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Trends in Usage of Chromium

A Report of the

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TRENDS IN USAGE
OF
CHROMIUM

REPORT OF
THE PANEL ON CHROMIUM
of the
COMMITTEE ON TECHNICAL ASPECTS OF CRITICAL AND STRATEGIC MATERIALS

NATIONAL MATERIALS ADVISORY BOARD
Division of Engineering - National Research Council

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ABSTRACT

Chromite ores of several grades (all imported are used by three industries:

1. Metallurgical—50% Cr_2O_3—for ferrochrome which is used primarily in stainless and alloy steels (61% of total Cr usage—growing 5% per year). Current ferrochrome practice uses in mix 75% of the highest quality ore (with Cr/Fe ratio in excess of 3/1 being desired), available mostly from Russia, Turkey, and Rhodesia (closed by sanctions). Stockpile releases have been supplementing requirements.

2. Chemical—45% Cr_2O_3—for pigments, plating, leather, foundry facings (16% of total Cr usage—growing 2.4% per year). Ore is primarily from South Africa and is in plentiful supply.

3. Refractory—34% Cr_2O_3—high alumina—for melting furnace linings (19% of total Cr usage—shrinking 4% per year). Ore from Philippines is in decreasing supply. Application is important but declining as open hearths are replaced by basic oxygen furnaces.

Potential substitutes and technical developments:

1. Metallurgical—There is no adequate replacement for chromium in corrosion, oxidation-resistant, or high temperature alloys. This lack of a possible alternate is unique among alloying elements: it may be possible to use something else in place of stainless steel, but stainless steel cannot be made without chromium. Limited quantity (5% of total stainless capacity) may be replaced by copper-nickel, or titanium-alloys at cost penalty. Decorative uses and alloy steel uses can generally be substituted. Emission control for autos may accelerate stainless growth by over 15%. New technology may partially circumvent requirement for highest quality ore.

2. Chemical—Most major applications can use other chemicals at some cost or performance penalty. Drilling muds are essential and have no known substitutes.

3. Refractory—Magnesite can be substituted for some applications, but chromite is necessary for others.

The many stockpile specifications for various ores and ferroalloys are reviewed, with some recommendations made for changes in the specifications along with recommendations regarding grades for holding and for disposal.

Of strategic importance is our current dependence on Russia for high quality metallurgical ore, and the danger of losing the output from the other major source, Rhodesia, if sanctions continue.

I. SUMMARY AND RECOMMENDATIONS

As summarized in Table 1, U. S. consumption of chromite falls into three principal categories, each requiring a different grade of ore: (1) metallurgical, about 50% Cr_2O_3, (2) chemical, about 45% Cr_2O_3, and (3) refractory, about 34% Cr_2O_3 with high alumina. All ore is imported; domestic supplies would cost three to four times as much, are of much lower quality, and would last only three to four years.(1) The metallurgical application is growing at an estimated 5% per year. Chemicals are expected to grow at 2.4% annually while the refractory use is decreasing 4% per year as open hearth furnaces are replaced by basic oxygen melting.

For the largest application (61% of total consumption), ferroalloy additions to stainless and alloy steels, a high quality ore is desired. Quality considerations include the physical nature (hard lump), a high Cr_2O_3 content (48% or better), a Cr/Fe ratio of over 3/1, and an MgO/Al_2O_3 ratio of 1.8 or below. These factors significantly affect the grade of ferroalloy produced, the conversion cost, and the output of the ferroalloy facility. In times of emergency, lower quality ores could be utilized but at a significant sacrifice in facility output of both the ferroalloy and steel furnaces and a substantial increase in cost. Of the Free World's supply of high-grade ore, 70% of the reserves in this quality are found in Rhodesia and it was a principal source until recent sanctions stopped all shipments. Currently, essentially all requirements for this grade are being obtained from Russia (over 50%), which has large high-quality reserves, from Turkey and from U.S. stockpile releases.

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(1) F. E. Brantley, Chromium Chapter, 1970 Mineral Facts and Problems, Bureau of Mines, U.S. Department of the Interior (Draft).

TABLE 1

Principal Sources and Applications of Chromite in U.S., 1967, by Grade of Ore(1)

Grade of Ore	Average % Cr_2O_3 in Ore	Ore Usage in 1000 short tons	Principal Reserves of Ore	Principal Applications	Growth %/yr(5)
Metallurgical; for ferroalloys and Cr metal	50.3%	818(2)		Stainless & alloy steels, jet engine alloys, castings, tool steel	+5%
	77% of net ore; Cr/Fe >3/1		Rhodesia, Russia, Turkey		
	14% of net ore; Cr/Fe = 2/1 to 3/1		Rhodesia, Russia Turkey, So. Africa		
	9% of net ore; Cr/Fe < 2/1		So. Africa		
Chemical	45.2%	234(3)	So. Africa Rhodesia	Pigments, plating, leather, foundry facings	+2.5%
Refractory	34.0%	340(4)	Philippines	Furnace linings	-4%

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(1) Source: "Chromium" by John L. Morning, Bureau of Mines Minerals Yearbook, 1967 (supplemented by additional data from the Panel).

(2) Actual usage of 50.3% ore. Ferroalloys also used 42,000 tons of chemical grade and 30,000 tons of refractory grade. Direct melting additions used 13,000 tons of chemical grade. These make totals of all ores for metallurgical usage: 818 + 42 + 30 + 13 = 903,000 tons.

(3) Actual usage of 45.2% ore. Of this, 55,000 tons went to metallurgical uses, including 42,000 tons to ferroalloys, and 13,000 tons to direct melt additions.

(4) Actual usage of 34.0% ore. Of this, 30,000 tons went into ferroalloys for metallurgical uses.

(5) See text for discussion and qualification of data in column.

Figure 1 illustrates the supply/demand relationships for all three grades of chromite ore. The South African and Philippines ores are used primarily for chemical and refractory purposes, and are economically unsuitable for most metallurgical purposes.

The historical consumption of chromite and its contained chromium are reviewed for the three industries in Table 2.

Table 3 summarizes data from the body of the report for 1968 and projected 1973 chromium use in principal applications, with estimated allowances for chromium recovery in recycled scrap, and resultant net new chromium requirements. Foundry facing sands which use the chemical grade of ore may experience rapid growth.

Table 4 translates the data from Table 3 into chromite ore requirements in 1968 and 1973, with growth rates indicated for each application. As described in the footnotes, an estimate was incorporated for recycled scrap, beneficiation losses, etc.

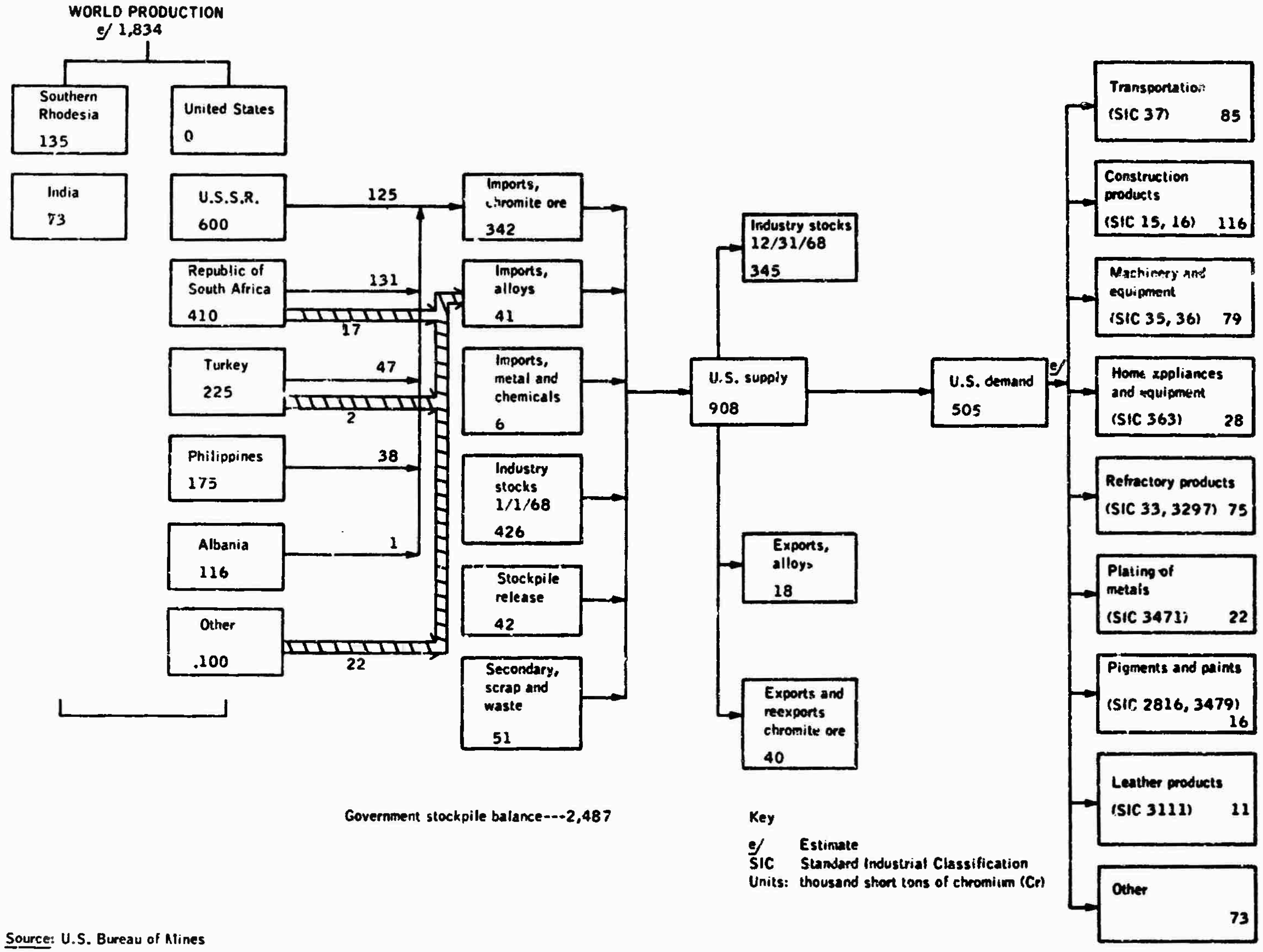
Table 5 summarizes chromium usage trends by major product, and Table 6 provides a similar summary by industry. The comments cover potential major substitutions and reasons for usage trends.

A technological development that could significantly affect chromium consumption is emission control devices for automobiles. These may employ ten pounds of additional stainless steel per car or 50,000 tons additional stainless product, equivalent to up to 25,000 tons additional chromite, required per year.

Recent developments in the technology of producing stainless steel which reduce the partial pressure of CO in the bath (by means of vacuum or inert gas purging) enable the use of cheaper high carbon ferrochrome and raise the recovery of chromium (to about 97%). These developments are projected to increase the consumption of high-carbon ferrochrome at the expense of low-carbon ferrochrome and ferrochrome-silicon. A licensor of one such process

Preliminary

Figure 1. - Supply-Demand Relationships for Chromium, 1968



Government stockpile balance---2,487

Key

e/ Estimate
SIC Standard Industrial Classification
Units: thousand short tons of chromium (Cr)

Source: U.S. Bureau of Mines

TABLE 2

U. S. Consumption of Chromite by Industry of Usage

Thousand Short Tons

Year	Metallurgical Total*	Metallurgical Cr Cont.	Refractory Total**	Refractory Cr Cont.	Chemical Total	Chemical Cr Cont.	Metallurgical Consumption as % of Total Chromite
1952	677	218	340	80	147	45	58
1953	743	236	441	101	152	46	56
1954	502	159	278	65	133	41	55
1955	994	316	431	101	159	49	63
1956	1212	388	475	112	160	50	66
1957	1177	379	435	104	148	46	67
1958	778	250	312	75	131	41	64
1959	796	252	379	91	162	50	60
1960	665	211	391	93	164	47	54
1961	662	211	375	89	163	51	55
1962	590	188	365	87	176	55	52
1963	632	210	368	87	187	58	53
1964	832	279	430	99	189	58	57
1965	907	309	460	109	217	67	57
1966	828	281	439	104	194	60	57
1967	866	294	310	72	179	55	63
1968	804	273	311	72	202	62	61

*Some part of the total, usually between 10,000 and 20,000 tons, was added directly to steel. The balance was used to make ferroalloys and Cr metal.

**A small quantity, usually between 5,000 and 10,000 tons, was in direct furnace repairs; the balance was used in making brick and other refractory products.

Source: Bureau of Mines Minerals Yearbooks

TABLE 3

Contribution of Scrap to Total Supply of Chromium in 1968 and 1973 (projected)

Thousand Short Tons

	1968			1973		
End Use	Total Cr Consumption	Net Cr from Scrap	Net Cr Needed After Allowance for Scrap	Total Cr Consumption	Net Cr from Scrap	Net Cr Needed After Allowance for Scrap
Metallurgical						
Stainless	263	100	163	342	137	205
Alloy	46	7	39	58	9	49
Tool	6	1	5	7	1	6
High-Temp.	21	2	19	31	4	27
Foundry	25	6	19	35	9	26
Misc.	2	0	2	3	0	3
Sub-Total	363	116	247	476	160	316
Refractory	74	0	74	60	0	60
Foundry Sands	8	0	8	20	0	20
Chemical	70	0	70	78	0	78
TOTAL	515	116	399	634	160	474

TABLE 4

Forecast Growth in Chromite and Chromium Consumption in the U. S.

Thousand Short Tons

	Chromite After Allowance for Scrap		% Change	Chromium Content After Allowance for Scrap	
	1968	1973		1968	1973
Stainless Steel	525	659	+26	163	205
Alloy Steel	125	157	+26	39	49
Tool Steels[1] (all types)	16	19	+19	5	6
High-Temp & Non-ferrous Alloys	61	87	+43	19	27
Foundries-Metallurgical	61	84	+38	19	26
Miscellaneous Metallurgical Applications [2]	6	10	+67	2	3
Sub-Total, Metallurgical	794[4]	1016	+28	247	316
Foundries-Facing Sand	26	65	+150	8	20
Refractories	310	250	-19	74	60
Chemicals[3]	226	254	+12	70	78
GRAND TOTAL	1356	1585	+17	399	474

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[1] Based on production of 96,000 tons of tool steel with an average Cr content of 6%.

[2] Includes cutting and wear-resistant materials, welding and hard facing rods and use in other steels.

[3] Consumption in chemicals market in 1968 was estimated at 149,000 tons of sodium dichromate equivalent. One ton of $Na_2Cr_2 . 2H_2O$ requires 1.4 tons of ore based upon an 80 to 85% recovery.

[4] This is calculated as 50% ore, but small quantities of chemical grade ore (44-45% Cr) and refractory grade ore (34-37% Cr) are used.

Notes:

a. The projection includes allowance for losses during use of the ferroalloys in metallurgical processing.

b. The projection includes an additional 10% loss for processing chromite into ferroalloys.

c. Average assay of ore for metallurgical uses is 50% Cr_2O_3.

d. Average assay of ore for refractory use is 35% Cr_2O_3 and no processing loss is assumed.

e. Average assay of ore for chemicals and facing sand uses is 45% Cr_2O_3.

TABLE 5

Future Chromium Usage Trends by Major Product

	Estimated Chromium Usage, 1968 (in tons)	Usage Trend 1968 - 1973	Potential Substitutions
Stainless Steel	263,000	Increasing	No major substitutes obvious for chemical process equipment or high temperature applications requiring corrosion or oxidation resistance. In small quantities (5% of total stainless capacity), copper-nickel or titanium-base alloys could be substituted at higher cost.
Alloy Steel	46,000	Increasing	Main markets are in the construction and automotive industries. Substitutions usually feasible.
Refractories	74,000	Decreasing	Due to rapid decline in use of open hearth furnace for steel manufacture. Magnesite can be substituted in some applications.
Chemicals	70,000	Increasing	Segments including pigments, plating, metal treatment, catalysis will increase. Use in leather tanning will decrease. Substitution in major uses is usually feasible at cost or performance penalty.
Foundry Applications Iron & Steel Castings	31,000	Increasing	Production of steel castings and increasing use of chromite as a facing sand is responsible for most of the increase. Zircon sand could be substituted at higher cost.

TABLE 6

Future Chromium Usage Trends by Industry

Market	Estimated Chromium Usage, 1968 (in tons)	Usage Trend 1968 - 1973	Comments
Motor Vehicles	89,000	Increasing	All applications for automotive use appear to be rising.
Aircraft	22,000	Decreasing*	Alloy and superalloy consumption has been, and continues to be, on the decline.
Marine Trans.	1,000	Decreasing*	Alloy use is dropping irregularly.
Appliances, Utensils, Service Machinery	19,000	Increasing	Population growth alone means growth here.
Clothing (leather)	6,000	Decreasing	Synthetics and hide shortages together with increased imports mean a drop in usage of chrome tanning chemicals.
Electrical and Electronics	10,000	Increasing	The increasing general importance of this industry presages growth in chromium usage.
Process Industry	13,000	Increasing	This use should continue to increase with population growth.
Heavy Industry Equip., Agriculture, Mining, Construction, Metalworking, Petroleum Chemicals	168,000	Increasing	Expansion may be somewhat slowed in next few years but increases are still projected.
Construction and Contractors Products	79,000	Increasing	This market should increase at an above average rate in the next few years.
All Others Includes Ordnance, Export, Misc. Chemicals	51,000	Little Change	Some of the items in this category will increase - others will decrease.
TOTAL	515,000		

*Predicted on lower production of military aircraft and naval vessels, A sharp increase would occur should our defense effort require more aircraft and ships.

(oxygen-argon) estimates that 20% of U.S. stainless steel will be made by this process in 1971 and 40% in 1972. Another process (ASEA-SKF) involves electric arc melting followed by vacuum treatment and induction stirring. Because of this change in stainless practice, it is estimated that during the next five years high-carbon ferrochrome consumption will increase by 50%, while ferrochrome-silicon and low-carbon ferrochrome usage will be relatively static. This change in product mix will increase the demand for hard lump, low MgO/Al_2O_3 ratio ores as these two quality features are of considerable importance in producing the high-carbon grade of ferrochrome. This increase in requirement for high-carbon ferrochrome will exist despite higher chromium recoveries by the new methods. Some development work has been done on the blast furnace melting of chemical-grade (fine) ore into a high-chromium pig iron for subsequent refining into steel, but this work has been discontinued because of the need for major capital investment, and it is not expected to be a commercial process within the next five years.

In the manufacture of stainless steels, the steel industry draws on a variety of chromium-bearing materials, various types of ferrochromium, chromium-bearing scrap steel and chrome ores. The amounts of the available materials for a heat are selected to give the least cost of production based on the unit prices of chromium and important physical and quality factors that influence operating costs. Thus, the amounts used in a heat of a given grade of steel will vary with the costs and availability of these materials. It is generally desirable to have the ratio of chromium to iron in the ferroalloys as high as possible and, in turn, the manufacturers of the ferrochromium alloys prefer to use ores whose Cr/Fe ratio is greater than 3. In the absence of such high-quality ores, both the producers and users of the ferrochromium incur some penalties in the cost of their products and in the loss of chromium.

The metallurgical grade chromite and ferroalloy specifications are generally satisfactory. While the standard grade of low-carbon ferrochrome now being used by the industry is .05% maximum carbon compared to the stockpile inventory specification of .10% maximum carbon, the material in the stockpile is satisfactory for general or emergency use. With the current oxygen blowing practice, the stainless steel melter is capable of obtaining carbon levels well below specification. Further, with the reduced pressure practices for decarburization, the low-carbon ferrochrome additions will be less than in the present practice; therefore, the .10% carbon alloy can be used without difficulty. However, to provide maximum flexibility, it is recommended that any future purchases for the stockpile be specified as .05% or .02% maximum carbon.

The refractory grade specifications should be brought into line with current ores by reducing the silica content from 6.0% maximum to 3.0% maximum and raising the iron allowable to 20.0% maximum. If purchased to the existing specification, it is further suggested that much of the present refractory grade ore in the stockpile be sold and replaced with smaller stockpiles of current Philippine and Transvaal concentrates.

With regard to the stockpile specifications, the chemical grade chromite should have the Cr_2O_3 content raised to 44-46%, the SiO_2 content lowered from 5.0 to 2.5%, and vanadium to 0.25% maximum, with no specific recommendations on its disposition. Although chemical grade ores are currently available on the market, reserves in the stockpile should be maintained at a level to supply the industry's needs for two and a half years.

II. CHROMIUM SUPPLY

A. World Resources

Chromium is obtained from deposits of chromite that occur in igneous complexes found in many areas of the world. The Western Hemisphere has no important commercial grade reserves, nor do the free nations of Europe have indigenous supplies. Of all the leading industrial nations, only the U.S.S.R. is considered to be self-sufficient in chromite. Reserves of the present commercial grade chromite in the U.S. are insignificant, and although moderate reserves of low-grade material exist, concentrates have been produced from the material only by expensive beneficiation.

The name "chromite" is applied to those members of the spinel group of minerals in which chromium oxide is an essential constitutent. Chromite ore varies considerably in chemical composition and physical character, which determines the end-use of the ore as metallurgical, refractory or chemical. Commercial chromite contains from 35 to 54% Cr_2O_3 (23-37% Cr) and can be considered, basically, as oxides of chromium and iron, but alumina and magnesia are present in varying amounts.

Commercial chromite comes from two principal groups of chromite deposits, (1) deposits in layered complexes of mafic and ultramafic igneous rocks, commonly termed "layered" or "stratiform," and (2) deposits or bodies of dunitic and related rocks, normally referred to as "pod" type deposits.

Deposits of the "stratiform" type contain the great bulk of the world's known and inferred reserves of chromium ore. The largest deposits of this type of ore are those in the Bushveld complex in Transvaal Province of the Union of South Africa. Second in importance are the deposits of the Great Dyke of

Rhodesia. The layers or seams of ore range from 1 inch to 18 inches thick in the Great Dyke, but may be up to several feet thick in the South African deposits. Ores from the "layered" deposits are friable in nature, and most of the South African material is low-grade with a chromium/iron ratio of 1.5/1. The deeper seams of the Great Dyke deposits in Rhodesia have chromium/iron ratios as high as 3/1. Because of the chemical composition and/or physical nature of the "stratiform" ores, their use has largely been restricted to the manufacture of chromium chemicals. Agglomeration of fines into a pellet or briquet strong enough to hold together in a furnace may be difficult to achieve. In any case, such treatment is not now a commercial process.

Chromite deposits in dunite, peridotite and related rocks are the principal source of high-grade metallurgical and refractory ores. The deposits, which range from tabular to podlike deposits, contain from a few tons to hundreds of thousands of tons and have been found in many parts of the world. Most deposits of this type are in U.S.S.R., Turkey, the Philippines, Albania, Iran, and Rhodesia. Because of the difficulty in exploration for the "pod" type deposits, as compared to the "layered" complexes, the reserves are not well known; however, it would appear that the tonnage of ores ultimately recovered from the "pod" deposits will be a fraction of that taken from the "layered" complexes.

For most metallurgical use, the "pod" type ore is more desirable as its physical nature (hard lump) results in superior furnace operation, a high chromium recovery, and resultant ferrochrome alloys of low-carbon and low-silicon contents. Currently, the industry's purchases are approximately 72% high-grade lump ore, 16% high-grade fines or concentrates, and 11% low-grade South African ore. The consumption of high grade fines and/or concentrates is limited to about 50% of ore requirements for low-carbon ferrochrome production. Usage of the low-grade South African ore is limited by the availability of lump ore of this type and the economics of converting the lower Cr/Fe ratio ores to ferro-alloys. In an emergency, an increased amount of the South African ore could be utilized at the expense of furnace output, ferroalloy product quality, and cost. However, at prevailing prices and with normal mining, transportation and smelting costs, the overall economics are in favor of the high-grade lump ores.

Ores for refractory usage have traditionally been obtained from "pod" type deposits of high-alumina content. The principal source of this type of ore is the Philippines. However, some tonnage is produced by Albania, Turkey, and the U.S.S.R. Recent technological changes have resulted in an increasing use of the high-iron stratiform ore by the refractory industry in place of high-alumina "pod" type ore.

Based on geological surveys,(2) the Free World reserves of chromite ore are estimated at 2,650,000,000 tons. No up-to-date information is available concerning the ore reserves in the U.S.S.R.; however, indications are that these reserves are substantial—in view of the fact that Russia currently represents one-third of the chrome ore production of the world. Of the Free World reserves, 2,000,000,000 gross tons are located in South Africa, 600,000,000 gross tons in Rhodesia, and about 50,000,000 gross tons in other areas of the world. Of the Free World reserves, other than Rhodesia, it is estimated that not more than 15,000,000 tons exist as high-grade ore with a chromium/iron ratio of 3/1. Over 75% of current metallurgical uses require this 3/1 ore, and any future downgrading will significantly increase costs. Table 7 shows the estimated Free World reserves of chromite by types and countries.

The reserves of high-grade, lump ore, both metallurgical and refractory, are being depleted rapidly, but there is no shortage of reserves of high-grade concentrating ores or "stratiform" low chromium/iron ratio ores. Although the metallurgical and refractory industries are using an increasing amount of fines

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(2) Dr. T. P. Thayer in Materials Survey, Chromium, 1962, BDSA, Department of Commerce.

TABLE 7

Estimated Free World Reserves and Potential Resources of Chromite

(thousand long tons)

Country	Total	Highest Grade Metallurgical(1)	High Chromium(2)	High Iron(3)	High Aluminum(4)
So. Africa, Rep. of	2,000,000		100,000	1,900,000	
*Rhodesia	600,000	-- Total both grades	300,000	300,000	
Turkey	10,000	Remainder of Free World = 15,000,000 tons total (estimate)	9,000		1,000
United States	8,000		400	7,400	200
Philippines	7,500		1,500		6,000
Finland	7,500			7,500	
Canada	5,000			5,000	
India	2,000		1,200		800
Malagasy Republic	2,000		2,000		
Yugoslavia	1,500		1,500		
Iran	1,000		1,000		
Greece	750		375		375
New Caledonia	600		600		
Japan	500		250		250
Sierra Leone	150		150		
Brazil	150		150		
Pakistan	100		100		
Cyprus	100		100		
Other	1,000		600	200	200
Free World Total	2,647,850		418,925	2,220,100	8,825

(1) 45% Minimum Cr_2O_3, Minimum 3/1 Cr/Fe—This quality currently represents over 75% of the ore used for metallurgical purposes, which, in turn, is 60% of all chromite consumption.

(2) 45% Minimum Cr_2O_3, Minimum 2/1 Cr/Fe.

(3) 40% Cr_2O_3, Less than 2/1 Cr/Fe.

(4) 20% Minimum Al_2O_3, Refractory Usage.

Source: "Mineral Facts and Problems," 1965 Edition, Bureau of Mines, Bulletin 630.

*Under sanctions.

and low-grade friable ores, most processes are based on lump ore, and the use of fines will require expensive change-overs (or agglomeration) and, possibly, lowering the quality specifications for ferroalloy compositions.

B. World Production

There has been a definite shift in the world production of chromite since 1959 with the U.S.S.R. producing an increasingly greater share. As of 1965-1968, the U.S.S.R. represented about 30-35% of the total world production. More significant is the fact that the Russian production consists of approximately 70% high-grade metallurgical ore and 30% refractory ore, respectively. This trend of world dependence on Russian ore was accelerated in 1966 when voluntary sanctions were imposed by various countries, including the United States, against the importation of chrome ore from Rhodesia, and on December 16, 1966, mandatory sanctions were imposed by the United Nations Security Council. This action has created an artificial Free World shortage of high-grade metallurgical ore, with Russia, Turkey, and the other producing countries apparently able to increase their production only enough to cover about one-half of the normal Rhodesian exports.

Table 8 summarizes estimated world demand for chromium ore in 1961-1967. Comparison with Table 9 clearly shows that of the industrial countries needing chromium, only U.S.S.R. has any significant production of chromite.

Rhodesian ore represented about 45% of the high-grade metallurgical ore consumed by the United States industry. Therefore, the United States has been particularly affected by the sanctions. Since 1966, the United States importation of metallurgical-grade chrome ore has not been in balance with consumption. It is estimated that the current ore mix for the domestic metallurgical industry contains approximately 10 to 12% chemical ore (South African). Table 10 shows that in 1968 the importation of metallurgical grade ore was equal to only two-thirds consumption. Furthermore, about 70% of the imported chromite came from the U.S.S.R. The physical quality of the Russian lump ore has deteriorated

TABLE 8

Estimated Demand for Chromite, 1961-1967

(thousand long tons)

	1961	1962	1963	1964	1965	1966	1967
United States	1178	1289	1233	1269	1345	1648	1220
U.S.S.R.	475	665	652	647	664	595	486
Japan	388	308	266	433	394	447	586
W. Germany	312	224	171	231	299	303	280
France	194	158	150	189	221	234	245
U.K.	257	116	159	222	201	186	98
Sweden	105	104	113	150	139	156	138
Poland	123	100**	84	116	153	142	148
Yugoslavia	116	102	127	122	120	80	100**
Norway	100	50	32	108	75	69	62
Austria	81	61	46	48	40	46	52**
All Others*	83	93	81	70	78	84	80**
TOTAL	3412	3270	3114	3605	3729	3990	3495

*Includes Belgium, Luxembourg, Spain, Switzerland, E. Germany, Hungary, Netherlands, Greece, Canada.

**Estimate.

Source: Statistical Summary of the Mineral Industry Institute of Geological Sciences, Mineral Resources Division, U.K. and Metals Bulletin Handbook.

Note: Demand for chrome ore was calculated roughly by adding imports to production (if any) and subtracting exports. Many of the countries listed above import and export ferrochromium alloys and chromium metal, the figures for which are not included in this table.

TABLE 9

World Production of Chromite by Countries

(thousand short tons)

	1964[1]	1965[1]	1966[1]	1967[1]	1968	1968 (Estimated)[2] % of Total
U.S.S.R.	1,435	1,565	1,653	1,731	1,815	35.0
So. Africa, Rep. of	936	1,038	1,169	1,267	1,268	24.4
Philippines	516	611	617	462	445	8.6
Rhodesia	493	645	NA	NA	NA	NA
Turkey	455	625	583	678	550	10.6
Albania	338	342	345	349	360	6.9
Iran	132	165	193	198	200	3.9
India	39	66	86	114	227	4.4
All Other	288	291	327	311	320	6.2
TOTAL	4,632	5,348	4,973	5,110	5,185	100.0

(1)John L. Morning, CHROMIUM, 1967 Bureau of Mines Minerals Year Book.

(2)Preliminary estimate.

TABLE 10. **U.S. Imports (thousands of short tons)**

Chrome Ore - All Grades

	1965	1966	1967	1968
Rhodesia	329	182	147	1
U.S.S.R.	242	281	299	336
Turkey	164	185	108	151
South Africa	481	797	481	424
Philippines	279	332	194	167
Other	23	87	11	6
TOTAL	1,518	1,864	1,240	1,085

Metallurgical Ore Only

	1965	1966	1967	1968
Rhodesia	325	182	147	1
U.S.S.R.	245	281	299	336
Turkey	175	185	108	151
Other	15	22	11	6
TOTAL	760	670	565	494

Consumption - Metallurgical Industry

	1965	1966	1967	1968
Metallurgical	830	760	780	760
Chemical (So. Africa)	75*	65*	85*	100*
TOTAL	905	825	865	860

Consumers' Stocks of Chromite at Year-End

	1965	1966	1967	1968
Metallurgical	443	463	459	381
Refractory	526	578	486	307
Chemical	142	265	252	207
TOTAL	1,111	1,306	1,197	895

Shortfall in Metallurgical Grade (consumption less imports)

1965	1966	1967	1968
70	90	215	266

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*Estimated at 8% in 1965 increasing to approximately 12% in 1968.

since the sanctions on Rhodesian ore were invoked, and the increase in the Russian import rate over the 240,000 tons of 1965 has been largely run-of-mine ore some of which contained excessive fines, which drastically limits its utility particularly in the production of high-carbon ferrochrome.

The 1965-1968 shortfall of 640,000 net tons of metallurgical grade ore has been made up by purchases of 939,000 tons of medium and high-grade lump and fines from the Supplemental Government Stockpile and by reduction in consumers' inventories. No uncommitted high-grade metallurgical ore now remains in the Supplemental Stockpile; however, approximately 425,000 tons of the quantity purchased has not yet been physically removed. This remaining tonnage is mostly in the form of concentrates or fines and, therefore, is usable at a very limited rate.

Based on the projected growth of the United States metals industry, it is estimated that the use of chromium ore for metallurgical purposes will be 794,000 net tons in 1968, increasing to 1,016,000 net tons by 1973 (see Table 4). The use of chemical grade ore is projected to increase by 2.4% a year, resulting in a requirement of 252,000 net tons and 319,000 net tons in 1968 and 1973, respectively; these totals include facing sand. Due to the decline in the use of open hearth steel furnaces, the refractory ore requirement is expected to decline over the next five years from 310,000 net tons in 1968 to 250,000 net tons in 1973. Because of the large reserve and ease of production of the chemical grade ore deposits of South Africa and the lower projected usage of refractory ores, there should be ample supplies of these grades.

The current rate of imports of metallurgical grade chrome ore is insufficient to sustain the metallurgical industry during the next five-year period, and it appears that the following options are available:

1. Removal of sanctions on the importation of Rhodesian ore.

2. Release of suitable chromium-containing material from the National Stockpile. Current inventories in the National, Supplemental, and DPA Stockpiles of metallurgical ore and ferroalloys, as compared to stockpile objectives (May 13, 1969) are as follows:

	Thousand Short Tons	
	Inventory	Objectives
Metallurgical Ore–Stockpile Grade	2,376	2,911
High-Carbon Ferrochrome	403	70
Low-Carbon Ferrochrome	319	0
Ferrochrome Silicon	59	0
Chromium Metal	8	3.8

3. A switch by the industry to the use of substantial quantities of the low-grade South African ore. This option would result in substantial changes in ferroalloy composition, reducing the capacity of the ferroalloy industry, and increasing the cost of the chromium-bearing steels. For example, the grade of high-carbon ferrochrome which can be produced from the respective ores are tabulated below:

	High-Grade Lump	So. Afr. Low-Grade
Chrome	67.00-70.00%	52.00-55.00%
Silicon	1.50% Maximum	5.00% Maximum
Carbon	5.50% Maximum	7.00% Maximum

The above reduction in chromium content would lower the output of the ferroalloy furnace in units of chrome by 20%, and the higher carbon and silicon levels will reduce the production rate of the stainless steel furnace. The effects of such a change in alloy composition would also be reflected in increased usage of electrical power, labor, coal, and coke.

4. Technological developments in ferroalloy or steel production could reduce our dependence on the scarce high-grade ores. Some possibilities which warrant exploitation include:

a. Pelletizing (or briquetting) of chromite ore fines. The improvement in physical characteristics could be combined with chemical upgrading and/or partial reduction.

b. Further development of steelmaking innovations such as vacuum or inert gas treatments which might permit better recoveries and/or use of lower grade charge material.

C. Government Stockpile Specifications

1. National Stockpile purchase specifications are provided for the three grades of chromite, as well as the various ferroalloys used for metallurgical purposes. Following are the chemical and physical requirements for each grade, together with suggestions for changes received from interested groups:

CHROMITE - METALLURGICAL GRADE

Specification P-11-R1, June 4, 1956
(Supersedes Issue of January 10, 1955)

1. Description:

This specification covers chromite ore suitable for use in the production of commercial ferrochromium and special chromium alloys.

2. Chemical and Physical Requirements:

Each lot of chromite ore purchased under this specification shall conform to the following chemical and physical requirements:

a. Chemical Requirements:

			Percent by Weight (Dry Basis)
Chromic Oxide	(Cr_2O_3)	Minimum	48.0
Silica	(SiO_2)	Maximum	8.0
Sulfur	(S)	Maximum	0.08
Phosphorus	(P)	Maximum	0.04

The minimum chromium-to-iron ratio shall be 3 to 1.

b. Physical Requirements:

All chromite ore shall be lumpy and shall be hard, dense, non-friable material of which not more than 25% shall pass a 1-inch sieve (ASTM Designation: E 11). Chromite ore of a friable nature, regardless of an initially lumpy appearance, shall be rejected.

3. Suggested Changes:

None.

FERROCHROMIUM - LOW CARBON

Specification P-11a-R5, July 12, 1963
(Supersedes Issue of February 14, 1961)

1. Description:

This specification covers low-carbon ferrochromium.

2. Chemical and Physical Requirements:

Each lot of low-carbon ferrochromium purchased under this specification shall conform to the following chemical and physical requirements.

a. Chemical Requirements:

			Percent by Weight
Chromium	(Cr)	Minimum	65.0
Carbon	(C)	Maximum	0.10
Silicon	(Si)	Maximum	1.50
Phosphorus	(P)	Maximum	0.025
Sulfur	(S)	Maximum	0.10

b. Physical Requirements:

Low-carbon ferrochromium shall be furnished in the form of lumps, bricks, briquettes, or pellets. All lump material shall be hard, dense, nonfriable material and shall be free of pores, slag, and inclusions or adhesions of other foreign materials. They shall be produced in a manner that will preclude their cracking or disintegration during long-term outdoor storage. All material in any lot shall be in the same form. Lumps shall be 8 mesh or larger and no lumps shall exceed 50 pounds in weight. The bricks, briquettes, or pellets shall be the size and shape normally supplied to industry.

3. Suggested Changes:

Current usage of low-carbon ferrochrome in stainless production is almost entirely the .05% maximum carbon and .02% maximum carbon grades. In order to assure the wide utility of a stockpile of low-carbon ferrochrome, the carbon specification should be lowered from .10 to .05% or 0.02%.

FERROCHROMIUM - HIGH CARBON

Specification P-11b-R2, July 15, 1963
(Supersedes Issue of March 3, 1958)

1. Description:

This specification covers high-carbon ferrochromium.

2. Chemical and Physical Requirements:

Each lot of high-carbon ferrochromium purchased under this specification shall conform to the following chemical and physical requirements:

a. Chemical Requirements:

			Percent by Weight
Chromium	(Cr)	Minimum	65.0
Carbon	(C)	Range	4.0 to 6.0
Silicon	(Si)	Maximum	1.50
Phosphorus	(P)	Maximum	0.025
Sulfur	(S)	Maximum	0.10

b. Physical Requirements:

All high-carbon ferrochromium shall be hard, dense, nonfriable lumps, free of pores, slag, and inclusions or adhesions of other foreign materials. The lumps shall be produced in a manner that will preclude their cracking or disintegration during long-term outdoor storage. Each lump shall be one-inch or larger in size and shall not exceed 50 pounds in weight

3. Suggested Changes:

None.

FERROCHROMIUM - SILICON

Specification P-11c-R3, March 3, 1958
(Supersedes Issue of December 23, 1957)

1. Description:

This specification covers ferrochromium-silicon (chrome-silicide) for use in the production of low-carbon chrome alloy steels.

2. Chemical and Physical Requirements:

Each lot of ferrochromium-silicon purchased under this specification shall conform to the following chemical and physical requirements:

a. Chemical Requirements:

			Percent by Weight
Chromium	(Cr)		39.0 to 41.0
Silicon	(Si)		42.0 to 46.0
Carbon	(C)	Maximum	0.05
Sulfur	(S)	Maximum	0.05
Phosphorus	(P)	Maximum	0.025

b. Physical Requirements:

Ferrochromium-Silicon shall be furnished in lump size, one inch or larger. No lumps shall exceed 50 pounds.

3. Suggested Changes:

None.

CHROMIUM METAL

Specification P-96-R1, January 5, 1961
(Supersedes Issue of January 7, 1957)

1. Description:

This specification covers electrolytic and aluminothermic chromium metal intended primarily for use in the production of high-temperature and nonferrous alloys.

2. Chemical and Physical Requirements:

Each lot of chromium metal purchased under this specification shall conform to the applicable chemical and physical requirements as follows:

a. Chemical Requirements:

			Percent by Weight	
			Electrolytic	Aluminothermic
Chromium	(Cr)	Minimum	99.20	98.75
Iron	(Fe)	Maximum	0.20	0.27
Aluminum	(Al)	Maximum	0.01	0.25
Carbon	(C)	Maximum	0.02	0.06
Silicon	(Si)	Maximum	0.01	0.20
Sulfur	(S)	Maximum	0.03	0.03
Phosphorus	(P)	Maximum	0.02	0.03
Lead	(Pb)	Maximum	0.003	0.01
Copper	(Cu)	Maximum	0.01	0.02
Combined Gases	(O+N+H)	Maximum	--	0.12
Oxygen	(O)	Maximum	0.55	0.08
Nitrogen	(N)	Maximum	0.03	0.04
Hydrogen	(H)	Maximum	0.008	0.01
Other Elements	(Ea)	Maximum	0.05	0.05

b. Physical Requirements:

All electrolytic chromium metal shall pass a 2-inch sieve and all aluminothermic chromium metal shall pass a 1-inch sieve (ASTM Designation: E 11).

3. Suggested Changes:

None.

CHROMIUM METAL

Proposed Specification P-96-R2, October 23, 1969
(To Supersede Issue of January 5, 1961)

1. Description:

This specification covers three types of chromium metal intended primarily for use in the production of high-temperature and nonferrous alloys.

2. Chemical and Physical Requirements:

Each lot of chromium metal purchased under this specification shall conform to the applicable chemical and physical requirements as follows:

a. Chemical Requirements:

			Percent by Weight			
			Type A 1/	Type B 1/	Type C 1/	Type D 1/
Chromium	(Cr)	Minimum	99.25	99.30	99.40	99.40
Iron	(Fe)	Maximum	0.20	0.20	0.35	0.35
Aluminum	(Al)	Maximum	0.10	0.01	0.02	0.02
Carbon	(C)	Maximum	0.02	0.02	0.05	0.05
Silicon	(Si)	Maximum	0.10	0.01	0.04	0.04
Sulfur	(S)	Maximum	0.010	0.03	0.015	0.015
Phosphorus	(P)	Maximum	0.005	0.01	0.002	0.002
Lead	(Pb)	Maximum	0.001	0.002	0.001	0.001
Copper	(Cu)	Maximum	0.002	0.005	0.005	0.005
Antimony	(Sb)	Maximum	0.001	0.001	0.001	0.001
Tin	(Sn)	Maximum	0.001	0.001	0.002	0.002
Arsenic	(As)	Maximum	0.001	0.001	0.001	0.001
Bismuth	(Bi)	Maximum	0.001	0.001	0.001	0.001
Oxygen	(O_2)	Maximum	0.10	0.50	0.05	0.05
Nitrogen	(N_2)	Maximum	0.02	0.05	0.02	0.02
~~Hydrogen~~	~~(H_2)~~	~~Maximum~~	~~0.001~~	~~0.01~~	~~0.002~~	~~0.002~~
Other Elements	(Ea.)	Maximum	0.01	0.01	0.01	0.01

1/ Type A - Chromium metal produced by aluminum reduction of chromic oxide and/or related chromium compounds.

Type B - Chromium metal produced by electrolysis of a chromium-bearing solution.

Type C - Chromium metal produced by electrolysis of a chromium-bearing solution, followed by grinding, pelletizing, and vacuum treatment to lower gas content.

Type D - Chromium metal produced by electrolysis of a chromium-bearing solution with subsequent hydrogen treatment to lower gas content.

b. Physical Requirements:

Types A, B, and D chromium metal shall pass a 2-inch sieve (2-inch by down) and not more than 5 percent shall pass an 8 mesh screen (ASTM Designation: E-11).

Type C chromium metal shall be in the form of pellets, shall pass a 1-3/4-inch sieve (1-3/4-inch by down) and not more than 5 percent shall pass an 8 mesh screen (ASTM Designation: E-11).

CHROMITE - CHEMICAL GRADE

Specification P-65-R, January 1961
(Supersedes Issue of June 1, 1949)

1. Description:

This specification covers chromite ore satisfactory for use in the manufacture of chromium chemicals.

2. Chemical and Physical Requirements:

Each lot of chromite ore purchased under this specification shall conform to the following chemical and physical requirements:

a. Chemical Requirements:

			Percent by Weight (Dry Basis)
Chromic Oxide	(Cr_2O_3)	Minimum	44.0
Silica	(SiO_2)	Maximum	5.0

b. Physical Requirements:

All chromite ore shall be of a friable nature.

3. Suggested Changes:

a. Cr_2O_3 44-46% with highest assay preferred, assuming no cost penalty per unit of Cr_2O_3.

b. SiO_2 2½% maximum, below 2% preferred.

c. Vanadium 0.25% maximum, below 0.2% preferred.

c. No specifications needed on Al_2O_3, Fe_2O_3, MgO.

CHROMITE - REFRACTORY GRADE Specification P-12-R3, December 4, 1963

1. **Description**:

This specification covers chromite ore satisfactory for production of standard refractory brick.

2. **Chemical and Physical Requirements**:

a. Chemical Requirements:

		Percent by Weight (Dry Basis)
Cr_2O_3	Minimum	31.0
Fe	Maximum	12.0
$Cr_2O_3+Al_2O_3$	Minimum	58.0
SiO_2	Maximum	6.0
CaO	Maximum	1.0
MgO		Not Specified (to be determined for each lot and reported)

b. Physical Requirements:

All refractory-grade chromite shall be hard, dense, non-friable lump ore. Not more than 15 percent by weight of each lot shall pass a U.S. Standard Sieve No. 16 (ASTM Designation E-11). Chromite ore of a friable nature, regardless of an initially lumpy appearance shall be rejected. The chromite ore shall be from sources and of a type that is used, directly without chemical modification or processing by at least three manufacturers of standard refractory chrome ore brick in the United States that consume at least 50 percent of the refractory chromite.

3. **Suggested Changes**:

To correspond with current use of Philippine concentrate and Transvaal concentrate, silica content should be reduced to 3.0% maximum and iron allowable should be raised to 20.0% maximum.

2. Inventories and Objectives:

	Thousand Short Tons		
	National Stockpile		Supplement & DPA
	Objective*	Inventory*	Stockpiles*
Chemical Grade:			
Stockpile Grade	260*	559	684
Refractory Grade:			
Stockpile Grade	368**	1,047	180
Non-Stockpile Grade			
Metallurgical Grade:			
Stockpile Grade	2,911**	2,053	323
Non-Stockpile Grade		591	901
High-Carbon FeCr	70**	126	277
Low-Carbon FeCr	0 **	128	191
FeCr-Si	0**	26	33
Cr Metal	3.8**	0.975	7.040

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*Statistical Supplement, Stockpile Report to Congress, July-December 1969.

**Office of Emergency Preparedness press release 353, March 4, 1970.

Table 11 summarizes the usage of various ferroalloys during the years 1963 to 1968. Note that the mix remains quite consistent.

TABLE 11

Consumption of Chromium in Metallurgical Uses by Type of Chromium

(thousands of tons)

	LCFeCr		HCFeCr		FeCrSi		All Other		
Year	Total	Cr	Total	Cr	Total	Cr	Total	Cr	Total Cr*
1963	119	82	103	66	73	31	15	8	187
1964	149	103	126	82	88	35	15	8	228
1965	163	113	134	88	80	33	17	10	244
1966	171	118	143	93	87	36	17	10	257
1967	142	100	132	89	77	32	16	12	233
1968	152	105	136	90	75	30	5	4	229
% TOTAL:	43 to 46%		36 to 39%		13 to 15%		2 to 5%		

*These totals are about 20% lower than the total metallurgical Cr consumption of 275 to 300,000 tons. The difference is believed due to incomplete canvass of users.

Source: U. S. Bureau of Mines Minerals Yearbooks

D. Conclusions

The current polical situation has resulted in the imposition of sanctions on importing Rhodesian metallurgical chrome ore. The actual impact on Rhodesia is unknown; however, there is evidence that Rhodesia is mining at approximately half the normal rate and that this ore is moving into the world markets. The relative importance of Rhodesia as a source of chromite is brought out in Table 7. There is a possibility that some ore is being reshipped by the countries of the Red Bloc. The United States as well as the other nations of the Free World are highly dependent on the U. S. S. R. for this strategic raw material. During the five-year period of 1969-1973, adequate supplies of chemical and refractory grades of ore will be available, but a definite shortage of metallurgical grade chrome will exist so long as the sanctions on the Rhodesian ore are in effect. Options that could be exercised to eliminate or alleviate this shortage are:

1. Removal of the sanctions on Rhodesian ore.
2. The use of substantial quantities of low-grade South African ore by the metallurgical industry. This could only be accomplished at a penalty in the cost of producing the chromium-bearing steels and the commitment of new capital for the additional ferroalloy furnace capacity required in the processing of the low-grade ore.
3. Disposal of material from Government Stockpiles.
4. Conduct research which might lead to methods for economically using low-grade ores.

III. METALLURGICAL APPLICATIONS

A. Stainless, Alloy, and Tool Steels

Of the total domestic consumption of chromite in 1968, 61% was used for metallurgical additions. Chromite ore was converted to various chromium alloys such as low-carbon ferrochromium (46%), high-carbon ferrochromium (39%), ferrochromium silicon (13%), and chromium metal (2%). These various chromium alloys were used in the following summary of major metallurgical end uses (see Table 12).

1. Stainless Steel

The major end use of chromium ferroalloys is in stainless steels (66% of total) and the secondary major use is in alloy steel, including tool steel (18% of total). It should be emphasized that for its major use— stainless steel— chromium is unique; unlike nickel or molybdenum which have alternates to perform the desired function, there is no other element which can be used as a substitute for chromium. Stainless steel cannot be made without chromium. If chromium were unavailable, alternates, such as cupronickel, ferritic steels, and titanium, might be employed, but at a cost and performance penalty.

Ingot production data for the past five years of the major types of stainless steels, including the austenitic Cr-Ni 200 and 300 series, the ferritic or martensitic Cr 400 series steels, and the special heat resisting alloys, are shown in Table 13. Except for the outstanding year in 1966 and moderate decrease in 1968, production remained generally constant. Shipments are approximately two-thirds of the ingot production figures. In 1968, total shipments were 819,042 tons of stainless plus heat resisting steel. AISI projections of stainless steel production are given in Figure 2.

TABLE 12

Consumption, by End Uses, and Stocks of Chromium Ferroalloys and Metal in the United States, in 1968*

(short tons)

	Ferrochromium				Ferrochromium Silicon		Other Chromium Alloys[1]	
	Low Carbon		High Carbon					
	Gross Weight	Contained Weight	Gross Weight	Contained Weight	Gross Weight	Contained Weight	Gross Weight	Contained Weight
Steel (ingots and castings):								
High speed and tool	1,129	788	2,653	1,748	217	101	16	16
Stainless	119,655	82,578	71,270	47,792	60,643	24,048	301	200
Alloy (excluding stainless)	13,568	9,263	42,711	27,986	9,702	4,131	323	180
Carbon	1,999	836	5,856	3,594	2,606	1,138	1,127	588
Other Steel	1,187	818	286	185	-------	-------	321	164
Cast irons	1,878	1,107	7,475	4,986	23	11	322	238
Cutting and wear resistant materials	161	118	1,110	756	-------	-------	76	68
Welding and hard facing rods and materials	450	308	813	554	-------	-------	179	176
Nonferrous alloys	8,822	6,305	891	586	588	273	2,177	2,079
Miscellaneous and unspecified[2]	4,166	2,819	2,765	1,823	1,565	733	504	487
TOTAL	152,215	104,940	135,830	90,010	75,344	30,435	5,246	4,196

[1] Includes aluminothermic and electrolytic metal and other chromium alloys.

[2] Includes electrical materials, catalysts and other chemical and ceramic uses.

NOTE: Figures shown are estimated to about 10% lower than actual consumption due to incomplete canvass of users.

*Chromium, Bureau of Mines Minerals Yearbook, 1968, U. S. Department of the Interior.

TABLE 13

Stainless and Heat Resisting Steel Production by Type Numbers
1964 to 1968*

(net ingot tons)

Type Number		1964	1965	1966	1967	1968
201		44,895	23,818	23,955	29,295	35,836
202		1,631	1,772	942	474	2,354
301		116,620	105,135	107,805	107,919	120,882
302		38,295	35,744	36,178	29,234	30,478
302B		623	118		99	
303		35,636	42,109	51,947	41,064	39,261
303Se		1,791	2,390	3,070	3,813	1,953
304		473.615	466,373	577,076	484,586	463,862
304L		50,270	52,890	56,194	38,545	38,722
305		11,327	13,629	21,601	15,446	14,633
308		3,178	4,970	4,688	4,731	2,042
309		6,818	6,836	7,888	8,548	8,308
309S		2,154	3,914	3,951	2,211	1,976
310		7,069	6,513	7,207	5,745	5,292
310S		1,218	983	572	273	209
314		309	220	218	46	132
316		69,776	84,810	93,854	76,169	66,103
316L		31,160	36,683	39,214	27,913	26,470
317		1,812	1,330	3,036	883	1,866
321		30,925	33,214	37,486	24,258	24,105
347		12,186	11,512	13,553	9,333	8,843
348		1,026	2,880	2,523	1,507	2,299
Other Cr-Ni stainless steels with:						
Nickel	Other Alloys					
Under 8%	Under 10%	15,858	13,211	22,039	21,445	16,526
Under 8%	Over 10%	14,570	17,410	24,225	24,154	24,540
8-16%	Under 10%	3,093	1,217	1,383	1,082	416
8-16%	Over 10%	12,125	9,085	13,389	8,362	7,242
16-24%	Under 10%		1,402	590	378	94
16-24%	Over 10%	2,668	2,866	5,249	4,900	3,005
Over 24%	Under 10%	6,347	7,771	5,234	2,211	22,979
Over 24%	Over 10%	14,039	17,226	28,938	22,201	

A

Other Cr-Ni stainless steels with:						
Nickel	Other Alloys					
Under 8%	Under 10%	15,858	13,211	22,039	21,445	16,526
Under 3%	Over 10%	14,570	17,410	24,225	24,154	24,540
8-16%	Under 10%	3,093	1,217	1,383	1,082	416
8-16%	Over 10%	12,125	9,085	13,389	8,362	7,242
16-24%	Under 10%		1,402	590	378	94
16-24%	Over 10%	2,668	2,866	5,249	4,900	3,005
Over 24%	Under 10%	6,347	7,771	5,234	2,211	22,979
Over 24%	Over 10%	14,039	17,226	28,938	22,201	
Total Cr-Ni Stainless		1,011,034	1,008,031	1,194,005	996,825	970,428
403		17,043	19,935	19,971	26,151	20,325
405		2,539	3,334	4,240	3,315	4,058
406		2,192	1,589			
410		48,012	53,472	64,041	55,035	53,772
414		338	462	501	417	228
416		31,405	35,820	48,823	45,758	45,439
416Se		116	200	1,056		
420		6,058	8,277	8,169	6,284	5,950
430		178,030	178,293	146,408	134,912	135,858
430F		3,247	3,701	4,531	2,919	4,494
430F Se		578			421	
431		2,900	3,690	4,684	3,917	2,356
440A		4,379	5,003	4,601	3,164	4,120
440B		184	186	111	218	185
440C		6,128	6,676	10,913	9,411	7,305
442		1,313	376	1,164	596	1,467
443		319	319	419	360	
446		2,654	3,540	2,863	1,986	2,202
All Other		97,685	111,985	97,893	123,496	133,659
Total Cr Stainless		405,170	446,858	420,388	418,360	421,418
501 and 502		6,642	13,265	11,051	11,299	13,919
All Other High Chromium Heat Resisting Steels		18,335	23,318	23,715	23,285	24,171
Total		24,977	36,583	34,766	34,584	38,090
TOTAL ALL TYPES		1,441,181	1,491,472	1,649,159	1,449,769	1,429,936

*Data from P. 73 of AISI Annual Statistical Report 1968.

B

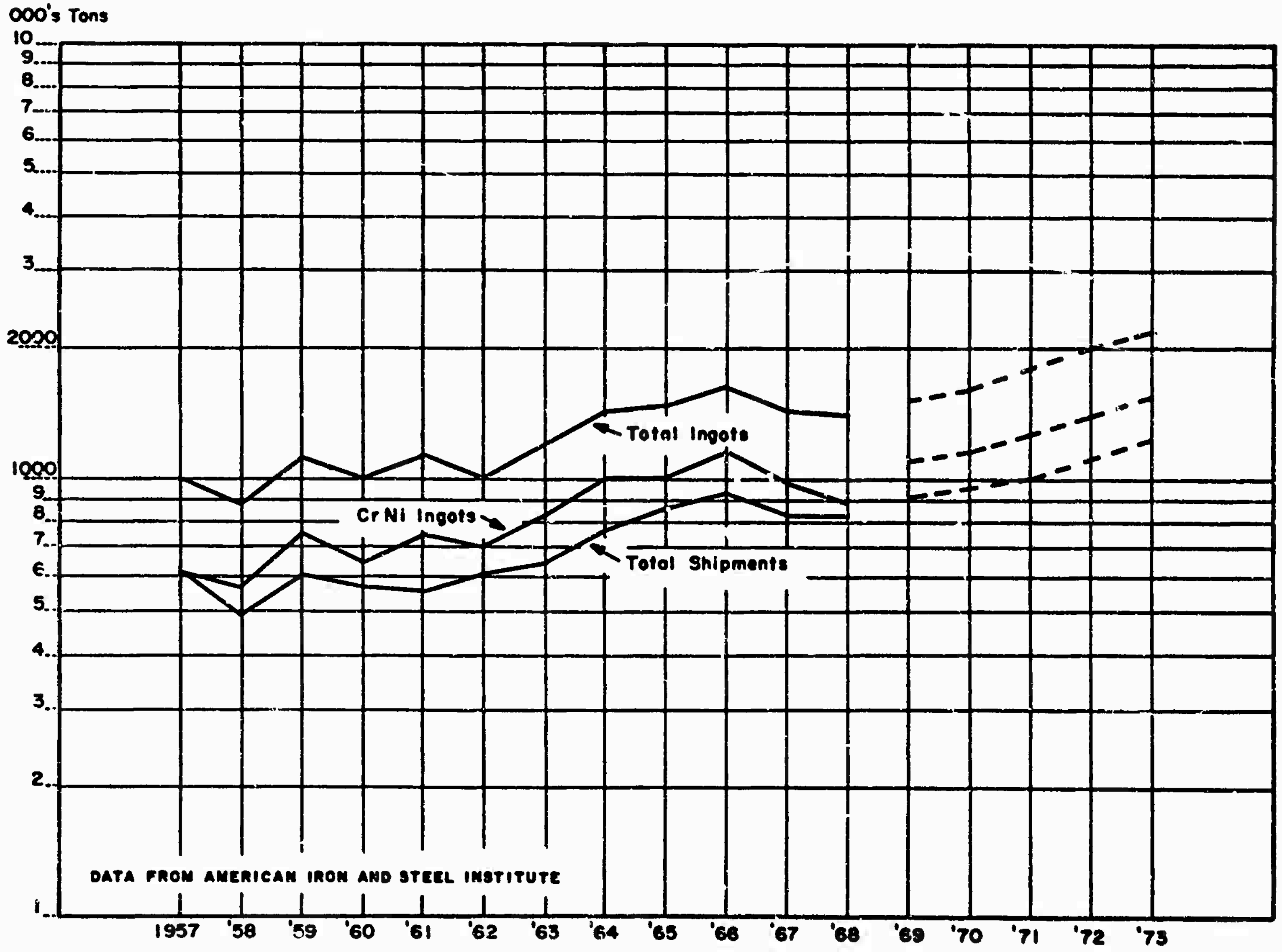

Figure 2. Total Stainless Steel Ingot and Cr Ni Ingot Production in the United States 1957-1968 and Total Stainless Steel Shipments with Projections 1969-1973

During the next five year period, 1969 to 1973, stainless steel production is projected to increase by about 26%. Approximately similar rates of increase are projected for Cr-Ni and Cr stainless steels, thus, an increase from about (1) 1,000,000 to 1,250,000 tons of Cr-Ni and (2) 400,000 to 500,000 tons of Cr stainless steels is projected by 1973. The average chromium content can be considered to be 17.9% for austenitic Cr-Ni grades, 15.2% for ferritic and martensitic Cr grades, and 5% for the 500 series. Therefore, the chromium contained in stainless steel in 1968 was (1) 17.9% of 970,428 tons or 174,000 tons for Cr-Ni grades and (2) 15.2% of 421,418 tons or 64,000 tons plus 5% of 13,919 tons or 700 tons for Cr grades, for a total of 238,700 tons. In addition, another 24,171 tons of high chromium heat resisting steel with an average chromium content of 15% was made, adding 3,600 more tons of chromium, making the total 242,000 tons. Assuming an irretrievable loss of about 8% of all chromium handled, total chromium consumption in stainless steel in 1968 was 263,000 tons (see Table 3). By 1973, the amount of contained chromium required is projected to be 252,000 tons for Cr-Ni and 90,000 tons for Cr stainless steel grades for a total of 342,000 tons. The total projected increased use of chromium by 42,000 tons by 1973 constitutes a major additional requirement of about 134,000 tons of 50% chromite ore, allowing for chromium recovery in scrap, and melting losses. Considering that the consumption rate of chromite for metallurgical use is now about 800,000 tons/year, most of which is imported, the projected increase is substantial.

Table 14 lists the scrap input, and its chromium content, used in melting stainless and alloy steels for the past five years.

The major austenitic Cr-Ni and martensitic/ferritic Cr grades, their primary applications, trend of use, and potential substitutes, are given

TABLE 14

Scrap Consumption

(thousands of tons)

	Stainless Steel			All Alloy Steel			
Year	AISI[1]	BofM[2]	Cr Content Avg. 13.5%	AISI	BofM	Cr Content 0.3%[3]	Total Cr
1963	661	719	97	2306	2627	8	105
1964	772	839	113	2656	3040	9	122
1965	748	840	113	2951	3358	10	123
1966	857	969	129	3024	3429	10	139
1967	752	863	117	2598	3004	9	126
1968	650	878	119	2553	2949	9	128

[1] AISI data from AISI Form 112.

[2] Bureau of Mines data from Minerals Yearbook.

[3] In 1968, the average chromium content for 5 million tons of chrome-bearing steel was 0.83%. This was about 37% of all alloy steel produced. This type of pattern has been maintained historically so that (0.37) x (0.83%) or 0.3% is used as the average Cr content for all alloy steel scrap.

in Table 15. In an emergency, substitutes, in general, could be used for such applications as decorative trim, architectural, certain cookware, cutlery, etc. However, where corrosion resistance in chemical processing and/or elevated-temperature applications is required, economical non-chromium containing substitutes are scarce. Furthermore, copper-base and nickel-base alloys that might be substituted are themselves subject to serious scarcities and are produced in only limited quantities, about 5% of stainless steel. Titanium or titanium-clad steels may develop into feasible substitutes on chemical tanks and piping.

Two stainless steelmaking developments, one involving the experimental blast furnace smelting of iron and chemical grade chromite together to produce a chromium-rich pig iron before refining into steel, and the other employing high-carbon rather than low-carbon ferrochrome in gas injected melting, to the extent that they are adopted, may take some of the pressure off demands for high-grade metallurgical ore and permit use of lower grades.

Within the next five years, depending upon the final device and design selected, emission control units (for auto fume control) may employ 10 pounds of stainless steel per car. This could amount to 100 million pounds or 50,000 tons of additional stainless per year—a 2.5% increase over and above the projected 1973 stainless production.

For further detailed information on stainless steel applications and trends in various industries, please refer to MAB-248, "Applications of Nickel," prepared by some members of this Committee (and others) in December 1968.

2. Alloy Steel

For the next five years, alloy steel production and shipments are expected to increase at about a rate of 3% per year, so that an increase of 15% in total alloy steel produced would be projected by 1973. Alloy steels include the AISI series such as 41xx, 43xx, 51xx, 52100, 61xx, 86xx, and 92xx types. In addition, some chromium is used in high-strength low alloy steels. Table 16 lists the principal alloy steel grades, their 1968 production, and contained chromium. Table 17 shows the historical trends in production of these grades. The

TABLE 15

Production Trends, Applications, and Potential Substitutes

Steel	Present (1968) Production (X1000) Steel (lbs)	Present (1968) Production (X1000) Cr (lbs)	Production Trend	Applications	Potential Substitutes
301, 201	300,000	51,000	Increase	Automotive trim & wheel covers. truck trailer bodies, railroad cars, aircraft structures	12 Cr grades, coated 12 Cr grades, Al, plastics
302, 202	52,000	9,400	Static	Food handling equipment, architectural, cookware, trim	12 Cr grades, coated 12 Cr grades, Al, Cr plated steel
303	70,000	12,500	Increase	Free machining Cr-Ni, screw machine products, valves, nozzles, shafts.	12 Cr grades (416), Cr plated steel, Al
304	855,000	154,000	Increase	Chemical industry, food processing, architecture	Coated 12 Cr grades, Al, Cu, Monel, Plastics
304L	73,000	13,100	Increase	Welded structures, chemical industry, nuclear field	Coated 12 Cr grades
305	26,500	5,000	Increase	Nuclear energy, cold headed fasteners, spin form applications, high oxidation resistance.	Bronze
309, 309S	20,000	4,800	Increase	Heat treatment equipment, furnace parts, aircraft heaters	Hasteiloy B
316	120,000	21,600	Increase	Chemical industry, pulp & paper industry, food equipment, elev.-temp. applications, e.g., power generating industry.	Monel, Ti, Cupro-Nickel, plastics
316L	50,000	9,000	Increase	316 applications where welding is used.	Cupro-nickel
321, 347	60,000	11,000	Static	Stabilized grades to minimize sensitization during elev.-temp. exposure. Process equipment,	Coated 12 Cr grades

				generating industry.	
316L	50,000	9,000	Increase	316 applications where welding is used.	Cupro-nickel
321, 347	60,000	11,000	Static	Stabilized grades to minimize sensitization during elev.-temp. exposure. Process equipment, boiler shells, aircraft exhaust manifolds.	Coated 12 Cr grades
310 310S 314	11,000	2,800	Static	Higher oxid. resist. and strength than 309. Heat exchangers, furnace parts, combustion chambers, weld filler metal.	Hastelloy B
Others	12,500	1,900			
All 300 grades	1,650,000	296,100	Increase		
B 403	38,000	4,600	Increase	Steam turbine blading and highly stressed parts.	Alloy steel
410	93,000	11,200	Increase	Machine parts, pump shafts, some 12 Cr modifications finding use in cargo containers, trailer truck stiffeners, auto mufflers.	Cr plated steel, chromized steel
416	88,000	10,600	Increase	Free machining modification for screw machine production of nozzles, valves, fittings	Cr plated steel, Al
430, 434	282,000	48,000	Static	Automotive trim, architectural, nitric acid tanks, annealing baskets	Aluminum, plastics, coated 12 Cr grades, Cr plated steel, chromized steel
440A 440B 440C	46,000	7,800	Increase	Bearing balls, and races, cutlery, valve parts, surgical tools	Alloy steel
Others	244,000	36,600			
All 400 grades	791,000	118,800	Increase		

TABLE 16

1968 Production of Principal Cr-Alloy Steels

Series	Type	%Cr	1968 Prod., 000 tons	Cr Used, 000 tons
5100	Cr	0.85	1056[1]	8.975
6100	Cr-V	0.90	86	0.775
3100	Ni-Cr	0.65	66	0.430
8100) 8600) 8700)	Ni-Cr Mo-V	0.50	170	0.850
4100	Cr-Mo	1.05	1583	16.620
4100	Cr-Mo-V	1.05	170	1.785
8600	Ni-Cr-Mo	0.50	1607	8.035
52100[2]	Cr	1.45	300[1]	4.350
			5038 total	41.820 Avg. Cr Content 0.83%

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[1] Actual Cr steel production as listed by AISI was 1,356,000 tons but 300,000 tons is estimated to be 52100 steel with a higher chrome content.

[2] An additional, unknown quantity of chromium was used in the manufacture of high-strength low alloy constructional steels but the quantity shown above probably represents about 90% of the total chromium used in alloy steel.

TABLE 17

Historical Production, 1962 to 1968, of Principal Cr-Alloy Steels

(thousands of tons)

Series	Type	1962	1963	1964	1965	1966	1967	1968
3100	Ni-Cr	99	103	130	114	103	80	66
4100	Cr-Mo	1087	1109	1304	1583	1654	1430	1583
4100	Cr-Mo-V	90	157	167	209	209	158	170
5100	Cr[1]	1284	1367	1512	1570	1420	1201	1356
6100	Cr-V	61	69	78	89	83	75	86
8100) 8600) 8700)	Ni-Cr Mo-V	62	123	138	131	130	183	170
8600	Ni-Cr-Mo	1224	1238	1497	1656	1718	1434	1607
TOTAL		3907	4166	4826	5352	5317	4561	5038
% Change		+7	+16	+11	-1	-14	+10	
% Change, Avg.	+5%							

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[1] Includes 52100 steel.

average chromium content of the listed types of alloy steel is .83%, so that 42,000 tons of chromium was contained in 5.038 million tons of these chromium-bearing alloy steels produced in 1968.

The main markets for alloy steels include construction (22%), automotive (22%), general purpose industrial equipment (12%), steel service centers (11.5%), and power generating and distributing equipment (7.7%), rail transportation (5%) and forgings (5%). In emergency periods, some substitution of boron treated low alloy steels could be considered to obtain the hardenability required. The shipments of alloy steels to the various markets, Table 18, for the past three years shows the main growth to be in the construction field.

A lion's share of alloy steel applications are non-strategic, and those that are strategic could be considered for alloy substitutions. Response to heat treatment, expressed by hardenability, along with fatigue and other properties, are principal criteria for alloy steel selection. These lend themselves to a broad range of alloy substitutions, but, unfortunately, many of the alternates, like Ni and Mo, are also subject to shortages. Very low alloy or carbon steels, fortified by small non-strategic additions of boron, are gaining acceptance, and could offer greater possibility for non-strategic substitutions in the future.

3. Tool Steels

As shown in Table 19, total tool steel production has been irregular in recent years. However, a future growth rate of 3% per year seems consistent with future steel production and national growth.

In the 96,000 tons produced in 1968, the average chromium content is about 6% and 8% loss is allowed, resulting in an estimated 6,000 tons of chromium consumed in 1968.

TABLE 18

Application of Alloy Steels from U.S. Mills

(net tons)

	Alloy Steel (other than stainless)		
Market Classifications	1968	1967	1966
Converters & Processors	89,742	98,423	138,464
Forgings (except automotive, aircraft, agricultura, general purpose industrial equip., and power generating & distributing equip.)	388,643	440,089	501,112
Bolts, Nuts, Rivets & Screws	72,167	78,025	87,460
Steel Service Centers	869,700	714,996	823,686
Construction (including maintenance)	1,748,988	1,445,648	1,431,644
Contractors' Products	27,339	20,012	35,528
Automotive	1,740,301	1,483,962	1,766,604
Rail Transportation	394,365	445,981	647,029
Shipbuilding & Marine Equip.	75,225	65,247	112,889
Aircraft	59,353	64,200	83,009
Oil & Gas Drilling	142,116	104,726	136,637
Mining, Quarrying & Lumbering	112,090	42,675	64,840
Agricultural	59,532	59,490	70,893
General Purpose Industrial Equipment	601,557	644,422	642,420
Appliances, Utensiles & Cutlery	8,271	7,160	7,807
Domestic & Commercial Equip.	24,708	21,795	22,741
Containers, Packaging & Shipping Materials	25,111	31,239	32,970
Ordnance & Other Military	147,313	110,922	69,107
Export	160,971	149,951	142,756
Unclassified	147,694	152,475	163,330
Totals	7,815,606	7,018,427	7,973,652

TABLE 19

Production of Tool Steel, All Types

(thousands of tons)

Year	Production	% Change
1961	74	
1962	85	+15
1963	91	+ 7
1964	95	+ 4
1965	107	+13
1966	110	+ 3
1967	103	- 6
1968	96	- 7
		+ 4 Avg.

No dramatic changes in chromium content are anticipated in tool steels. All high speed cutting steels contain 4% chromium which is essential for hardenability and some corrosion resistance. In high carbon-high chromium steels, 12% chromium forms hard chrome-carbides for wear resistance. In the 5% Cr cold work and hot work die steels, the chromium is needed to impart, with molybdenum additions, the deep air hardenability needed for large dies (up to 10-20 inches in thickness). High carbon-high chromium steels could be replaced in many applications at greater cost, with high vanadium grades.

All of these applications would be considered indirectly strategic for defense tooling, and the potential for substitutions is limited by the specialized steel property and heat treat requirements of tool and die making.

B. Heat- and Corrosion-Resistant Materials

Most of the chromium consumed annually by the metallurgical industry, 85 to 90% of the total, is used in the production of stainless and alloy steels. The balance is used primarily in heat-and corrosion-resistant materials of which the nickel-base superalloys constitute the largest requirement. Smaller tonnages of chromium are also used in cobalt-base alloys, in high-iron heat-resistant alloys (in addition to those classified by AISI as stainless steels), and in various surface coatings applied for protection against environmental attack or for wear resistance. In each of these instances, the single most important factor in the selection of chromium as a major alloying constituent is its beneficial effect on oxidation and corrosion resistance. Alloys that contain sufficient concentrations of chromium tend to form, upon exposure to oxygen-bearing environments at elevated temperatures, stable surface scales based on Cr_2O_3 or $MO.Cr_2O_3$ spinels, where M designates a divalent metal such as Ni, Co, Mn, etc. Such scales are significantly more protective than most of the other oxidation products that would form in the absence of chromium, particularly when the operating environment contains highly corrosive species such as SO_2, NaCl, PbO, or V_2O_5. In addition, the rates of attack by various products or processing media in the petroleum and chemical industries are markedly retarded by use of high-chromium alloys, under both oxidizing and reducing conditions.

Chromium also provides moderate solution strengthening in superalloys and, through its effect on the solvus temperatures of precipitated phases, moderate increases in thermal stability of microstructure. However, much more effective solutes are available for each of these latter functions. It is in the area of oxidation and corrosion resistance that chromium is uniquely effective as an alloying constituent, and no fully adequate substitutes are known or foreseen. There has been a trend in the aircraft gas turbine industry toward the use of higher strength alloys, which are somewhat lower in chromium content. In addition, particularly with low-chromium alloys with inherently inadequate hot oxidation or sulfidation resistance, there is increasing use of surface coatings, which also frequently contain chromium. In the event of a sudden curtailment in the supply of metallurgical grade chromite these trends could be accelerated and extended to some other applications. However, the impact of such a move on the overall requirements for chromium in this field would be quite small.

A summary of projected consumption figures for chromium in heat- and corrosion-resistant materials for 1969 and 1974 is presented in Tables 20 and 21. A brief discussion of the trends in each of the categories listed in the tabulation follows below:

1. Nickel-Base Alloys

Due largely to the current shortage of nickel, much attention has recently been focused on the trends in nickel consumption. Several estimates of the use of nickel in nickel-base high-temperature alloys have appeared in the past year. They range from a low of 66 million pounds of contained nickel in nickel-base superalloys, from MAB Publication 248, "Applications of Nickel,"

TABLE 20

Projected Chromium Consumption High-Temperature Alloys

Alloy System	Average Chromium Content (Wt.%)	Thousands of Short Tons Total Alloy Production 1969	1974	Chromium Contained 1969	1974	Growth Rate % per Year
Fe-Base[(a)]	15	22	24.5	3.3	3.7	2.3
Ni-Base	17	94.5	139	16.15	23.65	9.4
Co-Base	22	5	7	1.1	1.55	8.0
Coatings, Cr-Base[(b)] Alloys	--	--	--	0.4	.75	17.2
Total of All High-Temp. Alloys	--	--	--	20.9	29.65	8.2

(a) Includes only alloys not classified as stainless by AISI.

(b) Excludes electrolytic and chemical conversion coatings.

TABLE 21

Breakdown of Chromium Consumption in Nickel-Base Alloys

Nickel Alloy Classification	Average Chromium Content (Wt.%)	Thousands of Short Tons Total Alloy Production 1969	1974	Chromium Contained 1969	1974	Growth Rate % per Year
Sand Castings	15	17.0	28.5	2.55	4.25	13.5
Investment Castings	12	5.5	9.0	.65	1.1	12.7
Wrought Product	18	72.0	101.5	12.95	18.3	8.2
Total Ni-Base(a)	17	94.5	139.0	16.15	23.65	9.4

(a) 1969 production includes 21 million pounds of scrap in melt charges, containing 3.3 million pounds of Cr. Total recovery of Ni-containing scrap in 1968 was 80 million pounds, which included 13.5 million pounds of Cr.

to a high of 97 million pounds of nickel in high-temperature alloys reported in the current Bureau of Mines Minerals Yearbook. Although these figures appear to be rather widely divergent, such is not actually the case. The lower estimate includes only the nickel used in those alloys normally classified as "superalloys," and does not include castings. When these classifications are added, the resultant estimate from MAB-248 is 101 million pounds of nickel consumed in the broader alloy field. The Bureau of Mines estimate, which covers both superalloys and "heat-resistant" alloys (including sand castings) is quite close to this adjusted value. An independent survey of both the nickel and chromium consumption in the entire high-temperature, corrosion resistant alloy field for 1968 was conducted for the present report. The resultant figure for nickel consumption was 115 million pounds, including about 9 million pounds in high-nickel, iron-base alloys. After subtracting the latter, the remainder of 106 million pounds of nickel in nickel-base alloys is seen to be about 5-10% higher than the earlier estimates derived from 1967 and 1966 production and consumption data, and undoubtedly reflects the market growth in the interim between surveys.

When approached from the viewpoint of chromium consumption, the present survey indicated a use of 30.2 million pounds of chromium in all categories of heat-resistant and corrosion-resistant nickel alloys in 1968. The total volume of such alloys last year, including best available estimates of production by the casting industry, was 184 million pounds. Comparison of this value to the individual figures for chromium and nickel consumptions indicates that the "average" nickel alloy in this category contains about 57% Ni and 16.5% Cr. A tabulation of the concentrations of these elements in selected superalloys that are representative of those of current interest is presented below:

Ni-Base Alloy	Nominal Concentration (Wt. %) Ni	Cr
Inconel 713C	75	12.5
Inconel X (Inconel X-750)	74	16
B-1900	65	8
IN-738	61.5	16
IN-100	60.5	10
Mar-M-246	60	9
Waspalloy	58	20
M-252	57.5	19
Astroloy	57	15
René 41	55.5	19
Udimet 500	55	18.5
Udimet 700	54	15
Udimet 710	54	18
Inconel 718	52.5	19
Hastelloy X	49	22
Incoloy 901	42.5	13

Note that the "average" nickel and chromium contents estimated in the preceding paragraph are weighted heavily toward those of alloys that are generally employed in the wrought condition. Over 70% of the shipments of heat-resistant and corrosion-resistant nickel alloys in 1968 were of wrought product. Although there is a continuing tendency toward castings replacing forgings in some applications, such as hot-section components in aircraft gas turbines, the overall trend of the ratio of wrought to cast alloy production is expected to remain in the range of 2:1 to 3:1 through the projection period covered by this report. The chromium content of alloys operating at the higher temperature range will probably decrease, but this will be offset by usage of higher chromium alloys in the 1200-1400 F range (for example, replacement of A-286 and Inconel X by Waspaloy and Rene 41).

2. Iron-Base Alloys

There are several iron-rich, heat-resistant alloys for intermediate temperature application that are in some respects similar to austenitic stainless steels but are not so classified by AISI. The iron and chromium contents of six of the more popular of such alloys are:

	Nominal Concentration (Wt. %)	
Fe-Base Alloy	Fe	Cr
A-286	53	15
CG-27	48	13
Discaloy	54	13.5
Incoloy 801	46	20.5
N-155	30.5	21
V-57	55	15

As shown in Tables 20 and 21, the projected production of alloys of this class in 1969 is 44 million pounds. Considerable quantities are used in shafting, bearing housings, and duct work for turbomachinery, for structural applications in segments of the petrochemical industry, (e.g., hydrocracking), and in marine transportation. In the aircraft gas turbine industry, a number of components that are made from the 13 to 15% Cr alloys in today's engines are being replaced in the next generation by superalloys because of the temperature increases throughout the engines, resulting from ever-increasing turbine inlet temperatures.
Due partly to this factor, as well as to the general reduction in the rate of growth of the overall austenitic market experienced during the past several years, the projected requirement of alloys of this class shows the smallest relative increase between 1969 and 1974. It should be pointed out, on the other hand, that this does not reflect a reduced demand for chromium in the applications considered here.
In many cases, the chromium contents of possible replacement materials are higher than those in these iron alloys for which substitutions are being made.

3. Cobalt-Base Alloys

Free World production and consumption of cobalt have remained relatively constant within the range of 30 to 35 million pounds per year since 1954, with exception of a peak production of 40.5 million pounds in 1966 and a sharp decrease in 1967. Of this total, the United States has consumed 40 to 45% annually over the same period. According to the Cobalt Information Center, the distribution of cobalt consumption by application in the United States differs significantly from that in the Free World as a whole. In this country, approximately 35% of the total is used in the production of heat-resisting alloys and that percentage is growing. The remainder is divided between magnetic materials (20%), nonmetallic uses such as salts, pigments, and ground-coat frit (20%), alloy, high-speed and other tool steels (10%), cemented carbides (5%), and miscellaneous metallic uses (10%). In other nations of the Free World, only about 15% of their total consumption is in the heat-resistant alloy field, with magnetic materials and nonmetallic uses each comprising well over 30% of the cobalt consumed.

The cobalt and chromium contents of several cobalt-base alloys in current use in the United States are shown below:

	Nominal Concentration (Wt. %)	
Co-Base Alloy	Co	Cr
HS-21	62	27
HS-23	66.5	24
HS-151	65	20
HS-188	40	22.5
L-605	53	20
Mar M-322	60	21.5
Mar M-509	55	23.5
S-816	42	20
WI-52	61.5	21
X-40/-45	54	25.5

Alloys such as those listed are used primarily in lower stress, higher temperature components of industrial and aircraft gas turbines such as combustors and stator vanes. These alloys are relatively weak compared to nickel-base superalloys because of the absence of a potent strengthening mechanism such as precipitation of a B_3A phase or other analog to gamma prime. However, they have a higher melting range, which makes them attractive in components subject to non-uniform thermal profiles at elevated temperatures. They are particularly attractive in applications exposed to highly corrosive conditions, largely because of the higher chromium concentrations of 20 to 25%. Nearly equivalent hot-corrosion resistance could be achieved in nickel-base alloys at the same chromium levels, but phase instabilities result from such chromium contents in all but the simplest compositions and cause large reductions in strength. For these reasons, cobalt-base alloys are likely to see expanded use as turbine inlet temperatures increase. If employment of high-pressure gas turbines for prime propulsion in marine transportation increases during the next decade as presently indicated, a substantially greater rate of growth than that shown in Tables 20 and 21 for the period 1969-1974 could result, arising from the superior hot corrosion behavior of high-chromium, cobalt-base alloys.

4. Chromium in Surface Coatings

In this category are considered only those coatings that are produced by techniques that employ the chromium-rich material in the solid state, as opposed to electrolytic or chemical conversion processes. The consumption of chromium in such coatings is difficult to determine accurately both because of the proprietary nature of some coatings and because of the somewhat fragmented structure of the coating and hard-facing industry. A significant fraction of the application is performed by small, specialty shops or by field service organizations. Assuming that approximately 60% of the total quantity of such coatings is produced by the six largest concerns in this field, we arrive at the declared consumption shown in Tables 20 and 21, about 800,000 pounds in 1969.

Although the use of chromium in this area is apparently rather small in comparison to that in plating or chemical conversion coatings, all indicators point to a substantial rate of growth during the projection period. Surveys of the major producers suggest that the expected consumption of chromium in coatings by 1974 will nearly double that estimated for this year. This growth thus represents the largest relative increase in the "high-temperature" field. Increasing requirements for protective coatings in high-performance turbomachinery and processing equipment, and the growing tendency toward inclusion of chromium in the formulation of these coatings, accounts for much of the projected growth.

As a substitute for heavy duty galvanized or for stainless steel, chromizing of carbon sheet steel using low-carbon ferrochromium or chromium metal powder in an extended heat treatment process (with or without rolling), is gaining increased acceptance. This chromized steel is being used to a growing extent for mufflers and tailpipe stock.

5. Tin Free Steel for Cans

Tin Free Steel is black plate which has been electrochemically or vacuum coated with chromium-chromium oxide or chromium phosphate. Shipments of TFS for the first 11 months of 1969 were 530,000 short tons, enough to make 7.9 million cans. The principal market is beer and beverage cans. An estimate of chromium consumption is made in the section on electroplating.

6. Chromium-Base Alloys

Since the end of World War II, a considerable research and development effort on chromium alloys has been sponsored by governments of several Free World nations, notably Australia and the United Kingdom in addition to this country. The sustained interest in chromium as a base for high-temperature structural components is founded on a number of factors. Chromium has a melting point advantage of 500° to 700°F over such more commonly used metals as iron, cobalt, and nickel, and its density is significantly lower than that of the latter two. The oxidation resistance of chromium is vastly superior to that of the heavier, more refractory metals such as columbium, tantalum, molybdenum, and tungsten. Hot-corrosion by environments which contain sulfur or marine salts is greatly retarded in superalloys with only moderate additions of chromium, and chromium-base alloys have shown attractive behavior in limited hot-corrosion testing. The elastic modulus of chromium is higher by about 30% than that of most superalloys, the coefficient of thermal expansion is considerably lower, and the thermal conductivity higher by factors of two to five. These properties combine to offer much greater resistance to thermal shock or thermal fatigue than that exhibited by superalloys. In addition to the physical properties mentioned above, considerations of availability lend support to research on chromium alloys. The world reserves of chromium are estimated at about one billion tons. Thus, chromium is more abundant than nickel, for example, by two orders of magnitude.

The use of chromium alloys as structural components in such applications as advanced air-breathing propulsion systems has been deterred by the lack of ductility at low temperatures, except in the purest forms of the unalloyed metal in the optimum microstructural condition, and by the further embrittlement due primarily to reaction with nitrogen during extended exposure to air at elevated temperatures. There were also some early indications that the potential strength advantage over superalloys, suggested by the increased melting point, could not be realized by conventional alloying approaches.

Several studies of chromium alloys over the past decade have identified alloy systems which not only have, in fact, achieved significant strength increases over the best currently available superalloys at temperatures above about 1800°F, but which also have given indications that the severity of the ductility and nitrogen-embrittlement problems could be greatly reduced. Power metallurgy alloys containing 2 to 5 volume percent MgO as rather massive particles show large tensile elongations at room temperature, have fairly low ductile-brittle transition temperatures in impact, and resist nitrogen embrittlement for reasonably long times at elevated temperatures. However, to date, they have exhibited disappointingly low strengths. The other alloying approach that has shown the most promise to date is based on dispersion of carbides or borides formed by the reactive metals of Groups IV-A and V-A in Cr-Mo or Cr-W matrices. On the basis of creep-rupture characteristics, some alloys of the latter type offer a temperature advantage of at least 200° to 250°F over the strongest superalloys, with 100-hour rupture strengths as high as 20,000 psi at 2100°F. Other carbide-strengthened alloys (which contain no major substitutional solutes for solution strengthening) have shown considerable tensile ductility at sub-zero temperatures in both the wrought and recrystallized conditions, even when produced from chromium grades of only moderate purity.

As noted above, rather large advances in chromium alloy technology have been made. However, all the alloys that offer a significant strength advantage over superalloys at elevated temperatures are brittle at low temperatures, particularly under impact loading. Furthermore, although rare-earth alloying provides increased resistance to further embrittlement during air exposure, there is some additional loss of low-temperature ductility during extended service in air at temperatures above 1800°F. Successful application of chromium alloys in structural components must 1), await the development of surface coatings for protection against nitridation, a field in which promising progress has been made within the last year, and 2), the emergence of an application in which design concessions can be made to the lack of toughness at temperatures below several hundred degrees F, through expedients such as pre-warming. Since properties of chromium alloys at intermediate and elevated temperatures are quite attractive, it is possible that such designs could evolve.

Chromium-base materials find quite limited use in some advanced turbomachinery in special applications such as igniters and shielding for instrumentation. In addition, use of high-chromium composites as high-performance brake linings for aircraft has been established for some time. This usage pattern is not expected to change appreciably by 1974. Within a ten- to twenty-year period either breakthroughs in coating development or design innovations could open the field of hot-section components in gas turbines to chromium-base alloys.

C. Usage of Heat- and Corrosion-Resistant Materials in Selected Applications

Of the overall annual consumption of nonferrous high-temperature alloys in the past several years, the largest fraction has been employed in two major industries— aerospace and petrochemical. Other substantial users include the manufacturers of heat-treating equipment, stationary gas turbines, industrial process equipment, and the hydrospace industry which includes the growing field of undersea exploration in addition to the more established categories such as marine transportation. In the latter area, there are indications that many new surface ships to be built for the U. S. Navy in the immediate future may be powered by high-performance gas turbines. If this proves to be the case, such application of gas turbines will undoubtedly result in a greater demand for chromium because of the superior hot-corrosion resistance of high-chromium alloys.

At the present time, the aerospace industry continues to be the principal user of heat- and corrosion-resistant structural alloys. Although airframe manufacturers and their subcontractors have employed relatively minor quantities of superalloys, this trend will grow as the SST and advanced manned strategic aircraft reach production in 1975 and beyond. Most of the superalloy consumption in this field has been, and will throughout the projection period continue to be, in the production of aircraft gas turbines. In a survey for this report, data were obtained from each of the four largest aircraft engine manufacturers concerning their projected use of chromium as an alloying constituent in high-temperature alloy mill product to be used in engine components for the period 1969-1974. The responses, which appear to be complete with respect to chromium requirements, varied insofar as specification of alloys, or even alloy classes, is concerned. Two responses included the use of chromium in iron-base alloys other than stainless or alloy steels, one specifically excluded such alloys, and a fourth made no mention of this category. Two engine manufacturers reported usage of cobalt-base alloys separately, while the other two combined the figures as total chromium in nickel and cobalt superalloys and in nickel, cobalt, and iron superalloys respectively. Furthermore, definitions of mill product (raw vs. finished) weights were not explicit in all responses. In spite of these limitations, the data are useful as an indication of the quantity of chromium required in superalloys for aircraft engines. They are summarized in Table 22.

TABLE 22

Projected Chromium Usage in Superalloys by Aircraft Engine Industry

Year	Total Mill Product Weight (10^6 Pounds)*	Weight of Contained Cr in Mill Product (10^6 Pounds)
1969	62.10	11.29
1970	61.02	11.10
1971	60.34	10.96
1972	59.02	10.50
1973	57.15	10.31
1974	54.20	9.76

*Estimated as described in text.

The figures presented above do not include (where such information is known) any of the requirements for developmental engine projects, nor do they include all of the mill product requirements for the many subassemblies and parts that are subcontracted to machining and fabricating vendors. They were compiled only from production forecasts for engines that are currently well enough defined to justify estimates of materials requirements. This restriction and the present slowdown in future orders throughout the aerospace industry account for the gradual decline throughout the 1969-1974 projection period. Comparison to Tables 20 and 21 suggests that this decline may not have been factored into the producers' estimates for the mid-1970's.

Detailed alloy requirements were made available by one of the two largest of the aircraft engine manufacturers. Approximately 84 to 87% of the overall superalloy usage estimated for 1969-1974 was in the nickel-base category, in which the average contained chromium was 19.2% in wrought product and 12.6% in castings. The remainder of the requirement was divided between iron-base alloys (averaging 15% Cr) and cobalt-base alloys (averaging 22% Cr). For this one concern, the grand average chromium concentration in all of the high-temperature materials declined from 18.2% Cr in 1969 to 18.0% Cr in the materials forecast for 1974. Assuming that these figures apply reasonably well to the rest of the industry, an estimate can be made of the total superalloy requirement in aircraft engines produced by the four manufacturers in the survey. Such estimates are shown in the center column of Table 22. There are a number of potential inaccuracies as outlined in the foregoing description, but most of these lean toward underestimates of the total consumption. At any rate, it is clear that a large fraction of the annual superalloy production is, and will continue to be, in the manufacture of aircraft gas turbines. For reasons discussed previously, chromium is uniquely required in such alloys, and an effective substitute is neither known nor foreseen.

D. Foundry Industry

1. Castings

There are three types of castings which use chromium:

a. Alloy cast iron

1) Heat, wear and corrosion-resisting castings
2) Automotive body dies
3) Machine tool castings
4) Heavy duty brake drums
5) Cylinder blocks and heads
6) Cam shafts
7) Diesel parts and cylinder liners
8) Automotive valves and valve seat inserts
9) Cast iron valve bodies
10) Exhaust manifolds

The history of all gray and malleable iron castings shipments and their growth rate is given below in thousands of tons:

Year	Shipments 000 tons	% Change
1960	12400	-
1961	11500	- 7
1962	12400	+ 7
1963	13700	+11
1964	15300	+12
1965	16800	+10
1966	16800	0
1967	15300	- 9
1968	16200	+ 6
		+ 4 Avg.

Out of a total of 16.2 million tons of iron castings shipped in 1968, about 2,000,000 tons were alloy cast iron containing an average of 0.4% Cr.

Based on this historical growth for all iron castings, the growth rate for alloy cast iron and the consumption of chromium have been forecast below:

Year	Alloy Cast Iron Shipments, Tons	Cr. Consumption, Tons
1969	2,080,000	8300
1970	2,165,000	8700
1971	2,250,000	9000
1972	2,340,000	9400
1973	2,435,000	9700

Potential substitutes for alloy cast iron: For white iron, highly wear-resistant applications, tellurium or chills can be employed, with changes in casting design and/or foundry controls required. For high-strength alloyed iron, nickel-molybdenum (both frequently scarce also) can be effectively substituted. For corrosion resistance, silicon is partially successful but chromium is still essential.

b. Cast low alloy steel

This category includes such AISI grades as:

1) 8600 series
2) 4100 "
3) 4300 "
4) 4700 "
5) 5000 "
6) 5100 "
7) 52100 "

The Bureau of Census publishes shipment information on (low) alloy steel castings in Series M33z of the Current Industrial Reports:

Year	Shipments of (low) Alloy Steel Castings, thousands of tons	% Change
1960	345	-
1961	346	+ 0.3
1962	431	+25
1963	441	+ 2
1964	487	+10
1965	521	+ 7
1966	546	+ 5
1967	484	-11
1968	454	- 6
		+ 4 Avg.

The estimated average chromium content in low alloy cast steels is 0.6% Cr. A forecast for chromium consumption in low alloy steels is shown below:

Year	Shipments of Low Alloy Steel Castings, tons	Chromium Consumption, tons
1969	473,000	2840
1970	493,000	2960
1971	513,000	3080
1972	533,000	3200
1973	555,000	3330

Potential substitutes for cast low alloy steel: Like the low alloy wrought steels described earlier, other elements (some like Ni and Mo are subject to shortages) can usually be substituted with equal performance. Boron can also be used to retain hardenability while reducing alloy contents.

c. Cast high alloy steel

Under this category is included:

1) 4-6% chromium cast steel
2) Cast 300 series steel
3) Cast 400 series steel
4) Heat-resisting alloys

The Current Industrial Report Census of High Alloy Steel Castings, shows the following:

Year	Shipments of High Alloy Steel Castings, Thousand Tons	% Change
1960	32	-
1961	28	-13
1962	28	0
1963	33	+18
1964	44	+33
1965	62	+41
1966	84	+35
1967	79	+ 6
1968	70	-11
		+14 Avg.

The estimated average chromium content in high alloy cast steels is 17%. A forecast for chromium consumption in high alloy cast steels is given below:

Year	Shipments of High Alloy Steel Castings, tons	Chromium Consumption, tons
1969	77	13,100
1970	85	14,400
1971	94	16,000
1972	103	17,500
1973	113	19,200

Potential substitutes for cast high alloy steel: Where chromium supplies essential corrosion resistance, substitution is limited to more expensive and less plentiful Cu-base, Ni-base, or titanium castings. For high temperature applications, chromium is essential for oxidation resistance.

Summary

The total chromium consumption for castings over the next five years is summarized below:

Chromium Consumption in Tons

Year	Alloy Cast Iron	Low Alloy Cast Steel	High Alloy Cast Steel	Total
1968	8000	2700	11900	22600*
1969	8300	2840	13100	24240
1970	8700	2960	14400	26060
1971	9000	3080	16000	28080
1972	9400	3200	17500	30100
1973	9700	3330	19200	32230

*The 1968 figure is about 70% higher than Bureau of Mines data for foundry chromium. This difference is probably due to incomplete canvass of users.

2. Facing Sands

Although using chemical grade chromite, this application is essentially a refractory application in a metallurgical process. The use for chromite sand is in the replacement of zircon sand. At the present time, zircon sand is the most commonly used facing sand in steel foundries. Chromite for this application should contain at least 44% Cr_2O_3 according to SFSA 16T-67 (Steel Founders Society of America). It seems to have advantages because it has a greater chilling effect, no chemical reactions occur at the higher temperatures of steel casting, and there is less metal penetration under high ferrostatic head. (Source: "Chromite Sand: A Fourth

Dimension for Suppliers," Industrial Minerals, October 1968). It is estimated that 90% of the chromite presently used as a foundry sand is for making steel castings. As a guideline, it is estimated that between 65,000 and 85,000 tons of zircon sand were used in the foundry industry last year. This quantity is a prime target for penetration, but it is possible that some areas where plain silica is now used (and is not considered entirely satisfactory) will qualify as potential markets. Chromite's 10% cost advantage over zircon is another factor in its favor. It is estimated that worldwide consumption of chromite in facing sands is 70,000 to 80,000 tons per year, usage being more popular outside the U.S. at this time.

There appears to be a good technological basis for the use of chromite sand. In addition, there is a possibility that zircon will be in short supply in a few years. For these reasons it is estimated that chromite's use in facing sands will continue to rise with a projection shown below (20 to 30% per year):

	Consumption for Facing Sands (thousands of short tons)	
Year	As Chromite	As Chromium (converted from Chromite)
1968	25	7.70
1969	30	9.24
1970	40	12.32
1971	50	15.39
1972	55	16.93
1973	65	20.01

E. Nonferrous and Special Metals

1966 consumption in these alloys, based on a total market of 581 million pounds of chromium:

Applications

1. Electrical resistance, hard facing, and welding rod (1-32% Cr), glass sealing (5-10% Cr), and Hadfield's manganese steel (0-2% Cr)—9 million pounds per year. Of the total 600,000 pounds per year is in electrical resistance alloys. Growth is about equal to GNP—about 3% per year, with a growth rate of 3-5% estimated for electrical resistance alloys.

2. As alloying element in aluminum (.1-.3% Cr)—1 million pounds per year, used as both oxide and chromium metal. There is a potential for rapid growth of this application, to perhaps 4 million pounds per year in ten years.

3. As alloying element in chromium copper (.5-1.0% Cr)—less than 500,000 pounds per year. Usage of chromium-copper grew rapidly in the past five years in spot welding electrodes, heater contacts and electrical structural elements. Substitutes may make inroads in these uses.

Potential Substitutions

1. There is no real substitute for 80-20 nichrome for electrical resistance heating elements.

2. For hard facing alloys, tungsten alloys could be substituted at much higher cost. Some chromium is probably essential in all hard facing alloys for necessary hardiness.

3. For welding rod, chromium is used to match parent metal properties. Finely ground powders (20 mesh) of FeCr and fluxes are applied to steel rod.

4. Aluminum alloys—small chromium additions important in influencing the precipitation rate in 7075, Al-Mg, etc. This is a small but important use.

5. Chromium copper—small but important usage as hardener in copper alloys—future criticality depends on potential development of alternative materials. For the near future, this application should be protected.

6. Glass sealing alloys—critical application requiring chromium to match expansion coefficients of nonmetallic materials— small but important application.

F. Summary of Metallurgical Applications

As stated above, many nonstrategic applications could be discontinued or substituted in an emergency. However, where a defense item needs corrosion or oxidation resistance, deep hardenability, or specialized tooling, the opportunities for substitution of chromium are much more limited than for molybdenum, nickel and similar elements in which a property such as hardenability can be achieved to some degree by any of several elements.

The Introduction to this report summarizes total chromium requirements for these alloys in 1968 and projected for 1973.

IV. CHEMICAL APPLICATIONS

A. Applications and Normal Growth Rates

Figure 3 projects total chromium chemical usage in the U. S. expressed as sodium bichromate. Table 23 summarizes the 1968 applications and expected growth rates to 1975. Table 24 projects, for the same time period, the distribution of various chromium chemicals and the portion derived from chemical imports.

1. Pigments

Chromium pigments represent the largest outlet for sodium bichromate with about 33.6% of the total production going for this use. This market is growing about $2\frac{1}{2}$% per year. Sodium bichromate is used to manufacture chrome green, chrome oxide green, chrome yellow, molybdate orange, and zinc chromate pigments. These pigments are used primarily in paints, inks, and roofing granules. Much of the chromium pigments are used in traffic paints and industrial paints for products such as tractors, taxis, and school buses. Chrome oxide green is used primarily in roofing and siding compounds and asphalt shingles.

Imports of chromium oxide pigments have increased rapidly over the past five years, particularly for chrome yellows, zinc chromate, and chrome oxide green. This is due to the much lower prices being quoted by foreign countries such as Japan.

2. Plating

The plating market is expected to grow at 3.1% per year and consumes about 20% of all the sodium bichromate produced. This is all in the form of chromic acid which is manufactured from sodium bichromate. It includes decorative chromium plating for automobiles, appliances and other consumer goods,

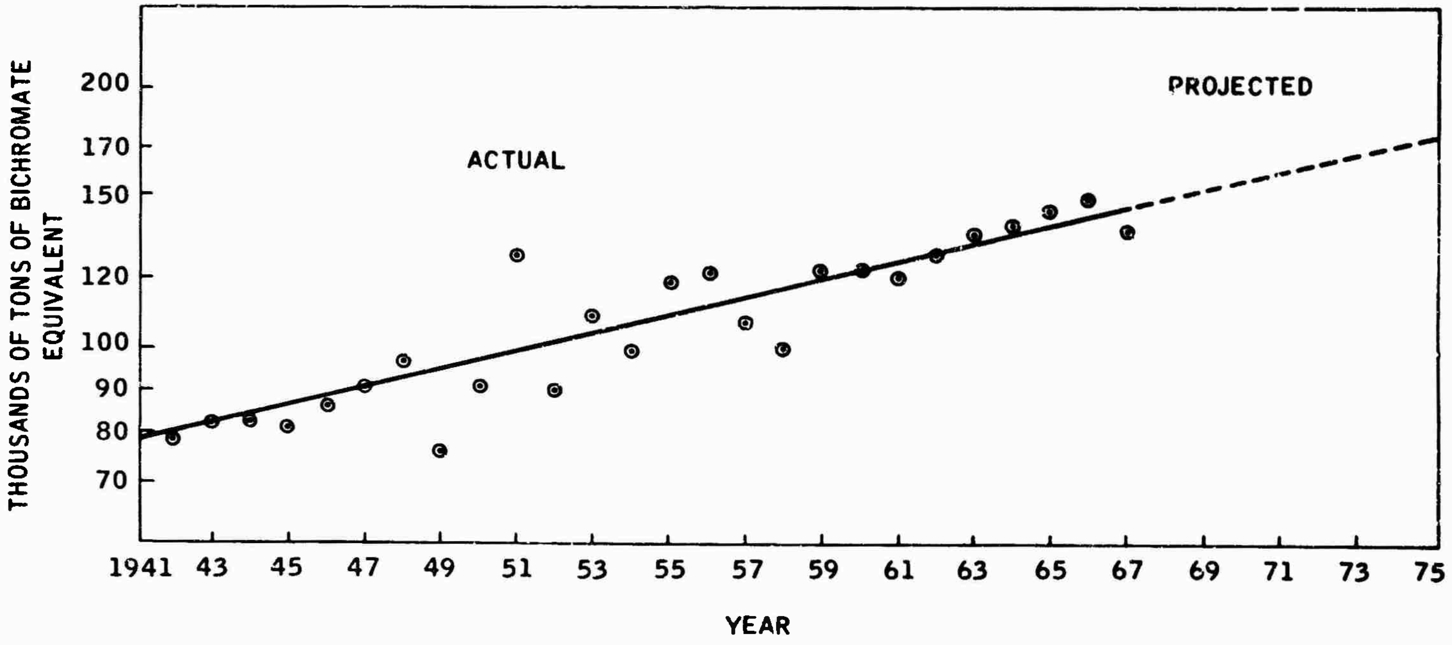


FIGURE 3. - History and Projection—U.S. Production Plus Imports of Chromium Chemicals (Expressed on Sodium Bichromate Equivalent Basis)

TABLE 23

Consumption of Chromium Chemicals - 1968

Segment	U. S. Consumption Chromium Consumption, Tons	U. S. Consumption % of Total	Expected Growth Rate 1968-1975 % per Year
Pigments	24,000	33.6	2.5
Plating	14,600	20.7	3.1
Leather	10,400	14.7	-1.1
Metal treatment	3,320	4.7	2.5
Drilling mud	3,270	4.6	4.0
Metallurgy and miscellaneous	3,230	4.6	1.9
Catalysts	2,490	3.4	4.0
Export	2,220	3.1	2.0
Textiles	2,110	3.0	2.5
Pharmaceuticals and fine chemicals	2,110	3.0	5.0
Water treatment	1,870	2.6	2.5
Wood treatment	1,440	2.0	5.0
TOTAL	71,060	100.0	2.4

TABLE 24

PROJECTED CONSUMPTION BY FORM

Sodium Bichromate Equivalent

(all weight in tons)

	1968	1969	1970	1971	1972	1973	1974	1975
Consumption - All Chromium Chemicals								
U.S. Production - Bichromate Equivalent	145,503	148,791	152,308	155,904	159,591	163,369	167,057	170,997
Imports	4,120	4,244	4,371	4,502	4,637	4,776	4,919	5,067
Total Consumption Including Exports	149,600	153,000	156,700	160,000	164,200	168,100	172,000	176,000
Consumption By Product - Bichromate Equivalent								
Sodium Bichromate (Incl. Tans)	103,243	105,274	107,359	109,511	111,738	114,040	116,318	118,676
Chromic Acid	40,781	42,041	43,464	44,901	46,354	47,822	49,226	50.802
Potassium Bichromate	4,786	4,885	4,998	5,113	5,231	5,353	5,477	5,605
Sodium Chromate	813	835	858	881	905	930	955	981
Total	149,600	153,000	156,700	160,400	164,200	168,100	172,000	176,100

and hard chromium plating of machine tools. Tin free steel-chromium type (TFS-CT) is a relatively new replacement for tinplate in the canning industry. Although it consumes a relatively minor amount of chromium, it has been a fast growing development. Table 25 summarizes 1967 applications in plating expressed as chromic acid.

If a nickel shortage persists, the growth of chromium decorative plating may be curtailed or actually decline. Parts, such as automotive trim, would then tend toward aluminum or stainless steel (also chromium containing). Plated plastics, on the other hand, would use the same amount of chromium in plating, but eliminate the nickel.

There are some potential pollution problems in this area which have not yet been quantified. There are systems available for recovering waste plating solutions and these may be installed in plants in the future.

3. Leather

The leather market consumes about 14.7% of the total sodium bichromate and is expected to decline at about 1.1% per year. This is due primarily to the decline in leather produced because of increasing competition from poromeric materials and imported shoes. The bichromate is used in the tanning process as a prepared tanning solution.

4. Miscellaneous

The remaining uses are small in number and none account for over 5% of the total. These will be discussed briefly:

a. Metal treatment

Sodium bichromate or chromic acid is used as a corrosion inhibitor for ferrous and nonferrous metals. Its effectiveness with steel lies with its ability to form a resistant film of ferric oxide and ferric chromic oxide on metal.

TABLE 25

Consumption of Chromic Acid in Various Plating Processes During 1967

(short tons)

	Chromic Acid	As Chromium (converted from anhydrous CrO_3)
Decorative Plating	11,000	5,720
Industrial Hard Chromium Plating	5,000	2,600
Other Metal Finishing (Chromate conversion coatings, anodizing, stripping)	5,000	2,600
TOTAL	21,000	10,920

b. Drilling muds

Sodium bichromate is used to produce ferrochrome lignosulfonate which is used in oil drilling muds. The product gives effective deflocculation, good sealing characteristics, and has a high density. Growth is expected to be about 4% per year.

c. Catalysts

There are a number of catalysts produced from sodium bichromate and chromic acid. One of the largest uses is in production of hydrogen for ammonia plants. Chromium is used with iron oxide as a promoter in the high temperature catalytic reaction. Other catalysts include copper chromite for hydrogenating soy bean oil and the hydrogenation of aromatics. Growth is projected at about 4% per year.

d. Textile dyes

Wool and silk are first dyed with azo dyes. The dyed wool is then chromed with a solution of sodium bichromate. The hexavalent chromium is reduced by the wool or silk fiber to chromium hydroxide which forms a complex for the dye. Most of the use is for chrome black which will grow at about 2½% per year. Competition from other dyes is reducing the growth in this area.

e. Pharmaceutical and fine chemicals

Sodium bichromate and chromic acid are used to produce Vitamin K and other fine chemicals by oxidizing the organic compound. Future pollution problems in this area will limit growth to about 5% per year.

f. Water treatment

Sodium bichromate is used in the manufacture of water treating compounds for use in water cooling towers and for refrigeration and air conditioning. Increased enforcement of stream pollution laws will reduce the growth in this area to 2½% per year because of the added expense for treating chromium containing wastes when systems are purged and the solutions discarded.

g. Wood treatment

Sodium bichromate is reacted with copper and zinc compounds to produce proprietary wood treating compounds for railroad ties, telephone poles and other wood products which are exposed to the elements. The growth in this area is expected to be about 5% per year.

B. Potential Impacts of Changing Technology

1. Major Impact

a. Water treatment

Those industrial installations that prefer not to install waste chromium treatment facilities are expected to use much higher-priced water treatment chemicals. This will be a direct result of enforcement of anti-pollution legislation.

b. Textiles

Though a small use, it will be adversely affected by anti-pollution measures. Sodium bichromate has been especially popular as a mordant to produce lasting colors on wool and a portion of broad woven cotton goods production. Bichromate has been a starting material to make other chromium mordants. Classically, it is also an oxidizer to convert aniline to aniline black.

2. Intermediate Impact

a. Leather tanning salts based on chromium

The advent of Corfam and similar synthetics will bring price pressure on natural leather. Continuation of beef and other animal slaughterings in this country will assure a large supply of hides. In all probability more hides will be exported and finished leather goods, such as shoes, will be imported from abroad from such hides. The net result will be a further decline in the output of domestically tanned leather.

b. Electroplating

Improved plating processes should increase the demand for chromium deposits on metals and plastics in the future. Chromium based conversion coatings for aluminum, zinc, cadmium, and magnesium should also consume increased quantities of chromium chemicals.

Tin free steel-chromium type (TFS-CT) is the most widely accepted substitute for tinplate in the container industry. It is already extensively used for beer and soft drink cans, and could be used for the closures and ends of process food cans. The shift to TFS-CT is dependent on the capability and cost of converting to adhesive bonding or welding, which it requires, from the conventional soldering of tinplate. With current trends, it is estimated that chromium requirements for TFS-CT would be about 240 tons of bichromate (115 tons Cr) in 1970 and 480 tons (230 tons Cr) in 1973, resulting in an added 1.5% to projected 1973 consumption. This shift from tinplate to TFS-CT could be accelerated, if a tin shortage were to develop.

c. Medicinal and related products

Alternative manufacturing routes are available to make certain of these products, such as some sweeteners and vitamins, and cloud the growth for chromium chemicals in this minor end use.

3. No Impact

a. Pigments

Pigments based on chromium are inexpensive and effective. Demand in the future for this major end use are expected to grow at 2.5% annually. No encroachment is anticipated from newer products.

b. Wood treatment

Wood treatment has been a minor outlet for chromium chemicals for decades. Chromium-containing formulations are used for preservation of wood and to render it termite resistant. No substitutions are currently visualized.

c. Drilling muds

Drilling muds use chromium chemicals in several ways. Because of their use, twistoffs of drillstrings are minimized. Chromium containing muds reduce corrosion of the casing of the well bore. Chromium aids in dispersing clays and other fillers and helps in adjusting the viscosity of the mud, thereby reducing loss of mud into the formation. Popularity of such chemical formulations, entrenched for 25 years, is expected to continue.

d. Catalysts

Catalysts containing chromium values are highly specific, with no short term rivalry anticipated now. Such catalysts are used to synthesize ammonia and methanol, etc. and for many hydrogenation and polymerization reactions.

C. Possible Substitutes for Chromium Chemicals During a National Emergency

1. Water Treatment

Water treatment with chromium chemicals could be halted on short notice but the inplace facilities would undergo rapid corrosion. Sodium silicate, though only about 70% as efficient as chromium salts, is a possible replacement.

2. Textiles

For mordant usage, aluminum hydroxide may be used but it is slower acting. Hydrogen peroxide will serve where an oxidizing agent is required, but at a higher cost than chromium.

3. Leather

Chromium tanning salts could be replaced by the less effective vegetable tans. Since most of these latter compositions are based on imported quebracho bark, the availability on an emergency basis would be speculative. More likely, Corfam and similar products would satisfy part of the market need. Substitute plastics, not ideally tailored for leather markets, could temporarily fill the residual market void. Meanwhile, hides could be salted and stored. Zirconium salts could be used to make critically needed leather goods.

4. Electroplating and Conversion Coatings

There are no good substitutes for chromium in industrial hard plating. However, decorative plating could be eliminated in a national emergency. Nickel, cadmium, zinc, or ceramics could be substituted for functional coatings. Automobile bumpers could be painted or plated with other metals, such as nickel, provided that it were not in short supply.

5. Medicinal and Related Products

Chromium-consuming reactions may be replaced by alternative routes although yields are lower where chromium usage is specific.

6. Pigments

Chrome yellow has no replacement. Without the availability of this pigment, yellow-colored volume commodities would vanish from the scene. Consumers would be forced to use other colors. An example would be white paints made from precipitated calcium carbonate and titanium dioxide. Because of its brittleness molten sulfur applied directly to highways would not be suitable under weathering and traffic conditions. Paving-brick. colored with the admixture of sulfur as a coloring agent, would serve on a short-term basis. Chrome molybdenum orange could be replaced by other colors at a higher price. No substitute is felt to be currently available for chrome green although ersatz mixtures might be devised from other yellows and blues.

7. Wood Treatment

Wood treatment by chromium salts could be replaced with more toxic pentachlorophenol. Creosote is another substitute for preservation use.

8. Drilling Needs

Drilling needs would be set back 25 years by elimination of chromium salts in the mix. No replacements are known to do the same job as chromium chemicals for this application.

9. Catalysts

No overall replacements are visualized at this time. Mixtures of iron and manganese have been tried for some of these specific reactions but do not offer the same yields.

V. REFRACTORY APPLICATIONS

A. Current and Future Requirements

1. Usage in 1968 and Projection for 1975 (net tons)

Application	1968	1975	CHANGE Tons	CHANGE %
Open Hearth Furnaces	120,000	64,000	-56,000	-47
Electric Furnaces	33,000	60,000	+27,000	+83
Chrome Gunning Mixes	127,000	66,000	-61,000	-48
Others	30,000	40,000	+10,000	+33
TOTAL	310,000	230,000	-80,000	-26

These trends are illustrated in Figure 4.

2. Reason for Change

The consumption of refractory chromite is closely related to the open hearth furnace, which is experiencing a rapid decline. Other applications of refractories containing chromite are growing slightly but this growth cannot compensate for the open-hearth downtrend.

The projected chromite consumption for 1975 is 230,000 tons, a decline of 80,000 tons from estimated usage in 1968. This change is explained by the expected sharp drop-off of open-hearth steel production in this period. Increased use in refractories for electric arc furnaces and some other smaller applications should not be enough to offset open-hearth losses.

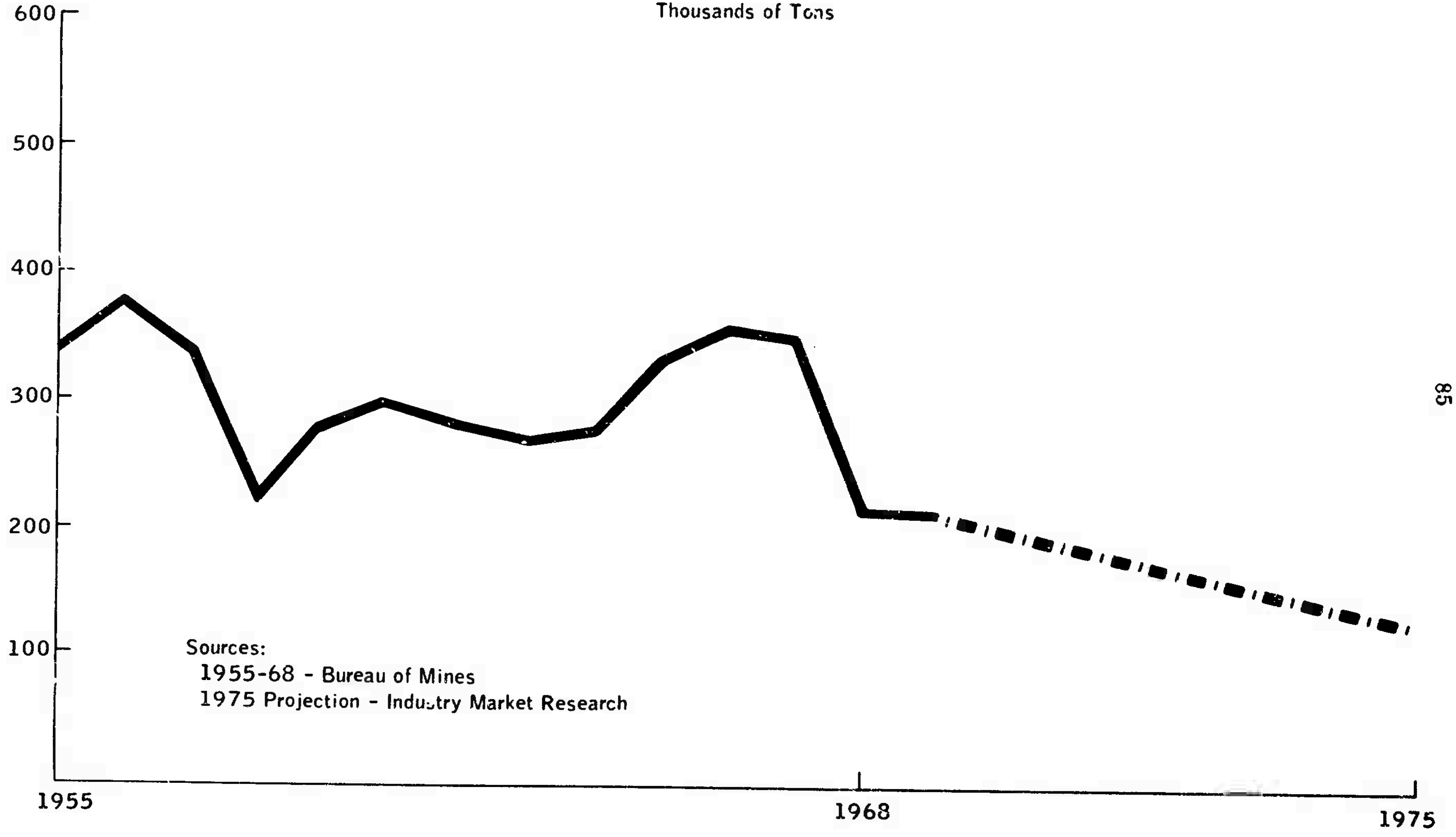
3. Growing Applications

Increased use in electric arc furnaces. Increased use in other smaller applications.

FIGURE 4.

U.S. Refractory Chrome Ore Consumption.

Thousands of Tons



Sources:
1955-68 - Bureau of Mines
1975 Projection - Industry Market Research

4. Declining Applications

Decreased use in the open-hearth furnaces due to the growth of the basic-oxygen furnaces.

Decreased use in chrome gunning mixes due to the growth of the basic-oxygen furnaces.

B. Supply and Availability

World reserves and potential resources are estimated to total 2,650 million long tons (Refer to Table 7, Chapter II, page 15. Two thousand million tons are in the Republic of South Africa, and 600 million tons are in Rhodesia. Eighty-four percent is high-iron, 16 percent high-chromium, and only 0.06 percent high-aluminum material (refractory grade). The Philippines reserves of refractory ore exceed 6 million tons.

Major changes in the supply and use patterns over the next ten to twenty years will involve increasing use of fines and concentrates, increasing interchangeability of use among the different chrome ore types, and increasing reliance on a relatively few large resources. *

C. National Emergency

1. Supply depends completely on foreign sources, mainly the Philippines and Republic of South Africa (Transvaal), for refractory grade.

2. As described in Chapter II, Section C, page 31. the present stockpile refractory-grade specification calls for lower chromium and iron, and higher silica, than the low silica Philippine and Transvaal concentrates now being used.

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*Mineral Facts and Problems - 1965 Edition Bureau of Mines, Bulletin 630.

If the ore in the stockpile corresponds to the specification, the refractory industry would recommend its further beneficiation to make it suitable for present refractory technology.

3. Substitution of magnesite for chromite can be effected for some refractory products. However, cost-performance would be adversely influenced.

D. Summary and Recommendations Regarding Chromite for Refractory Uses

It appears that a potential program might be:

1. If the present stockpile corresponds to the current specification, which is not very suitable for present refractory technology, the GSA should offer for sale a large portion, perhaps as much as 75% of the present refractory grade chromite stockpiles.

2. At the same time, smaller stockpiles of Philippine and Transvaal concentrates should be built to insure availability of this material in an emergency, keeping in mind that there will be a decreasing demand for even this type of chromite as open hearth furnaces disappear.

3. As an alternative to 1 and 2, the present stockpile could be maintained with the knowledge that in an emergency, refractories of lower quality could be produced from it "as is," or it could be beneficiated to "concentrate" quality with additional investment in beneficiating equipment and considerable loss of material as "tailings."

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THE NATIONAL ACADEMY OF ENGINEERING was established on December 5, 1964. On that date the Council of the National Academy of Sciences, under the authority of its Act of Incorporation, adopted Articles of Organization bringing the National Academy of Engineering into being, independent and autonomous in its organization and the election of its members, and closely coordinated with the National Academy of Sciences in its advisory activities. The two Academies join in the furtherance of science and engineering and share the responsibility of advising the Federal Government, upon request, on any subject of science or technology.

THE NATIONAL RESEARCH COUNCIL was organized as an agency of the National Academy of Sciences in 1916, at the request of President Wilson, to enable the broad community of U. S. scientists and engineers to associate their efforts with the limited membership of the Academy in service to science and the nation. Its members, who receive their appointments from the President of the National Academy of Sciences, are drawn from academic, industrial and governmental organizations throughout the country. The National Research Council serves both Academies in the discharge of their responsibilities.

Supported by private and public contributions, grants, and contracts, and voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

THE DIVISION OF ENGINEERING is one of the eight major Divisions into which the National Research Council is organized for the conduct of its work. Its membership includes representatives of the nation's leading technical societies as well as a number of members-at-large. Its Chairman is appointed by the Council of the Academy of Sciences upon nomination by the Council of the Academy of Engineering.

THE NATIONAL MATERIALS ADVISORY BOARD is a unit of the Division of Engineering of the National Research Council. Organized in 1951 as the Metallurgical Advisory Board, through a series of changes and expansion of scope, it became the Materials Advisory Board and, in January 1969, the National Materials Advisory Board. In consonance with the scope of the two Academies, the general purpose of the Board is the advancement of materials science and engineering, in the national interest. The Board fulfills its purpose by: providing advice and assistance, on request, to government agencies and to private organizations on matters of materials science and technology affecting the national interest; focusing attention on the materials aspects of national problems and opportunities, both technical and nontechnical in nature, and making appropriate recommendations as to the solution of such problems and the exploitation of these opportunities; performing studies and critical analyses on materials problems of a national scope, recommending approaches to the solution of these problems, and providing continuing guidance in the implementation of resulting activities; identifying problems in the interactions of materials disciplines with other technical functions, and defining approaches for the effective utilization of materials technologies; cooperating in the development of advanced educational concepts and approaches in the materials disciplines; communicating and disseminating information on Board activities and related national concerns; promoting cooperation with and among the materials-related professional societies; maintaining an awareness of trends and significant advances in materials technology, in order to call attention to opportunities and possible roadblocks, and their implications for other fields, and recognizing and promoting the development and application of advanced concepts in materials and materials processes.