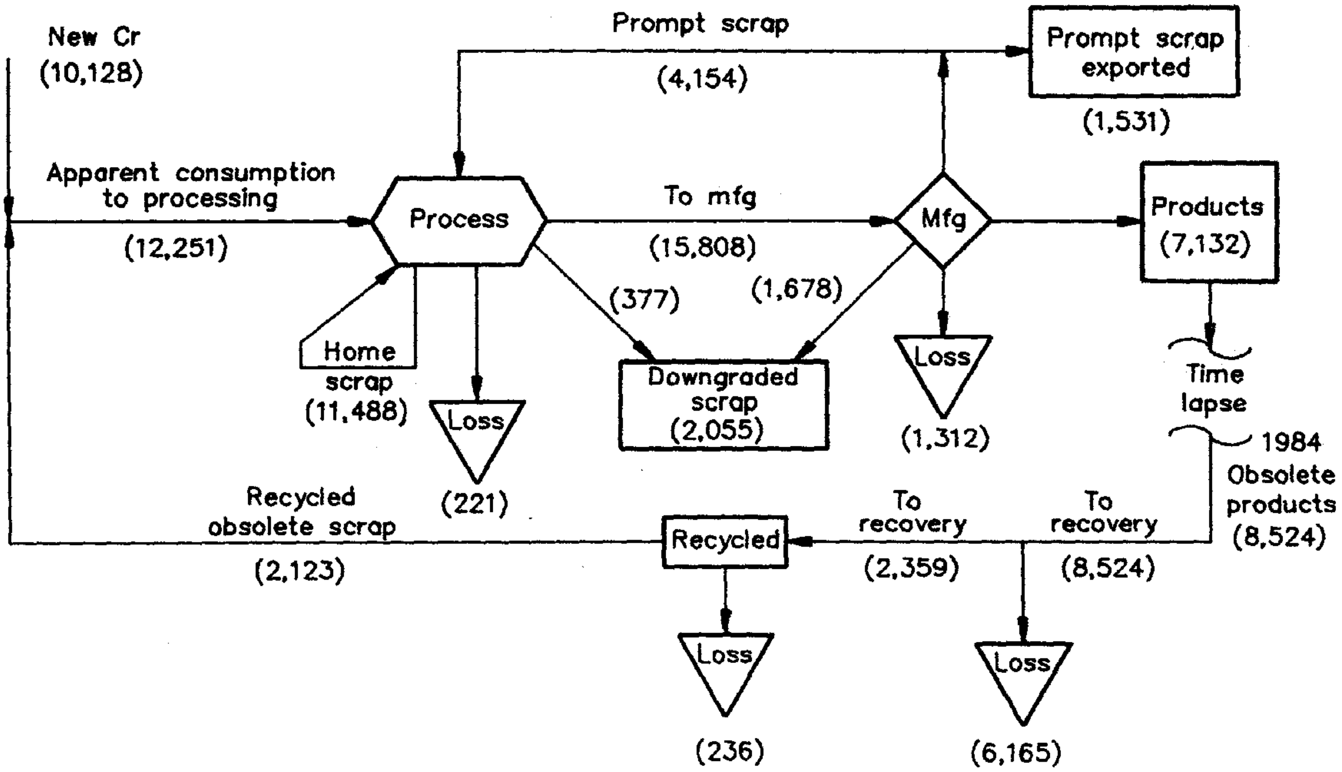
SUPERALLOYS

Superalloys are metals that have very high strengths and that are resistant to corrosion and oxidation at high temperatures. Because of their high values (up to $31/kg), much care is taken in recycling these materials. Typical uses are in jet aircraft engine components, both moving and stationary parts. A number of these alloys also are used for applications in highly corrosive environments. Typically, superalloys are nickel- or cobalt-based alloys; however, there are also some iron-based superalloys. Superalloys may contain from 8 to 30 pct chromium (27). The flow model for superalloys is shown in figure 10. Processing feed materials included new material containing 10,128 mt of chromium, 2,123 mt of chromium in obsolete scrap, 4,154 mt of chromium in prompt scrap, and 11,488 mt of chromium in home scrap. During processing, material containing 221 mt of chromium reported as processing losses, and scrap containing 377 mt of chromium reported to downgraded scrap. Processing metal feed to manufacturing contained 15,808 mt of chromium.

During manufacturing, material containing 1,312 mt of chromium reported to manufacturing losses, and scrap containing 1,678 mt of chromium reported to downgraded scrap. Prompt scrap containing 5,685 mt of chromium also was produced. Part of this prompt scrap, containing 1,531 mt of chromium, was exported. The remaining prompt scrap, containing 4,154 mt of chromium, was recycled to processing. Final products contain 7,132 mt of chromium.

Obsolete products from 1984 apparent consumption of chromium in superalloys contain 8,524 mt of chromium and potentially are available for recycling. During recovery, scrap containing 6,165 mt of chromium reported as unknown and unrecovered losses. Of the obsolete scrap going on to processing, material containing 236 mt of chromium reported to recycling losses, and scrap containing

Figure 10



Superalloys flow model. Amounts are metric tons of contained chromium.

2,123 mt of chromium was recycled. Thus, scrap containing about 6,401 mt of chromium, and also cobalt and nickel, is lost to efficient recycle. This would amount to about 52 pct of 1989 apparent consumption of chromium in superalloys.

Data shown by Papp give an estimated breakdown of the various scrap and loss components in the flow model for chromium in superalloys (*28*) (see table 4). Note that the prompt scrap that is exported contains mostly grindings and turnings (69 pct), which frequently are not suitable for recycle back to vacuum-melted superalloys because of possible contamination. All 1,531 mt of chromium in the exported prompt scrap is lost to domestic production of superalloys, which contain chromium, cobalt, and manganese—strategic and critical materials. Total losses of superalloys to wastes, downgraded scrap, and export (5,119 mt contained chromium) amounted to about 42 pct of 1989 apparent consumption of chromium in superalloys.

WELDING AND HARDFACING MATERIALS

These materials are used for joining steels and other alloys and for putting wear-resistant coatings on items such as teeth on digging equipment. These alloys are also used for automotive engine valves, fluid valves, knives, cutters, erosion shields, hot-working dies, and bearing surfaces that cannot be lubricated. These cobalt-base alloys may contain up to 31 pct chromium (*4*). The flow model for welding and hardfacing materials is shown in figure 11. In 1989, materials containing 1,208 mt of chromium were consumed for these alloys. Feed to processing also included prompt scrap containing 556 mt of chromium and home scrap containing 306 mt of chromium. During processing, material containing 259 mt of chromium reported to processing losses. An additional amount of material containing 145 mt of chromium reported to downgraded scrap. Processed material going to feed for manufacturing contained 1,360 mt of chromium.

During manufacturing, prompt scrap containing 556 mt of chromium was produced. Materials reporting as manufacturing losses contained 44 mt of chromium. Final products contained 760 mt of chromium.

Material from 1984 apparent consumption for welding and hardfacing applications contained 996 mt of chromium that potentially would be available for recovery and recycling. Significant amounts of this material are lost during their use life, and most of the rest, while it may be recycled, is not recycled back to this end use and, thus, is in unknown and unrecovered losses.

Table 4.—Composition of superalloy scrap and loss fractions, metric tons of contained chromium

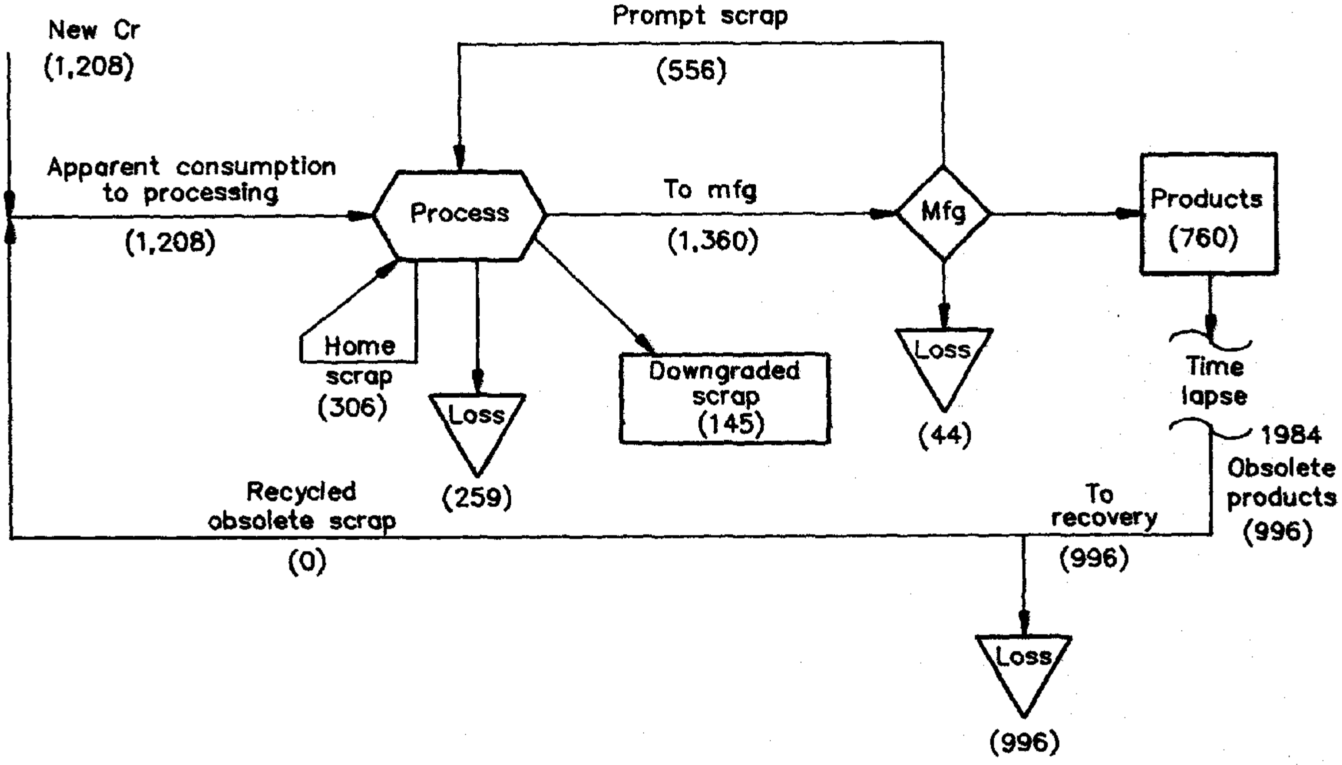
Fraction	*Content*
Home scrap:	
Grindings	331
Mixed scrap	662
Solid scrap	9,282
Turnings	1,213
Total	11,488
Processing losses: Dust	221
Processing-downgraded scrap:	
Grindings	147
Mixed scrap	230
Total	377
Manufacturing prompt scrap to processing:	
Solids	2,941
Turnings	1,213
Total	4,154
Manufacturing losses (waste):	
Grindings	228
Waste	1,007
Unknown	76
Total[1]	1,312
Manufacturing-downgraded scrap:	
Grindings	494
Solid scrap	423
Turnings	665
Unknown	97
Total[1]	1,678
Manufacturing prompt scrap exports:	
Grindings	450
Solid scrap	386
Turnings	607
Unknown	88
Total	1,531

[1] Data do not add to total shown due to independent rounding.

OTHER ALLOYS

Materials in this industry are cutting materials, magnetic alloys, aluminum alloys, copper alloys, nickel alloys, and various other alloys. The chromium content of these alloys varies widely: magnetic alloys, 0.5 to 5.75 pct chromium; aluminum alloys, 0.04 to 0.4 pct chromium; copper alloys, 0.4 to 3.2 pct chromium; nickel alloys, 0.25 to 27 pct chromium; cobalt alloys, 20 to 30 pct chromium; and thermocouple and electrical resistance alloys, 4 to 30 pct chromium (*29*). These materials are used in a wide variety of applications: aluminum alloys for marine, automobile, and aircraft parts, drilling rigs, TV towers, and armorplate; copper alloys for switches, circuit breakers, continuous

Figure 11



Welding and hardfacing materials flow model. Amounts are metric tons of contained chromium.

casting molds, heat exchanger tubes, and pipe; nickel alloys for seawater corrosion resistance, high-temperature applications, and heating elements; cobalt alloys for bearings and valve seats; magnet alloys for permanent magnets; and other alloys for thermocouples, resistance heating elements, and cutting materials (*29*).

The flow model for other alloys is shown in figure 12. Processing feed consisted of new materials containing 4,105 mt of chromium, prompt scrap containing 684 mt of chromium, and home scrap containing 832 mt of chromium. During processing, material containing 703 mt of chromium reported to processing losses, and the remaining materials, containing 4,087 mt of chromium, reported to feed for manufacturing.

During manufacturing, prompt scrap containing 684 mt of chromium and manufacturing loss material containing 64 mt of chromium were produced. The remaining material was final products containing 3,339 mt of chromium.

These products are assumed to have a 10-year use life (*20*). Thus, the 1979 apparent consumption of chromium in other alloys potentially is available for recycling; this material contains 4,535 mt of chromium. However, none of this material is known to be recycled for its chromium content, and thus, it reports as unknown and unrecovered losses, leaving no material for recycling.

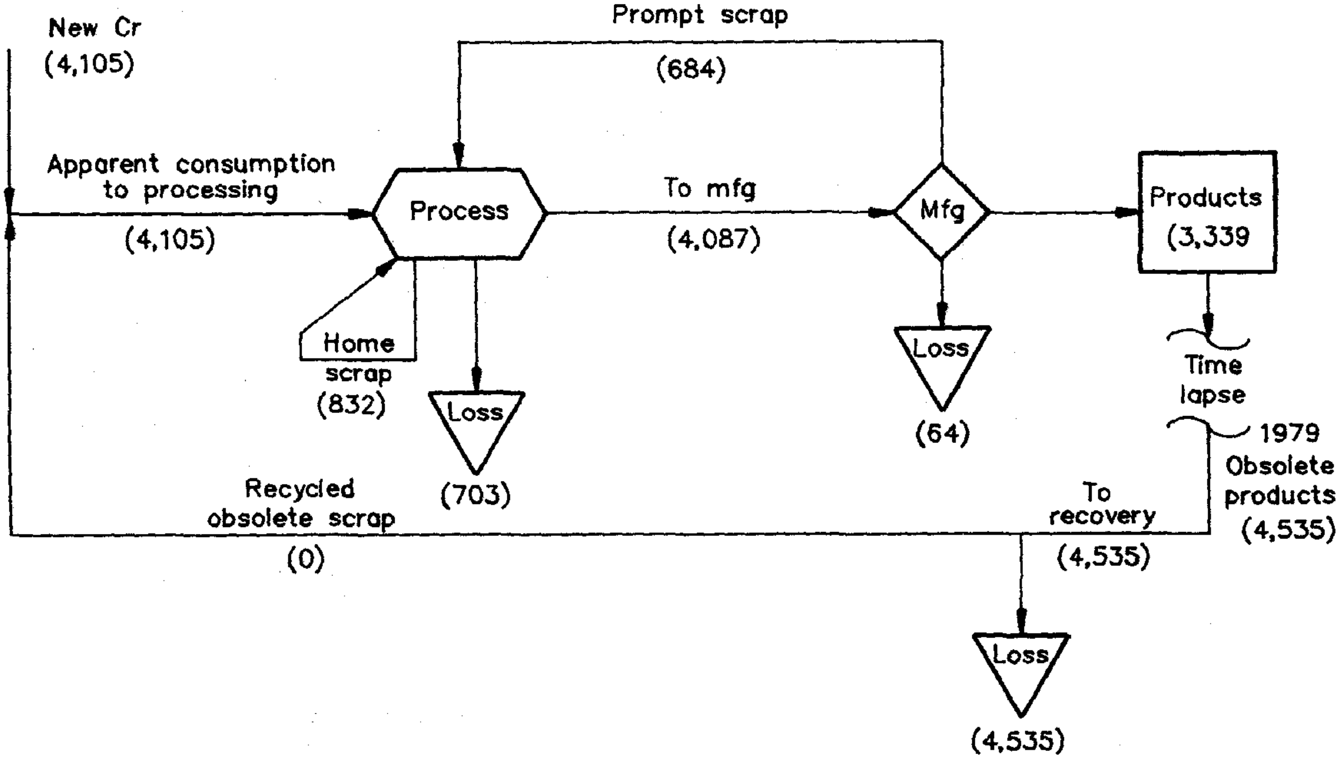
MISCELLANEOUS AND UNSPECIFIED MATERIALS

This category contains small metallurgical end uses of chromium, including the consumption of an unknown quantity of material in which ferrochromium silicon is used to produce tool steels. (This use of ferrochromium silicon in tool steels is withheld to avoid disclosing company proprietary data.) The assumed flow model for this category of material is shown in figure 13. Processing feed included new material containing 611 mt of chromium, prompt scrap containing 102 mt of chromium, and home scrap containing 124 mt of chromium. During processing, material containing 105 mt of chromium reported to processing losses and material containing 30 mt of chromium reported to downgraded scrap. Processing material feed to manufacturing contained 578 mt of chromium.

During manufacturing, material containing 102 mt of chromium reported as prompt scrap, material containing 91 mt of chromium reported to downgraded scrap, and material containing 9 mt of chromium reported to manufacturing losses. The final products contain 376 mt of chromium.

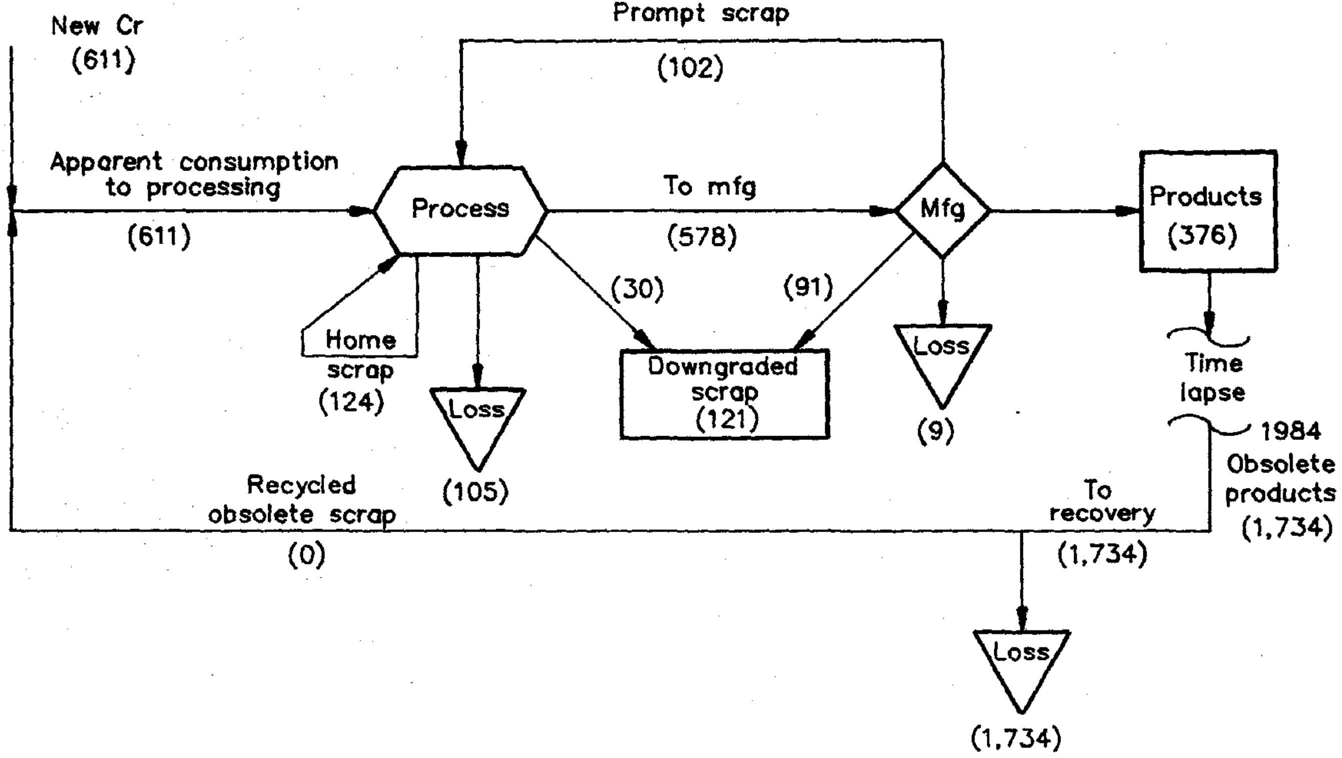
As with most other end uses of chromium, little or no material is recycled for its chromium content. Thus, the

Figure 12



Other alloys flow model. Amounts are metric tons of contained chromium.

Figure 13



Miscellaneous and unspecified materials flow model. Amounts are metric tons of contained chromium.

material from 1984 apparent consumption of chromium in miscellaneous and unspecified materials potentially available for recycle (containing 1,734 mt of chromium) reports to unknown and unrecovered losses.

CHEMICALS

Chromium chemicals are used for electroplating, pigments and paint, leather tanning, drilling muds, water treatment, and wood treatment (*18*). The flow model for chromium chemicals is shown in figure 14. Chemical processing consumed mostly chromite ore containing 60,210 mt of chromium in 1989. During processing, material containing 1,806 mt of chromium reported to processing losses. The remaining material, nearly entirely sodium dichromate, reported to chemical manufacturing and contained 58,404 mt of chromium. During manufacturing of chromium chemicals, material containing 2,920 mt of chromium reported to manufacturing losses. The final chemical products contained 55,484 mt of chromium.

Chromium chemicals, like most chemicals, are used in dissipative end uses. Thus, the chromium content is not readily available for recycle. However, ever stricter environmental controls on chromium will make recycling of chromium-bearing wastes a necessity. While most recycling processes suggested to date are not economically feasible at this time, the continuously escalating costs of disposal of chromium-containing wastes will eventually make recycling a necessity. For example, it soon may be prohibitively expensive to use plating waste as landfill. Thus, a process to reclaim the chromium content of these wastes may become economically feasible. Some end uses, such as pigments and paints, will continue to remain unavailable for recycling for the foreseeable future. This might make the use of alternative materials a necessity.

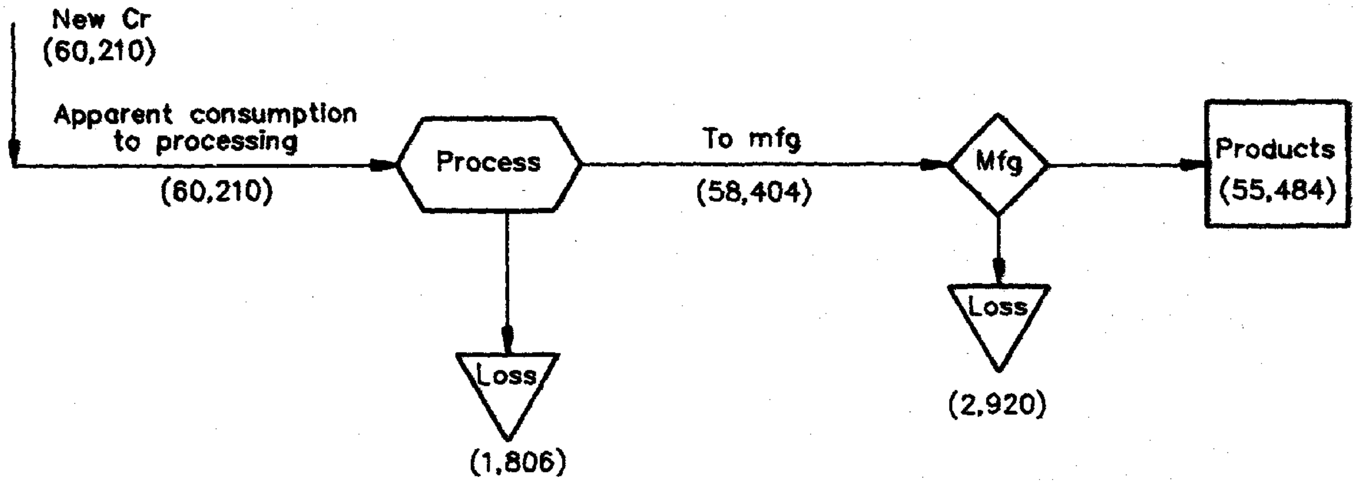
REFRACTORIES

Chrome refractories include chrome bricks, chrome-magnesite bricks, chrome-containing gunning mixes, and chromite foundry sands. There is a decreasing demand for chrome-containing bricks and gunning mixes because of the replacement of these materials with substitutes. Chromite refractory sands are still in high demand. The flow model for chromium refractories is shown in figure 15. New material containing 8,070 mt of chromium, recycled obsolete foundry sands containing 3,762 mt of chromium, prompt scrap containing 947 mt of chromium, and home scrap containing 592 mt of chromium were processing feeds. During processing, material containing 401 mt of chromium reported to processing losses, and material containing 12,377 mt of chromium reported as processing feed to manufacturing.

During manufacturing, prompt scrap containing 947 mt of chromium and manufacturing loss material containing 371 mt of chromium were produced. Final products contained 11,060 mt of chromium.

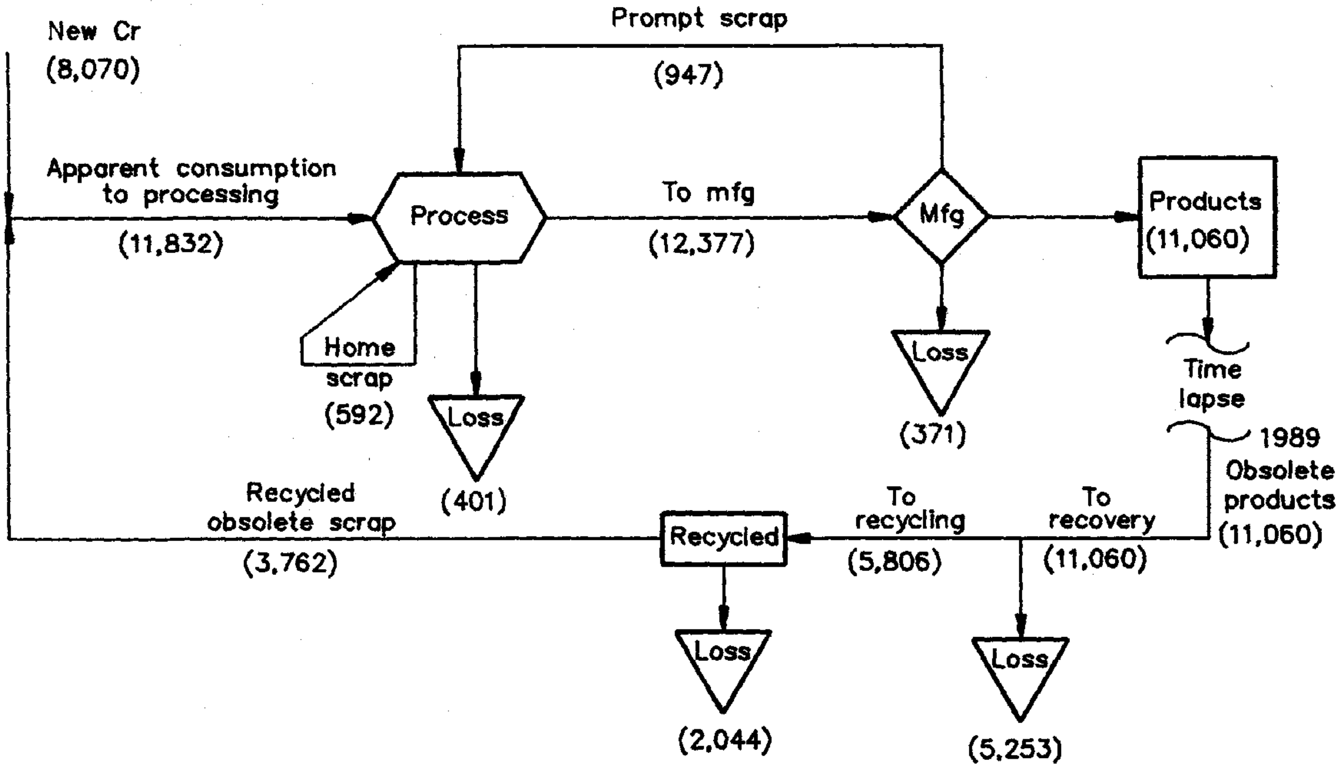
Because nearly all uses of chromium-containing refractories, except glass furnace linings, have life cycles of less than 1 year, material available for recycle would come from 1989 final products, which contained 11,060 mt of chromium. During recovery, only foundry sands are being processed, thus unknown and unrecovered losses account for a small fraction of foundry sands and essentially all chrome bricks and gunning mixes. This material contained 5,253 mt of chromium. During recycle, an additional amount of material reported as recycle losses containing

Figure 14



Chemicals flow model. Amounts are metric tons of contained chromium.

Figure 15



Refractories flow model. Amounts are metric tons of contained chromium.

2,044 mt of chromium. The final amount of recycled material, virtually all foundry sand, contained 3,762 mt of chromium.

OVERALL CHROMIUM INDUSTRY

A composite flow model summed from the values in all chromium industry flow models described previously is shown in figure 16. Processing feed consisted of new chromium material containing 347,759 mt of chromium, recycled obsolete scrap containing 102,983 mt of chromium, prompt scrap containing 59,566 mt of chromium, and home scrap containing 196,230 mt of chromium. Material reporting to processing losses contained 38,825 mt of chromium, and material reporting to downgraded processing scrap contained 18,227 mt of chromium. The remaining material, containing 453,257 mt of chromium, reported as processing feed to manufacturing.

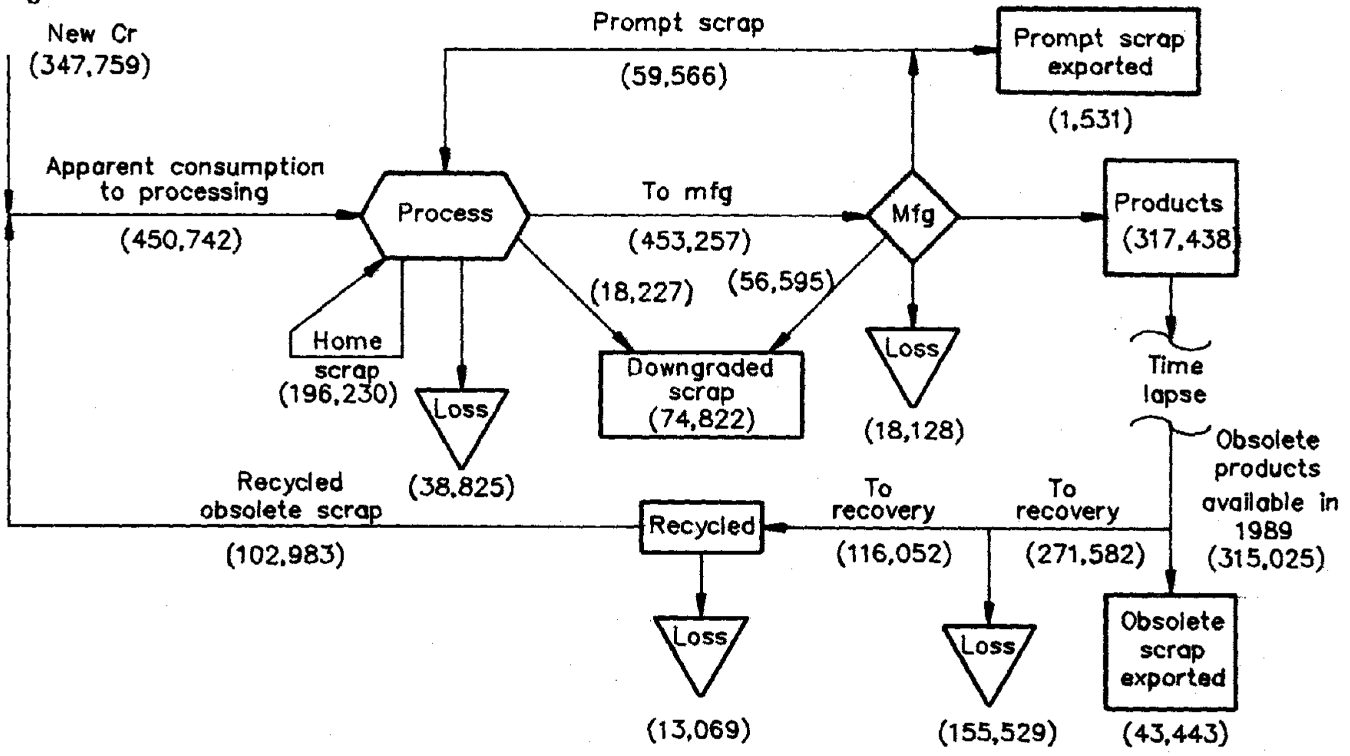
During manufacturing, prompt scrap containing 61,097 mt of chromium was produced. Superalloy prompt scrap containing 1,531 mt of chromium was exported, and the remaining prompt scrap, containing 59,566 mt of chromium, went to processing. In addition, downgraded manufacturing scrap containing 56,595 mt of chromium and manufacturing loss material containing 18,128 mt of chromium were produced. Final products contained 317,438 mt of chromium.

Potentially available obsolete materials for recovery and recycle contained 315,025 mt of chromium, an amount equal to about 70 pct of 1989 apparent consumption of chromium. Of this potentially available material, material containing 43,443 mt of chromium was exported, unknown loss and unrecovered material containing 155,529 mt of chromium reported as recovery losses, and waste material containing 13,069 mt of chromium reported as recycling losses. Recycled SHR steels, superalloys, and foundry sands (the only materials being efficiently recycled) contained 102,983 mt of chromium. This was about 33 pct of the material potentially available for recycle and accounted for 23 pct of 1989 apparent consumption.

CHROMIUM LOSSES

Overall, 345,347 mt of contained chromium was lost in 1989 (see table 5). This overall loss amounts to 76 pct of 1989 apparent consumption of chromium. Of this amount, 131,775 mt of chromium, representing 29 pct of 1989 apparent consumption, was lost during processing and manufacturing operations, and 213,572 mt of chromium, equaling 47 pct of 1989 apparent consumption, was lost

Figure 16



Overall chromium industry flow model. Amounts are metric tons of contained chromium.

from recovery and recycling operations on obsolete scrap material. The major loss of materials was in the SHR steels industry, where the total loss of chromium during processing and manufacturing in 1989 was 97,502 mt of contained chromium, while recovery and recycling operations on chromium-containing SHR steel obsolete scrap showed a loss of 134,365 mt of chromium, or about 30 pct of 1989 apparent consumption. At the same time, all other industries had a recovery and recycling loss of 79,207 mt of chromium, equal to 18 pct of 1989 apparent consumption.

If 90 pct of all chromium-containing obsolete scrap could be recycled efficiently (283,523 mt contained chromium), then the net import reliance[3] would fall from the 1989 level of 78 pct to a value near 37 pct (see table 6). Thus, our national reliance on imported chromium would be very significantly diminished. However, the materials potentially available for recycle would first have had losses to processing and manufacturing equal to about 42 pct during the years the materials were produced. Thus, the maximum possible recycle would be about 58 pct, which would equal a 60-pct net import reliance. This level of recycle would be the best level possible unless technology to process and manufacture could be developed that would lead to lower levels of losses and downgraded materials.

Table 5.—Chromium loss by category in 1989

Category	Contained Cr, mt	Pct of total
SHR steel unknown and unrecovered losses	80,133	23.2
SHR steel manufacturing-downgraded scrap	46,164	13.4
SHR steel scrap export losses	43,443	12.6
SHR steel processing losses	32,003	9.3
Alloy steel unknown and recovered losses	28,720	8.3
SHR steel processing-downgraded scrap	14,721	4.3
Cast iron unknown and unrecovered losses	11,304	3.3
SHR steel recycling losses	10,789	3.1
HSLA steel unknown and unrecovered losses	7,150	2.1
Superalloy unknown and unrecovered losses	6,165	1.8
Carbon steel unknown and unrecovered losses	5,859	1.7
Refractory unknown and unrecovered losses	5,253	1.5
Alloy steel manufacturing-downgraded scrap	4,941	1.4
Alloy steel manufacturing losses	4,941	1.4
SHR steel manufacturing losses	4,614	1.3
Other alloys unknown and unrecovered losses	4,535	1.3
Tool steel unknown and unrecovered losses	3,680	1.1
All others	30,932	9.0
Total	345,347	100.0

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[3] Net import reliance =

$$\frac{(\text{imports - exports + starting stocks - ending stocks}) \times 100\text{ pct}}{\text{1989 apparent consumption}}.$$

Table 6.—Net import reliance versus percent of potentially available obsolete scrap recycled for 1989

Pct recycled	*Potential net import reliance, pct*	*Pct recycled*	*Potential net import reliance, pct*
100	30	40	72
90	37	31[1]	78
80	44	30	79
70	51	20	86
60	58	10	93
50	65	0	100

[1] 1989 actual percent recycled.

SUMMARY

A commodity flow model was developed for the industries that consume chromium. Based on available data, the model follows chromium through its processing, manufacturing, and recycling operations, showing estimated values for material lost through these operations. The model was developed using certain estimates and assumptions and the best data available at the time. The model can be easily updated as new data become available. The multiplication factors will all change with time. New factors can replace older ones as data are acquired.

An industry flowchart was presented for each of the industries that consume chromium. The overall flow of the chromium commodity also was presented. The apparent consumption of chromium in 1989 was 451,769 mt. The estimated amounts consumed by the various industries are shown in table 3. The metallurgical industries consumed materials containing 379,728 mt of chromium, or about 84 pct of 1989 apparent consumption; the chemical industry, materials containing 60,210 mt of chromium, or about 13 pct; and the refractory industry, material containing 11,832 mt of chromium, or about 3 pct. Of the 84 pct of 1989 apparent consumption of chromium by the metallurgical industries, 294,423 mt of chromium or 65 pct of 1989 apparent consumption of chromium was in SHR steels. The next three highest metallurgical industry consumers of chromium were the alloy steel industry, 33,453 mt or 7 pct of the 1989 apparent consumption of chromium; HSLA steel industry, 13,049 mt or 3 pct; and the superalloy industry, 12,251 mt or 3 pct. All other metallurgical industries combined accounted for 26,552 mt or 6 pct of 1989 apparent consumption of chromium.

Based on the estimated lifetimes of the various products and the estimated amounts consumed in 1979 (10 years), 1984 (5 years), and 1989 (1 year), there were potentially recyclable products containing 315,025 mt of chromium (figure 16). From literature data, material containing an estimated 102,983 mt of chromium that can be traced was recycled in 1989 for consumption. Papp shows a total of 99,221 mt of contained secondary chromium (*2*). The difference between the reported 99,221 mt of chromium from secondary sources and the 102,983 mt of recycled chromium estimated from literature data is due to data concerning the recycling of chromium-bearing foundry sands. There currently is no means of tracing how much chromium-bearing steel scrap is actually recycled to the same end use or to another chromium-consuming end use.

During 1989, 345,347 mt of chromium was lost as processing waste and downgraded material, manufacturing waste and downgraded material, recovery and recycling loss material, and scrap exports. The major loss area was in the SHR steels industry, where losses amounted to 231,867 mt of chromium.

CONCLUSIONS

A chromium flow model was developed. The mathematical relationships in the model are discussed in the appendix. The model estimates the distribution of 451,769 mt of chromium consumed in the 12 chromium-consuming industries. The best available data estimate that about 131,775 mt of chromium was lost during processing and manufacturing operations, 56,953 mt of chromium to waste, and 74,822 mt of chromium to downgraded scrap. The 59,566 mt of chromium in prompt scrap that was produced during manufacturing and the 196,230 mt of chromium in home scrap that was generated during processing were efficiently recycled. Of the material potentially available for recycling, estimated with current available data, only the disposition of about 102,983 mt of chromium to recycling can be followed. Material, mostly SHR steel scrap and superalloy scrap, containing 44,974 mt of chromium was exported. The remaining material, containing 168,598 mt of chromium as unknown, unrecovered, use-life, or dissipative losses, cannot be traced with current data. There is a need to obtain data that trace where this material goes. Thus, it is recommended that the USBM make changes in its data-gathering survey sheets to obtain the required information on a continuing basis. This would provide a continuously up-to-date flow model that can be supplied to those requiring the information in developing national policy regarding chromium.

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APPENDIX

This section discusses the assumptions and mathematics used in developing the chromium commodity flow model. The assumptions for the overall chromium data are as follows:

1. Apparent consumption equals primary production plus secondary production plus (imports minus exports) plus (beginning stocks minus ending stocks). This information is summarized in table A-1. (Note: Primary denotes domestic mine production.)

Table A-1.—Elements of 1989 apparent consumption of chromium

Item	*Consumption, mt contained Cr*
Domestic production	0
Secondary production	99,221
Imports:	
Chromite ore	162,113
Chromium ferroalloys	208,152
Chromium metal	4,202
Chromium chemicals	4,688
Stocks: January 1, 1989	136,944
Exports:	
Chromite ore	-12,488
Chromium ferroalloys	-5,647
Chromium metal	-196
Chromium chemicals	-6,470
Stocks: December 31, 1989	-138,750
1989 apparent consumption	451,769

2. Apparent consumption of chromium by major industries was calculated as follows.

First the domestic ferrochromium production losses must be calculated:

$$SL = FC \times A \times C1, \qquad \text{(A-1)}$$

where SL = slag losses of chromium during ferrochromium production, metric tons,

FC = 1989 domestic ferrochromium production, metric tons (*2*),

A = metric ton of slag per metric ton of ferrochromium produced (*30*),

and C1 = fraction of chromium in slag (*30*).

Therefore, $SL = 146{,}884 \times 1.75 \times 0.00371$

= 953 mt of chromium lost in slag.

Then $$DL = FC \times B \times C2, \qquad \text{(A-2)}$$

where DL = dust losses of chromium during ferrochromium production,

B = metric ton of dust per metric ton of ferrochromium produced (*30*),

and C2 = fraction of chromium in dust (*30*).

Therefore, $DL = 146{,}884 \times 0.151 \times 0.00339$

= 75 mt of chromium lost in dust.

Then $$L = SL + DL, \qquad \text{(A-3)}$$

where L = chromium losses during domestic ferrochromium production,

$L = 953 + 75$

= 1,028 mt of chromium.

Now an adjusted apparent consumption of chromium can be calculated.

Then $$AAC = AC - L, \qquad \text{(A-4)}$$

where AAC = adjusted apparent consumption, metric tons,

and AC = 1989 apparent consumption of chromium, metric tons.

Therefore, $AAC = 451{,}769 - 1{,}028$

= 450,741 mt of chromium.

The next step is to calculate the consumption of chromium in refractories:

Now $$RC = OR \times C3 \times CR, \qquad \text{(A-5)}$$

where RC = 1989 apparent consumption of chromium in refractory industry, metric tons,

OR = 1989 consumption of chromite ore in refractory industry (2), metric tons,

C3 = average fraction of Cr_2O_3 in chromite ore consumed in refractory industry (2), and CR = fraction of chromium in Cr_2O_3.

Therefore, $RC = 43{,}780 \times 0.395 \times 0.6842$

$= 11{,}832$ mt of contained chromium.

Then, from historical data and 1989 ore consumption data, it is estimated that chemical chromite ore consumption in 1989 was 200,000 mt.

Then

$$CC = CO \times C4 \times CR, \qquad \text{(A-6)}$$

where CC = 1989 apparent consumption of chromium in chemical industry, metric tons,

CO = 1989 estimated chromite ore consumption by chemical industry, metric tons,

and C4 = average fraction of Cr_2O_3 in chromite ore consumed in chemical industry (estimated by J. Papp, chromium specialist, USBM).

Therefore, $CC = 200{,}000 \times 0.44 \times 0.6842$

$= 60{,}210$ mt of contained chromium consumed by chemical industry.

Finally, the metallurgical consumption of chromium must be calculated.

Then

$$MC = AAC - RC - CC, \qquad \text{(A-7)}$$

where MC = 1989 metallurgical apparent consumption of chromium, metric tons.

Therefore, $MC = 450{,}741 - 11{,}832 - 60{,}210$

$= 378{,}699$ mt of chromium.

3. It is assumed that apparent consumption of contained chromium in each metallurgical end use is proportional to reported consumption in that end use, gross weight.

Then

$$F_n = RPC_n/TCG, \qquad \text{(A-8)}$$

where F_n = fraction of metallurgical industry reported consumption of chromium ferroalloys and metal reporting to end use n,

RPC_n = metallurgical industry reported consumption of chromium ferroalloys and metal reporting to end use n, metric tons gross weight (2),

and TCG = metallurgical industry reported consumption of chromium ferroalloys and metal reporting to all end uses, metric tons gross weight (2).

Then

$$EAC_n = F_n \times MC, \qquad \text{(A-9)}$$

where EAC_n = apparent consumption allocated to metallurgical end use n.

Then, the data in table A-2 were determined by applying equations A-8 and A-9 to the data in table 6 of reference 2.

Table A-2.—Estimated 1989 apparent consumption of chromium in metallurgical end uses

End use	Metallurgical industry reported consumption to end use n, mt	Fraction of metallurgical industry reported consumption	Apparent consumption allocated to metallurgical end use n, mt contained Cr
Steels:			
Carbon	7,412	0.02053	7,776
SHR	280,633	0.77746	294,423
Alloy	31,886	0.08833	33,453
HSLA	12,438	0.03446	13,049
Tool	4,165	0.01154	4,370
Cast irons	7,105	0.01968	7,454
Superalloys	11,667	0.03235	12,251
Welding materials[1]	1,151	0.00319	1,208
Other alloys[2]	3,913	0.01084	4,105
Miscellaneous and unspecified	582	0.00161	611
Total[3]	360,962	1.00000	[4]378,699

[1] Includes structural and hardfacing welding materials.

[2] Includes cutting materials and magnetic, aluminum, copper, nickel, and other alloys.

[3] Data may not add to totals shown due to independent rounding.

[4] Metallurgical apparent consumption of chromium, 1989, metric tons.

4. Various sources have indicated the lifetime of industry products (*4, 20, 31*). From these sources, the lifetimes of the various products are estimated and shown in table A-3. For the estimation of potentially available products for recycling, the following two assumptions were made:

- The reported consumption of chromium ferroalloys and metal to metallurgical end uses in short tons of contained chromium is divided proportionally among the various end uses based on their gross weight fraction of the total reported gross consumption in that year.
- The ratio of apparent consumption to reported consumption in any end use also is proportional to the ratio of total apparent consumption to total reported consumption in that year.

Then $$F_n^y = RPC_n^y / TCG^y, \qquad \text{(A-10)}$$

where RPC_n^y = metallurgical industry reported consumption of chromium ferroalloys and metal reporting to end use n in year y, short tons gross weight (*2*).

and TCG^y = metallurgical industry reported consumption of chromium ferroalloys and metal reporting to all end uses in year y, short tons gross weight (*2*).

Then $$EAC_n^y = F_n^y \times MC^y \times 0.907185, \qquad \text{(A-11)}$$

where EAC_n^y = apparent consumption allocated to metallurgical end use n,

MC^y = apparent consumption of chromium in year y,

and 0.907185 = number of metric tons per short ton.

Then, the data in table A-4 were determined by applying equations A-10 and A-11 to the data in the appropriate tables of Minerals Yearbook chromium chapter for year y.

Table A-3.—Estimated life span of chromium-bearing industry products

Product	Life span, years	Reference	Year of manufacture[1]
Steels:			
Carbon	[2]10	20	1979
SHR	5	4	1984
Alloy	5	4	1984
HSLA	5	4	1984
Tool	5	4	1984
Cast irons	[2]10	20	1979
Superalloys	5	4	1984
Welding materials	5	4	1984
Other alloys	[3]10	4	1979
Miscellaneous and unspecified	[4]5	NAp	1984
Chemicals	([5])	NAp	NAp
Refractories	[6]<1	NAp	1989

NAp Not applicable.

[1] The year in which products that became obsolete in 1989 were manufactured.

[2] Assumed to be 10 years based on estimates of automobile life spans and the high content of cast iron (engines) and carbon steel (bodies and frames), and also based on the life span of many appliances and pieces of equipment.

[3] Assumed to be 10 years based on high content of magnetic alloys in this category.

[4] Based on the most frequent life spans of metal products in other industries.

[5] Chemical end products are assumed to go into dissipative or nonrecyclable end uses.

[6] Life spans of less than 1 year with the exception of some special refractories used in the glass industry. Thus, products are recycled in the same year they are consumed.

Table A-4.—Material potentially available for recycle in 1989

Industry	Industry reported consumption to end use n, gross weight, st	Fraction of industry reported consumption in year y	Apparent consumption allocated to end use *n* in year y, mt contained Cr
1979:[1]			
Carbon steels	8,064	0.01485	5,859
Cast irons	15,558	0.02865	11,304
Other alloys	6,242	0.01150	4,535
1980:[2]			
SHR steels	313,070	0.78061	231,463
Alloy steels	38,846	0.09686	28,720
HSLA steels	9,671	0.02411	7,150
Tool steels	4,977	0.01241	3,680
Superalloys	11,529	0.02875	8,524
Welding materials	1,347	0.00336	996
Miscellaneous and unspecified	2,346	0.00585	1,734
1989: Refractories[3]	NA	NA	11,832

NA Not available.

[1] For 1979, total apparent consumption was 586,000 st, and total reported consumption was 436,000 st (*32-33*).

[2] For 1984, total apparent consumption was 403,000 st, and total reported consumption was 286,000 st (*23, 34*).

[3] See equation A-5.

The apparent consumption of chromium-containing materials and the obsolete material potentially available for recycling during 1989 are shown in table A-5.

Now the consumption data and losses of chromium in each industry must be calculated.

Table A-5.—Apparent consumption and potentially available recyclable material by end use industry in 1989, metric tons of contained chromium

Industry	Apparent consumption	Potentially recyclable material
Carbon steels	7,776	5,859
SHR steels	294,423	231,463
Alloy steels	33,453	28,720
HSLA steels	13,049	7,150
Tool steels	4,370	3,680
Cast irons	7,454	11,304
Superalloys	12,251	8,524
Welding materials	1,208	996
Other alloys	4,105	4,535
Miscellaneous and unspecified	611	1,734
Chemicals	60,210	(1)
Refractories	11,832	[2]11,060

[1] Chemical end products are assumed to go into dissipative or nonrecyclable end uses.

[2] The value here is the net material found in the 1989 final refractory products.

SUPERALLOYS

Recent data on superalloy chromium consumption, wastes, and recycling were reported by Papp (*28*). The combined data for cast and wrought superalloys are separated by category in table A-6. Then the following equations give the amounts in each category.

Table A-6.—Superalloy chromium consumption and recycling

Category	Cr content, st	Factor[1]	Contained Cr, mt
Primary chromium	55.10	0.82671	10,128
Obsolete scrap	11.55	0.17329	2,123
Prompt scrap	22.60	0.33908	4,154
Home scrap	62.50	0.93773	11,488
Processing losses	1.20	0.01800	221
Processing-downgraded scrap	2.05	0.03076	377
Processing feed to manufacturing	86.00	1.29032	15,808
Manufacturing losses	7.14	0.10713	1,312
Manufacturing-downgraded scrap	9.13	0.13698	1,678
Prompt scrap to export	8.33	0.12498	1,531
Final products	38.80	0.58215	7,132

[1] Based on raw feed (primary chromium + obsolete scrap = 66.65) being equal to 1.

Assuming that apparent consumption in all cases is equal to primary chromium plus obsolete scrap and that this fraction is 1.00000,

then $C_n = D_n \times 12{,}251,$ (A-12)

where C_n = chromium contained in category, metric tons,

D_n = factor for each category,

and 12,251 = 1989 apparent consumption of chromium in superalloys, contained chromium, metric tons.

The quantity for 1989 consumption and recycling is shown in table A-6.

Because there are no data on recovery losses, the recovery and recycling losses must be worked backwards. There is a 10-pct loss of material during recycling.

Thus $R = S \times 2{,}123/T,$ (A-13)

where R = feed to recycling,

S = 100 pct (total feed to recycling),

T = 90 pct (fraction recycled),

and 2,123 = obsolete scrap recycled, metric tons.

Therefore, $R = 100 \times 2{,}123/90$

$= 2{,}359$ mt of chromium.

Then $U = R \times 0.1,$ (A-14)

where U = recycling loss, metric tons,

and 0.1 = fraction of recovered material lost during recycling (*28*).

Therefore, $U = 2{,}359 \times 0.1$

$= 236$ mt of contained chromium.

Note: This also can be calculated as follows:

$U = R - 2{,}123,$

$U = 2{,}359 - 2{,}123$

$= 236$ mt of contained chromium.

Then $V = Q - R,$ (A-15)

where V = unknown and unrecovered losses, metric tons,

and Q = 1984 apparent consumption of chromium in superalloys that is potentially available for recycling, metric tons.

Therefore, $V = 8{,}524 - 2{,}359$

$= 6{,}165$ mt of contained chromium.

Now, various categories have fractions reporting as grindings, mixed scrap, solid scrap, turnings, dust, and waste. The categories are broken down using the following equations.

Then $$W_n = TC \times GS_n/GX, \qquad \text{(A-16)}$$

where W_n = contained chromium in fraction, metric tons,

GS_n = portion of material in each category,

GX = total material in category,

and TC = contained chromium in total category.

Applying this equation to data from Papp (*28*) results in values shown in table A-7.

STAINLESS AND HEAT-RESISTANT STEELS

This industry is the major consumer of chromium-containing prompt and obsolete scrap. From published 1989 data, there was a secondary production from prompt and obsolete scrap containing 99,221 mt of chromium. The only obsolete scrap of any significance that is recycled for its chromium content is superalloy and SHR scrap.

Thus $$Y = Z - AA, \qquad \text{(A-17)}$$

where Y = chromium contained in obsolete scrap recycled to SHR production, metric tons,

Z = total chromium contained in recycled obsolete scrap (secondary production),

and AA = chromium contained in recycled obsolete scrap that went to superalloys, metric tons.

Therefore, $Y = 99{,}221 - 2{,}123$

$= 97{,}098$ mt of chromium.

Total chromium consumed in SHR steels in 1989 was 294,423 mt.

Table A-7.—Breakdown of scrap and waste categories by component

Category and item	Portion of material in item	Contained Cr, mt
Home scrap:		
Grindings	1.8	331
Mixed scrap	3.6	662
Solid scrap	50.5	9,282
Turnings	6.6	1,213
Total	62.5	11,488
Processing losses: Dust	1.2	221
Processing-downgraded scrap:		
Grindings	0.8	147
Mixed scrap	1.25	230
Total	2.05	377
Manufacturing prompt scrap to processing:		
Solids	16.0	2,941
Turnings	6.6	1,213
Total	22.6	4,154
Manufacturing losses (waste):		
Grindings	0.93	228
Waste	4.1	1,007
Unknown	0.31	76
Total	5.34	1,311
Manufacturing-downgraded scrap:		
Grindings	2.45	494
Solid scrap	2.1	423
Turnings	3.3	665
Unknown	0.48	97
Total	8.33	1,679
Manufacturing prompt scrap exports:		
Grindings	2.45	450
Solid scrap	2.10	386
Turnings	3.3	607
Unknown	0.48	88
Total	8.33	1,531

Then $$AD = AE - Y, \qquad \text{(A-18)}$$

where AD = primary chromium, metric tons,

and AE = total chromium consumed in SHR steels, in 1989, metric tons.

Therefore, $AD = 294{,}423 - 97{,}098$

$= 197{,}325$ mt.

Data in NMAB-335 show that the quantities of chromium in a 100-st SHR steel ingot are as follows (*18*) (in short tons):

Chromium from ferrochromium ...	7.1
Chromium from obsolete scrap	3.94
Chromium from home scrap	6.56
Chromium loss in slag	1.2

Other data show the ratio of chromium from prompt scrap to chromium from raw material (primary chromium and chromium from obsolete scrap) is 0.1/0.6 (*4, 18*).

Thus $$AF = 0.1 \times AG/0.6, \qquad \text{(A-19)}$$

where AF = short tons of chromium from prompt scrap for 100-st ingot,

0.1/0.6 = ratio of chromium from prompt scrap to chromium from raw material,

and AG = short tons of chromium in feed to 100-st ingot from raw material (primary chromium + chromium from obsolete scrap).

Therefore, $$AF = 0.1 \times 11.04/0.6$$

$$= 1.84 \text{ st of chromium.}$$

Now $$AH = 0.03 \times (AG + AF)/(0.6 + 0.1), \qquad \text{(A-20)}$$

where AH = chromium in processing-downgraded scrap, short tons,

0.03 = relative amount of processing downgraded scrap (*4*),

0.6 = amount of raw material (primary chromium + chromium from obsolete scrap) (*4*),

and 0.1 = relative amount of prompt scrap (*4*),

$$AH = 0.03 \times (11.04 + 1.84)/(0.6 + 0.1)$$

$$= 0.552 \text{ st chromium in processing-downgraded scrap.}$$

Relative amount of processing loss material during the production of a 100-st ingot = chromium loss in slag = 1.2 st (*18*).

Then $$AI = (AG + 6.56 + AF) - (1.2 + 6.56 + AH), \qquad \text{(A-21)}$$

where AI = chromium in processing feed to manufacturing, short tons,

6.56 = chromium in home scrap, short tons,

and 1.2 = chromium in processing loss material, short tons.

Therefore, $$AI = (11.04 + 6.56 + 1.84) - (1.2 + 6.56 + 0.552)$$

$$= 11.128 \text{ st of contained chromium in processing feed to manufacturing.}$$

Manufacturing output is prompt scrap (AF), manufacturing-downgraded scrap, manufacturing losses, and final products. Because AF is 1.84 st of chromium,

then $$AJ = AI - AF, \qquad \text{(A-22)}$$

where AJ = manufacturing-downgraded scrap + manufacturing losses + final product

$$= 11.128 - 1.84$$

$$= 9.288 \text{ st of contained chromium.}$$

From literature data, the relative amount of metal is 30 st in manufacturing-downgraded scrap, 3st in manufacturing losses, and 128 st in final products (*4, 21*). The relative total amount of metal in these three categories is 161 st.

Then for each category,

$$HA_n = HB_n \times HC/HD, \qquad \text{(A-23)}$$

where HA_n = contained chromium in each fraction in short tons relative to production of 100-st ingot of SHR steel,

HB_n = relative amount of metal in each fraction,

HC = contained chromium in manufacturing-downgraded scrap in manufacturing losses + in final products, short tons,

and HD = relative total amount of metal in all three categories.

For manufacturing-downgraded scrap (HA_{ds}),

$$HA_{ds} = 30 \times 9.288/161$$

$$= 1.731 \text{ st of chromium.}$$

For manufacturing losses (HA_{ml}),

$$HA_{ml} = 3 \times 9.288/161$$

$$= 0.173 \text{ st of chromium.}$$

For final products (HA_{fp}),

$$HA_{fp} = 128 \times 9.288/161$$

$$= 7.384 \text{ st of chromium.}$$

Based on the relative amounts calculated and given for contained chromium in each category for a 100-st SHR steel ingot, the relative fractions based on raw material flow (primary chromium + chromium from obsolete scrap) being equal to 1, and the estimated amounts in 1989 chromium consumption in SHR steel, the following equations result:

$$HE_n = HF \times HG_n/HH, \qquad \text{(A-24)}$$

where HE_n = amount of chromium contained in each category in 1989 flow model for SHR steel, metric tons,

HF = total amount of chromium in raw material (primary chromium and chromium from obsolete scrap) consumed in 1989, metric tons,

HG_n = relative amount in each category for 100-st ingot,

and HH = total relative amount in raw material (primary chromium + chromium from obsolete scrap), short tons.

Applying equation A-24 for each category calculates the amount of contained chromium in each category for 1989 apparent consumption of chromium in SHR steel. The results are shown in table A-8.

Minerals Yearbook 1989 data on chromium show that total secondary production (obsolete scrap) was 99,221 mt of contained chromium (*25*). Previous estimations show that chromium in obsolete scrap consumed in superalloy production was 2,123 mt of contained chromium.

Table A-8.—Amount of chromium in various fractions in 1989 consumption flow model for stainless and heat-resistant steels

Category	Relative amount of contained Cr in 100-st ingot, st	Fraction[1]	Contained Cr in each category in 1989 flow, mt
Primary chromium	7.1	0.64312	189,348
Obsolete scrap	3.94	0.35688	105,075
Prompt scrap	1.84	0.16667	49,071
Home scrap	6.56	0.59420	174,947
Processing losses	1.2	0.10870	32,003
Processing-downgraded scrap	0.552	0.05000	14,721
Processing feed to manufacturing	11.128	1.00797	296,770
Manufacturing losses	0.173	0.01567	4,614
Manufacturing-downgraded scrap	1.731	0.15679	46,164
Final products	7.384	0.66884	196,922

[1] Based on primary chromium + obsolete scrap being equal to 1.

Then $AK = AL - AM$, (A-25)

where AK = chromium in obsolete scrap consumed by SHR steel in 1989, metric tons,

AL = chromium in secondary production, metric tons,

and AM = chromium in obsolete scrap consumed by superalloys in 1989, metric tons.

Therefore, $AK = 99{,}221 - 2{,}123$

$= 97{,}098$ mt of contained chromium.

Then $AN = AO - AK$, (A-26)

where AN = chromium in primary material, metric tons,

and AO = chromium in raw materials (primary chromium metal and ferroalloys), metric tons.

Therefore, $AN = 294{,}423 - 97{,}098$

$= 197{,}325$ mt of contained chromium.

These values for recycled obsolete scrap and primary chromium feed are used in the flow model for SHR steel.

The lifetime for SHR steel is estimated as 5 years (*4*). Thus, the obsolete scrap available for recycle in 1989 is from 1984 SHR steel production. The reported consumption of chromium ferroalloys, metal, and obsolete scrap in 1984 was 313,070 st gross weight, and the total material in 1984 in metallurgical end uses was 401,057 st gross weight (*34*). The total contained chromium consumed in 1984 for metallurgical end uses was 231,959 st (*34*).

Then $$AP = AQ \times AR/AS, \qquad \text{(A-27)}$$

where AP = reported consumption of chromium in 1984 in SHR steel, short tons of contained chromium,

AQ = reported consumption of material for SHR steel in 1984, short tons gross weight,

AR = total reported consumption of contained chromium for metallurgical end uses in 1984, short tons,

and AS = reported total consumption of materials in metallurgical end uses in 1984, short tons gross weight.

Therefore, $AP = 313{,}070 \times 231{,}959/401{,}057$

$= 181{,}070$ st of contained chromium.

Then $$AT = AP \times AV/AW, \qquad \text{(A-28)}$$

where AT = 1984 apparent consumption of chromium in SHR steel, short tons of contained chromium,

AV = 1984 total apparent consumption of chromium, short tons of contained chromium,

and AW = 1984 total reported consumption of chromium, short tons of contained chromium.

Therefore, $AT = 181{,}070 \times 447{,}000/315{,}000$

$= 256{,}947$ st of contained chromium consumed in 1984 apparent consumption of chromium in SHR steel.

Then $$AX = AT \times 0.907185, \qquad \text{(A-29)}$$

where AX = 1984 apparent consumption of material for SHR steel potentially available for recycle in 1989, metric tons of contained chromium,

and 0.907185 = conversion factor, short ton to metric ton.

Therefore, $AX = 256{,}947 \times 0.907185$

$= 231{,}463$ mt of contained chromium.

Now, since material containing 97,098 mt of chromium was recycled in 1989 in SHR steel and an estimated 10 pct of material is lost during recycling,

then $$AY = 97{,}098 \times 10/90, \qquad \text{(A-30)}$$

where AY = contained chromium in recycling loss material,

97,098 = metric tons of contained chromium in 1984 recycled materials for SHR steel,

10 = percent lost in recycling,

and 90 = percent recycled.

Therefore, $AY = 97{,}098 \times 10/90$

$= 10{,}789$ mt.

Then, recycling feed was equal to 97,098 mt + 10,789 mt, or 107,887 mt of contained chromium.

Then $$AZ = AX - 107{,}887, \qquad \text{(A-31)}$$

where AZ = export, unknown, and unrecovered losses of material potentially available for recycle, metric tons of contained chromium.

Therefore, $AZ = 231{,}463 - 107{,}887$

$= 123{,}576$ mt of contained chromium.

About 292,000 st gross weight of SHR steel was exported in 1989 (*26*). The estimated average chromium content of SHR steel is 16.4 pct (*18*).

Then $BB = BC \times BD \times 0.907185$, (A-32)

where BB = exported SHR steel material, metric tons of contained chromium,

BC = average chromium content of SHR steel,

BD = SHR steel material exported, short tons gross weight,

and 0.907185 = conversion factor, short ton to metric ton.

Therefore, $BB = 0.164 \times 292{,}000 \times 0.907185$

= 43,443 mt of contained chromium exported in SHR steel in 1989.

Then $BE = AZ - BB$, (A-33)

where BE = unknown and unrecovered losses of material potentially available for recycle, metric tons of contained chromium.

Therefore, $BE = 123{,}463 - 43{,}443$

= 80,133 mt of contained chromium.

ALLOY STEELS

The typical alloy steel furnace charge contains primary chromium, prompt scrap, obsolete scrap, and home scrap. The chromium content of obsolete scrap is unknown and thus not shown here. Estimates of relative fractions of these materials put home scrap at 11 pct and prompt scrap at 3.91 pct (*18*).

Then $BF = BG \times BH/BI$, (A-34)

where BF = prompt scrap, metric tons of contained chromium,

BG = primary material, metric tons of contained chromium,

BH = percent chromium in prompt scrap in charge,

and BI = percent chromium in primary chromium (100 - 3.91 - 11 = 85.09).

Therefore, $BF = 33{,}453 \times 3.91/85.09$

= 1,537 mt of contained chromium in prompt scrap.

Now $BJ = BG \times BK/BI$, (A-35)

where BJ = home scrap, metric tons of contained chromium,

and BK = percent chromium in home scrap in charge.

Therefore, $BJ = 33{,}453 \times 11/85.09$

= 4,325 mt of contained chromium in home scrap.

Then $BL = BG + BF + BJ$, (A-36)

where BL = processing feed (furnace charge), metric tons of contained chromium.

Therefore, $BL = 33{,}453 + 1{,}537 + 4{,}325$

= 39,315 mt of contained chromium.

Then $BM = BL \times BN/BO$, (A-37)

where BM = processing loss, metric tons of contained chromium,

BN = relative portion of processing losses (*4*),

and BO = relative portion of processing feed (*4*).

Therefore, $BM = 39{,}315 \times 0.03/0.7$

= 1,685 mt of contained chromium in processing losses.

Then $BP = BL \times BQ/BO$, (A-38)

where BP = processing downgraded scrap, metric tons of contained chromium,

and BQ = relative portion of processing downgraded scrap (*4*).

Therefore, $BP = 39{,}315 \times 0.03/0.7$

= 1,685 mt of contained chromium in processing downgraded scrap.

Then $BR = BL - BJ - BM - BP,$ (A-39)

where BR = processing feed to manufacturing, metric tons of contained chromium.

Therefore, $BR = 39{,}315 - 4{,}325 - 1{,}685 - 1{,}685$

$= 31{,}620$ mt of contained chromium.

Then $BS = BR \times BT/BU,$ (A-40)

where BS = manufacturing loss, metric tons of contained chromium,

BT = relative portion of manufacturing loss (*4*),

and BU = relative portion of processing feed to manufacturing (*4*).

Therefore, $BS = 31{,}620 \times 0.1/0.64$

$= 4{,}941$ mt of contained chromium in manufacturing losses.

Then $BV = BR \times BW/BU,$ (A-41)

where BV = manufacturing-downgraded scrap, metric tons of contained chromium,

and BW = relative portion of manufacturing-downgraded scrap (*4*).

Therefore, $BV = 31{,}620 \times 0.1/0.64$

$= 4{,}941$ mt of contained chromium in manufacturing-downgraded scrap.

Then $BX = BR - BF - BS - BV,$ (A-42)

where BX = final products, metric tons of contained chromium.

Therefore, $BX = 31{,}620 - 1{,}537 - 4{,}941 - 4{,}941$

$= 20{,}201$ mt of contained chromium in final product.

There is no recycling of alloy steels specifically for their chromium content, and there are no data available. Thus, all material potentially available for recycling is assumed to report to unknown and unrecovered losses.

CARBON STEELS

The flow model for this end use has the same relative portions as the flow model for alloy steel. The flow model data are calculated as follows:

Assume chromium in raw materials equals 1.00 in the alloy steels flow model.

Then $BY_n = BZ_n/BG,$ (A-43)

where BY_n = relative fraction in each category,

BZ_n = quantity in each category for alloy steels, metric tons of contained chromium,

and BG = chromium contained in alloy steel products, metric tons of contained chromium.

For example, for prompt scrap the following would apply:

$BY_n = BZ_n/BG$

$= 1{,}537/33{,}453$

$= 0.04595$ mt (fraction in prompt scrap).

Then $CA_n = BY_n \times CB,$ (A-44)

where CA_n = material in each category, metric tons of contained chromium,

and CB = prompt scrap consumed by carbon steel, metric tons of contained chromium.

Therefore, $CA_n = 0.04595 \times 7{,}776/1.65601$

$= 357$ mt of contained chromium in prompt scrap.

The results of equations A-43 and A-44 for carbon steels are shown in table A-9.

HIGH-STRENGTH LOW-ALLOY STEELS

The flow model for this end use has the same relative portions as the flow model for alloy steels and carbon steels. The flow data are calculated in the same way as the data for carbon steel. The data are summarized in table A-9.

Table A-9.—Amount of chromium in various steels, metric tons of contained chromium

Category	Factor[1]	Alloy steel	Carbon steel	HSLA steel	Tool steel
Primary chromium	1.00000	33,453	7,776	13,049	4,370
Prompt scrap	0.04595	1,537	357	600	201
Home scrap	0.12929	4,325	1,005	1,687	565
Processing losses	0.05037	1,685	392	657	220
Processing-downgraded scrap	0.05037	1,685	392	657	220
Processing feed to manufacturing	0.94521	31,620	7,350	12,334	4,131
Manufacturing losses	0.14770	4,941	1,149	1,927	645
Manufacturing-downgraded scrap	0.14770	4,941	1,149	1,927	645
Final product	0.60386	20,201	4,696	7,880	2,639

[1] Based on raw materials being equal to 1.

TOOL STEELS

The flow model for this end use has the same relative portions as the flow model for alloy steels. The flow model data are calculated in the same way as for carbon steel. The data are summarized in table A-9.

CAST IRONS

The estimated values for prompt scrap and home scrap are 14.8 pct and 3.91 pct of furnace charge (*18*).

Then $$CD = 1.00 - CE - CF, \tag{A-45}$$

where CD = relative fraction for feed from primary chromium,

1.00 = total feed to processing (furnace charge),

CE = relative fraction for feed from prompt scrap (0.148),

and CF = relative fraction for feed from home scrap (0.0391).

Therefore, $CD = 1.00 - 0.148 - 0.0391$

$= 0.8129.$

Then $$CG = CD \times CH/CI, \tag{A-46}$$

where CG = relative fraction for processing loss,

CH = relative fraction for processing loss from NMAB-406 (*4*),

and CI = relative fraction for primary material from NMAB-406 (*4*).

Therefore, $CG = 0.8129 \times 0.03/0.6$

$= 0.040645.$

Then $$CJ = CD + CK - CG, \tag{A-47}$$

where CJ = relative fraction for processing feed to manufacturing,

and CK = relative fraction for prompt scrap.

Therefore, $CJ = 0.8129 + 0.148 - 0.040645$

$= 0.920255.$

Then $$CL = CJ \times CM/CN, \tag{A-48}$$

where CL = relative fraction reporting to manufacturing waste,

CM = relative fraction of material reporting to manufacturing waste from NMAB-406 (*4*),

and CN = relative fraction of processing feed reporting to manufacturing from NMAB-406 (*4*).

Therefore, $CL = 0.920255 \times 0.01/0.64$

$= 0.014379.$

Then $$CP = CJ - CE - CL, \tag{A-49}$$

where CP = relative fraction reporting to final products.

Therefore, $CP = 0.920255 - 0.148 - 0.014379$

$= 0.757876.$

Then $$CQ_n = CS_n/0.81290, \tag{A-50}$$

where CQ_n = final relative fraction in each category with raw material (0.81290) equal to 1.00,

CS_n = initial fraction in each category,

and 0.81290 = initial fraction of raw material equals 1.00.

These results are shown in table A-10.

Then $CT_n = CQ_n \times 7{,}454$, (A-51)

where CT_n = amount of contained chromium in each category,

and 7,454 = 1989 apparent consumption of chromium in cast irons.

The results of equation A-51 are also shown in table A-10.

Table A-10.—Fraction of material and amount of contained chromium in each category for cast irons

Category	Initial fraction	Final fraction[1]	Contained Cr, mt
Primary chromium	0.8129	1.00000	7,454
Prompt scrap	0.148	0.18206	1,357
Home scrap	0.0391	0.04810	359
Processing losses	0.040645	0.05000	373
Processing feed to manufacturing	0.920255	1.13206	8,438
Manufacturing losses	0.014379	0.01769	132
Final products	0.757876	0.93231	6,949

[1] Based on primary chromium being equal to 1.

WELDING AND HARDFACING MATERIALS

The flow model is based on NMAB data (*4*), where the fraction reporting to primary chromium is 0.50 and the fraction reporting to prompt scrap is 0.23. From another NMAB source, the fraction reporting to home scrap is 0.148 of total feed to processing (*2*). Then, the remaining part of total feed to processing (0.50 + 0.23 = 0.73) is equal to 1.00 - 0.148 or 0.852.

Then $CV = CW \times CX/CY$, (A-52)

where CV = relative fraction reporting to home scrap,

CW = NMAB fraction reporting to home scrap,

CX = relative fraction of primary chromium + relative fraction of prompt scrap,

and CY = NMAB fraction reporting to primary chromium + NMAB fraction reporting to prompt scrap.

Therefore, $CV = 0.148 \times 0.73/0.852$

$= 0.12681$ (fraction reporting to home scrap on the same basis as 0.50 is the primary chromium fraction and 0.23 is the prompt scrap fraction).

Data in the literature state that the fraction for loss in slag, dust, etc., is 0.125 of total feed to processing (*8*).

Then $CZ = DA \times DB$, (A-53)

where CZ = relative fraction reporting to processing loss,

DA = NMAB fraction reporting to processing loss,

and DB = total relative fraction reporting to processing feed (primary chromium + prompt scrap + home scrap).

Therefore, $CZ = 0.125 \times (0.50 + 0.23 + 0.12681)$

$= 0.10710.$

Then $DC = DB - CV - CZ - 0.06$, (A-54)

where DC = relative fraction of processing feed reporting to manufacturing,

and 0.06 = relative fraction reporting to processing-downgraded scrap (*4*).

Therefore, $DC = (0.50 + 0.23 + 0.12681) - 0.12681$

$- 0.10710 - 0.06$

$= 0.56290.$

Then $DD = DC \times 0.02/0.62$, (A-55)

where DD = relative fraction reporting to manufacturing loss,

and 0.02/0.62 = NMAB fraction of processing feed to manufacturing that reports to manufacturing loss (*4*).

$DD = 0.56290 \times 0.02/0.62$

$= 0.01816.$

Then $DE = DC - 0.23 - DD$, (A-56)

where DE = relative fraction reporting to final products,

and 0.23 = relative fraction reporting to prompt scrap (*4*).

Therefore, $DE = 0.56290 - 0.23 - 0.01816$

$= 0.31474.$

Then $$DF_n = DG_n/0.50000, \tag{A-57}$$

where DF_n = final relative fraction of category with primary chromium (0.50000) equal to 1.00000,

DG_n = initial fraction in each category,

and 0.50000 = initial relative fraction reporting to primary chromium.

The final fractions come from applying equation A-57 and are shown in table A-11.

Then $$DH_n = DF_n \times 1{,}208, \tag{A-58}$$

where DH_n = metric tons of contained chromium in each category,

and 1,208 = 1989 apparent consumption in welding and hardfacing materials.

The results of equation A-58 are also shown in table A-11.

Table A-11.—Fraction of material and amount of contained chromium in each category for welding and hardfacing materials

Category	Initial fraction	Final fraction[1]	Contained Cr, mt
Primary chromium	0.5	1.00000	1,208
Prompt scrap	0.23	0.46000	556
Home scrap	0.12681	0.25362	306
Processing losses	0.10710	0.21420	259
Processing-downgraded scrap	0.06	0.12000	145
Processing feed to manufacturing	0.56290	1.12580	1,360
Manufacturing losses	0.01816	0.03632	44
Final products	0.31474	0.62948	760

[1] Based on primary chromium being equal to 1.

OTHER ALLOYS

The flow model for this industry is similar to the flow model for other alloys in NMAB-406 (*4*). The assumption is made that there is no significant downgraded material produced. Literature data state that home scrap is about 14.8 pct of the total furnace charge (*18*); thus, prompt scrap and primary chromium equal 85.2 pct of the charge.

Then $$DJ = (0.148 \times (0.1 + 0.6))/0.852, \tag{A-59}$$

where DJ = relative fraction of home scrap,

0.148 = fraction of home scrap in total processing furnace charge (*18*),

0.1 = relative fraction of prompt scrap in processing furnace charge,

0.6 = relative fraction of primary chromium in processing furnace charge,

and 0.852 = fraction of prompt scrap + fraction of primary chromium in processing furnace charge.

Therefore, $DJ = 0.12160$ (relative fraction of home scrap).

Literature data state that the average amount of chromium lost in a melt to slag, dust, etc., is 12.5 pct, or a fraction of 0.125 (*35*).

Then $$DK = (DM + DN + DJ) \times 0.125, \tag{A-60}$$

where DK = relative fraction of processing losses,

DM = relative fraction of primary chromium in furnace charge,

DN = relative fraction of prompt scrap in furnace charge,

and 0.125 = fraction of furnace charge in processing losses.

Therefore, $DK = (0.6 + 0.1 + 0.12160) \times 0.125$

$= 0.10270.$

Then $$DO = (DM + DN + DJ) - DJ - DK, \tag{A-61}$$

where DO = relative fraction of processing feed to manufacturing.

Therefore, $DO = (0.6 + 0.1 + 0.12160) - 0.12160$

$- 0.10270$

$= 0.59730.$

Then $DP = DO \times 0.01/0.64,$ (A-62)

where DP = relative fraction of manufacturing losses,

0.01 = NMAB fraction of manufacturing losses (*4*),

and 0.64 = NMAB fraction of processing feed to manufacturing (*4*).

Therefore, $DP = 0.59730 \times 0.01/0.64$

$= 0.00933.$

Then $DQ = DO - DN - DP,$ (A-63)

where DQ = relative fraction reporting to final products.

Therefore, $DQ = 0.59730 - 0.1 - 0.00933 = 0.48797.$

Then $DR_n = DS_n/0.6,$ (A-64)

where DR_n = final relative fraction of each category with final materials equal to 1.00,

DS_n = initial relative fraction in each category,

and 0.6 = initial relative fraction of primary chromium.

The results of equation A-64 are shown in table A-12.

Table A-12.—Fraction of material and amount of contained chromium in each category for other alloys

Category	Initial fraction	Final fraction[1]	Contained Cr, mt
Primary chromium	0.6	1.00000	4,105
Prompt scrap	0.1	0.16667	684
Home scrap	0.12160	0.20266	832
Processing losses	0.10270	0.17117	703
Processing feed to manufacturing	0.59730	0.99550	4,087
Manufacturing losses	0.00933	0.01555	64
Final products	0.48797	0.81328	3,339

[1] Based on primary chromium being equal to 1.

Then $DT_n = DR_n \times DU,$ (A-65)

where DT_n = metric tons of contained chromium in each category,

and DU = 1989 apparent consumption of chromium in other alloys, metric tons of contained chromium.

The results of equation A-65 are also shown in table A-12.

MISCELLANEOUS AND UNSPECIFIED

The flow model for miscellaneous and unspecified materials, which was developed during work on the flow model for cobalt, is used for a starting point in deriving the flow model for chromium in this industry (*21*). Literature data show that the average fraction of home scrap in a metal melt is about 14.8 pct, or a fraction of 0.148 (*35*). Then the fraction of the other components of the furnace charge (primary chromium and prompt scrap) equals 0.852 (1.000 - 0.148).

Then $DV = (DW + DX) \times 0.148/0.852,$ (A-66)

where DV = portion of furnace charge that is home scrap,

DW = portion of furnace charge that is primary chromium (*21*),

DX = portion of furnace charge that is prompt scrap (*21*),

and $0.148/0.852$ = ratio of home scrap to sum of primary chromium + prompt scrap.

Therefore, $DV = (1{,}042 + 174) \times 0.148/0.852$

$= 211.230.$

The average chromium loss from a melt to slag, dust, etc. (processing losses) is about 12.5 pct of the furnace charge (*35*).

Then $DY = 0.125 \times (DV + DW + DX),$ (A-67)

where DY = portion of processing loss,

and 0.125 = average fraction of furnace charge that reports to processing losses (*37*).

Therefore, $DY = 0.125\ (211.23 + 1{,}042 + 174)$

$= 178.4038.$

The cobalt flow model for miscellaneous and unspecified materials gives processing-downgraded scrap an estimated value of 52 (*22*).

Thus $DZ = (DV + DW + DX) - DV - DY - EA,$ (A-68)

where DZ = portion of processing feed to manufacturing,

and EA = portion of material to processing-downgraded scrap.

Therefore, $DZ = (211.23 + 1{,}042 + 174) - 211.23 - 178.4038 - 52 = 985.5963.$

Then $EB = DZ \times 175/1{,}112,$ (A-69)

where EB = portion reporting to manufacturing-downgraded scrap,

and $175/1{,}112$ = ratio of manufacturing-downgraded scrap to manufacturing feed from processing (*22*).

Therefore, $EB = 985.5963 \times 175/1{,}112 = 155.1073.$

Then $ED = DZ \times 17/1{,}112,$ (A-70)

where ED = portion to manufacturing losses,

and $17/1{,}112$ = ratio of manufacturing losses to manufacturing feed from processing (*22*).

Therefore, $ED = 985.5963 \times 17/1{,}112 = 15.06757.$

Then $EE = DZ - DX - EB - ED,$ (A-71)

where EE = portion reporting to final products.

Therefore, $EE = 985.5963 - 174 - 155.1073 - 15.06757 = 641.4213.$

Then $EF_n = EG_n/1{,}042,$ (A-72)

where EF_n = final relative fraction of each category with primary chromium portion (1,042) equal to 1.00,

EG_n = initial portion in each category,

and 1,042 = initial portion of primary chromium.

The results of equation A-72 are shown in table A-13.

Then $EH_n = EF_n \times DX,$ (A-73)

where EH_n = metric tons of contained chromium in each category,

and DX = 1989 apparent consumption of chromium in miscellaneous and unspecified materials, metric tons of contained chromium (611 mt).

The results of equation A-73 are also shown in table A-13.

Table A-13.—Fraction of material and amount of contained chromium in each category for miscellaneous and unspecified materials

Category	Initial amount, mt	Final fraction[1]	Contained Cr, mt
Primary chromium	1,042	1.00000	611
Prompt scrap	174	0.16699	102
Home scrap	211.23	0.20272	124
Processing losses	178.4038	0.17121	105
Processing-downgraded scrap	52	0.04990	30
Processing feed to manufacturing	985.5963	0.94587	578
Manufacturing losses	15.0676	0.01446	9
Manufacturing-downgraded scrap	155.1073	0.14886	91
Final product	641.4213	0.61557	376

[1] Based on primary chromium being equal to 1.

CHEMICALS

NMAB states, "chemical processing is completed with yields of about 97 pct. In subsequent processing (manufacturing) yields are lower—on the order of 95 pct" (*4*). Thus, processing losses are about 3 pct of processing feed, and manufacturing losses are about 5 pct of manufacturing feed. There is essentially no scrap recycling in the chromium chemicals industry. Most end uses are dissipative in nature, i.e., printing inks, plating bath salts, leather tanning chemicals, etc.

Then $EI = EJ \times 0.03,$ (A-74)

where EI = fraction of material that is processing losses,

EJ = processing feed material (1.0),

and 0.03 = fraction of processing feed that goes to processing losses.

Therefore, $EI = 1 \times 0.03$

$= 0.03.$

Then $$EK = EJ - EI, \quad \text{(A-75)}$$

where EK = fraction of processing feed that goes to manufacturing.

Therefore, $EK = 1.0 - 0.03$

$= 0.97.$

Then $$EL = EK \times 0.05, \quad \text{(A-76)}$$

where EL = relative fraction of processing feed to manufacturing that goes to manufacturing losses,

and 0.05 = fraction of manufacturing feed that goes to manufacturing losses.

$EL = 0.97 \times 0.05$

$= 0.0485.$

Then $$FPR = EK - EL, \quad \text{(A-77)}$$

where FPR = relative fraction of manufacturing feed that goes to final products.

Therefore, $FPR = 0.97 - 0.0485$

$= 0.9215.$

Then $$LA_n = LB_n \times LC, \quad \text{(A-78)}$$

where LA_n = metric tons of contained chromium, in each category,

LB_n = fraction in each category,

and LC = 1989 apparent consumption of chromium in the chemical industry (60,210 mt).

The results of equation A-78 are shown in table A-14.

Table A-14.—Fraction of material and amount of contained chromium in each category for the chemical industry

Category	Fraction	Contained Cr, mt
Primary chromium	1	60,210
Processing losses	0.03	1,806
Processing feed to manufacturing	0.97	58,404
Manufacturing losses	0.0485	2,920
Final products	0.9215	55,484

REFRACTORIES

This industry uses chromite to manufacture refractory bricks and to produce foundry casting sands. There is essentially no recycle of used brick to make new brick. There is some recycle of foundry sands. NMAB states that chromite foundry sands are 90 pct recovered and 72 pct recycled (*18*). Using past data (1976), NMAB estimates that foundry sands consume 21,000 st/yr of chromium, and chromium-bearing refractories consume 19,000 st/yr (*18*).

Thus $$EO = 21{,}000/(21{,}000 + 19{,}000), \quad \text{(A-79)}$$

where EO = fraction of refractory chromite consumption that goes to foundry sands,

21,000 = portion of refractory chromite consumption that goes to foundry sands,

and 21,000 + 19,000 = total refractory chromite consumption (*18*).

Therefore, $EO = 21{,}000/(21{,}000 + 19{,}000)$

$= 0.525.$

Then $$EP = 19{,}000/(21{,}000 + 19{,}000), \quad \text{(A-80)}$$

where EP = fraction of refractory chromite consumption in chromium-bearing refractories,

and 19,000 = portion of refractory chromite consumption in chromium-bearing refractories.

Therefore, $EP = 19{,}000/(21{,}000 + 19{,}000)$

$= 0.475.$

The fractions of chromium consumed in yearly total consumption of chromite for refractories is assumed to still be valid and apply equally to total refractory apparent consumption in 1989.

Then $$EQ = EO \times ER, \quad \text{(A-81)}$$

where EQ = 1989 consumption of refractory chromite that goes to foundry sands, metric tons,

and ER = 1989 total apparent consumption of chromium in refractories, metric tons.

Therefore, EQ = 0.525 × 11,832

= 6,211.8 mt of contained chromium.

An amount equal to 8 pct of primary feed is assumed to be prompt scrap.

Then $ES = EQ \times 0.08,$ (A-82)

where ES = initial prompt scrap from foundry sands, metric tons,

and 0.08 = fraction of chromite that reports as prompt scrap.

Therefore, ES = 6,211.8 × 0.08

= 496.944 mt of contained chromium.

Home scrap is assumed to be an amount equal to 5 pct of primary chromium feed.

Then $ET = EQ \times 0.05,$ (A-83)

where ET = home scrap from foundry sands, metric tons,

and 0.05 = fraction of primary chromium that equals home scrap.

Therefore, ET = 6,211.8 × 0.05

= 310.59 mt of contained chromium.

Processing losses are assumed to be 3 pct of processing feed.

Then $EU = (EQ + ES + ET) \times 0.03,$ (A-84)

where EU = processing losses, metric tons,

and 0.03 = fraction of processing feed that reports to processing losses.

Therefore, EU = (6,211.8 + 496.944 + 310.59) × 0.03

= 210.58 mt of contained chromium.

Then $EV = (EQ + ES + ET) - EU - ET,$ (A-85)

where EV = processing feed to manufacturing, metric tons.

Therefore, EV = (6,211.8 + 496.944 + 310.59)

- 210.58 - 310.59

= 6,498.164 mt of contained chromium in processing feed to manufacturing.

Manufacturing losses are assumed to be about 3 pct of feed to manufacturing.

Then $EW = EV \times 0.03,$ (A-86)

where EW = manufacturing losses, metric tons,

and 0.03 = fraction of manufacturing feed that reports to manufacturing losses.

Therefore, EW = 6,498.164 × 0.03

= 194.9449 mt of contained chromium in manufacturing losses.

Then $EX = EV - EW - ES,$ (A-87)

where EX = final products, metric tons.

Therefore, EX = 6,498.164 - 194.9449 - 496.944

= 5,806.275 mt of contained chromium.

Then $EY = EX \times 0.90,$ (A-88)

where EY = amount of final product foundry sands recovered after casting, metric tons,

and 0.90 = fraction of final product foundry sands recovered.

Therefore, EY = 5,806.275 × 0.90

= 5,225.648 mt of contained chromium.

Then $EZ = EX - EY,$ (A-89)

where EZ = recovery losses of foundry sands, metric tons.

Therefore, EZ = 5,806.275 - 5,225.648

= 580.627 mt of contained chromium.

Then $FA = EY \times 0.72,$ (A-90)

where FA = amount of recovered foundry sands recycled, metric tons,

and 0.72 = fraction of recovered sands recycled.

Therefore, $FA = 5{,}225.648 \times 0.72$

$= 3{,}762.467$ mt of contained chromium.

Then $FB = EY - FA,$ (A-91)

where FB = recycling losses, metric tons.

Therefore, $FB = 5{,}225.648 - 3{,}762.467$

$= 1{,}463.181$ mt of contained chromium.

Thus, primary chromium feed to foundry sand consumption comes partly from recycled foundry sand, with the remainder as new chromite ore.

Then $FD = EQ - FA,$ (A-92)

where FD = new chromite feed to processing, metric tons of contained chromium.

Therefore, $FD = 6{,}211.8 - 3{,}762.467$

$= 2{,}449.333$ mt of contained chromium in primary chromium feed to foundry sands.

The other refractory use of chromite is in chromium-bearing refractories.

Then $FE = ER \times FF,$ (A-93)

where FE = chromite consumption in chromium-bearing refractories, metric tons of contained chromium,

ER = 1989 total apparent consumption of chromite in refractory industry, metric tons,

and FF = fraction of refractory industry apparent consumption of chromite for chromium-bearing refractories.

Therefore, $FE = 11{,}832 \times 0.475$

$= 5{,}620.2$ mt of contained chromium.

Then $FG = FE \times 0.08,$ (A-94)

where FG = prompt scrap from chromium-bearing refractories,

and 0.08 = fraction of primary chromium that reports as prompt scrap.

Therefore, $FG = 5{,}620.2 \times 0.08$

$= 449.616$ mt of contained chromium.

Then $FH = FE \times 0.05,$ (A-95)

where FH = home scrap from chromium-bearing refractories, metric tons,

and 0.05 = fraction of primary chromium that reports as home scrap.

Therefore, $FH = 5{,}620.2 \times 0.05$

$= 281.01$ mt of contained chromium.

Then $FI = (FE + FG + FH) \times 0.03,$ (A-96)

where FI = processing losses, metric tons,

and 0.03 = fraction of total processing feed that reports to processing losses.

Therefore, $FI = (5{,}620.2 + 449.616 + 281.01) \times 0.03$

$= 190.5248$ mt of contained chromium.

Then $FJ = (FE + FG + FH) - FH - FI,$ (A-97)

where FJ = processing feed to manufacturing, metric tons.

Therefore, $FJ = (5{,}620.2 + 449.616 + 281.01) - 281.01$

$- 190.5248$

$= 5{,}879.291$ mt of contained chromium.

Then $FK = FJ \times 0.03,$ (A-98)

where FK = manufacturing losses, metric tons,

and 0.03 = fraction of processing feed to manufacturing that reports to manufacturing losses.

Therefore, $FK = 5{,}879.291 \times 0.03$

$= 176.3787$ mt of contained chromium.

Then $$FL = FJ - FK - FG, \qquad \text{(A-99)}$$

where FL = final products, metric tons.

Therefore, $FL = 5{,}879.291 - 176.3787 - 449.616$

$= 5{,}253.296$ mt of contained chromium.

Because essentially no chromium-bearing refractories are recycled,

then $$FM = FL, \qquad \text{(A-100)}$$

where FM = unknown and unrecovered losses.

Therefore, $FM = 5{,}253.296$ mt of contained chromium.

The total components of the chromium refractory industry are shown in table A-15 (numbers rounded off).

Then $$FN_n = FO_n \,/\, 11{,}832, \qquad \text{(A-101)}$$

where FN_n = fraction of each category based on 1989 apparent consumption (primary chromium + obsolete scrap = 1.00000),

FO_n = portion of chromium in each category,

and $11{,}832$ = 1989 apparent consumption of chromium in refractories, metric tons.

The results of applying equation A-101 are also shown in table A-15.

OVERALL CHROMIUM INDUSTRY

This flow model was developed by summing the various categories from each flow model.

Table A-15.—Amount of contained chromium in each category for the chromium refractory industry, metric tons

Category	Foundry sands	Cr-bearing refractories	Total refractory industry[1]	Fraction[2] in each category
Primary chromium	2,449	5,620	8,070	0.68201
Obsolete scrap	3,762	0	3,762	0.31799
Prompt scrap	497	450	947	0.08000
Home scrap	311	281	592	0.05000
Processing losses	211	191	401	0.03390
Processing feed to manufacturing	6,498	5,879	12,377	1.04610
Manufacturing losses	195	176	371	0.03138
Final products	5,806	5,253	11,060	0.93472
Unknown and unrecovered losses	0	5,253	5,253	0.44399
Recovery losses	581	0	581	0.04907
Recovery feed to recycling	5,226	0	5,226	0.44165
Recycling losses	1,463	0	1,463	0.12366
Obsolete scrap feed to processing	3,762	0	3,762	0.31799

[1] Data may not add to totals shown due to independent rounding.
[2] Based on obsolete scrap + primary chromium being equal to 1.

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