

**IC 9275**

**BUREAU OF MINES  
INFORMATION CIRCULAR/1991**

# **Chromium, Nickel, and Other Alloying Elements in U.S.-Produced Stainless and Heat-Resisting Steel**

**By John F. Papp**



**UNITED STATES DEPARTMENT OF THE INTERIOR**

REPRODUCED BY  
U.S. DEPARTMENT OF COMMERCE  
NATIONAL TECHNICAL  
INFORMATION SERVICE  
SPRINGFIELD, VA 22161

**Mission:** As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. <b>PB92-178623</b>	2. REPORT DATE <b>1991</b>	3. REPORT TYPE AND DATES COVERED <b>IC 9275</b>	
4. TITLE AND SUBTITLE <b>Chromium, Nickel, and Other Alloying Elements in U.S.-Produced Stainless and Heat-Resisting Steel</b>		5. FUNDING NUMBERS	
6. AUTHOR(S) <b>John F. Papp</b>		8. PERFORMING ORGANIZATION REPORT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)		9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) <b>BOM 810 7th Street, NW Washington, DC 20241</b>	
11. SUPPLEMENTARY NOTES		10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
12a. DISTRIBUTION/AVAILABILITY STATEMENT		12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  <div style="text-align: center;"> <p><b>IC 9275. Chromium, Nickel, and Other Alloying Elements in U.S.-Produced Stainless and Heat-Resisting Steel</b>, by John F. Papp. 1991. 41 pp. The objective of this U.S. Bureau of Mines study is to calculate an accurate, reliable estimate of chromium and nickel content of stainless and heat-resisting steel produced in the United States. The columbium, manganese, molybdenum, titanium, tungsten, and vanadium contents of this steel are also calculated. Such contents are required for estimating the quantity of alloying element recovered from recycled stainless steel and consumed by market sectors. In this investigation, the elemental fraction of stainless and heat-resisting steel was calculated as the ratio of the weight of element contained in stainless steel to the weight of stainless steel produced. The elemental fraction has been calculated as a time-averaged, grade-averaged value. The elemental fraction was averaged from 1962 through 1983, and averaged over the grades for which production was reported by the American Iron and Steel Institute during that time period. The 1962-83 average elemental fraction of U.S.-produced stainless and heat-resisting steel was calculated for chromium to be about <math>0.17 \pm 0.01</math>; columbium, <math>0.00014 \pm 0.00003</math>; manganese, <math>0.015 \pm 0.005</math>; molybdenum, <math>0.004 \pm 0.001</math>; nickel, <math>0.07 \pm 0.01</math>; silicon, <math>0.009 \pm 0.001</math>; titanium, <math>0.0004 \pm 0.0001</math>; tungsten, <math>0.0001 \pm 0.00003</math>; and vanadium, <math>0.00003 \pm 0.00001</math>.</p> </div>			
14. SUBJECT TERMS		15. NUMBER OF PAGES <b>49</b>	
17. SECURITY CLASSIFICATION OF REPORT <b>Unclassified</b>		16. PRICE CODE	
18. SECURITY CLASSIFICATION OF THIS PAGE <b>Unclassified</b>	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT	

## GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to *stay within the lines* to meet optical scanning requirements.

### Block 1. Agency Use Only (Leave blank).

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C - Contract	PR - Project
G - Grant	TA - Task
PE - Program Element	WU - Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. (If known)

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

DOD - See DoDD 5230.24, "Distribution Statements on Technical Documents."

DOE - See authorities.

NASA - See Handbook NHB 2200.2.

NTIS - Leave blank.

Block 12b. Distribution Code.

DOD - Leave blank.

DOE - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.

NASA - Leave blank.

NTIS - Leave blank.

Block 13. Abstract. Include a brief (*Maximum 200 words*) factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code (*NTIS only*).

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

i.a

**Information Circular 9275**

**Chromium, Nickel, and Other Alloying  
Elements in U.S.-Produced Stainless  
and Heat-Resisting Steel**

**By John F. Papp**

**UNITED STATES DEPARTMENT OF THE INTERIOR  
Manuel Lujan, Jr., Secretary**

**BUREAU OF MINES  
T S Ary, Director**

**Library of Congress Cataloging in Publication Data:**

**Papp, John F.**

Chromium, nickel, and other alloying elements in U.S.-produced stainless and heat-resisting steel.

(Bureau of Mines information circular; 9275)

Supt. of Docs. no.: I 28.27:9275.

1. Chrome-nickel steel. 2. Steel, Stainless. 3. Steel, Heat resistant. I. Title.  
II. Series: Information circular (United States. Bureau of Mines); 9275.

TN295.U4 [TN757.C49] 6221.08s [669'.96142] 88-600144

## CONTENTS

	<i>Page</i>
Abstract .....	1
Introduction .....	2
Bureau of Mines role .....	2
Objective .....	2
Previous estimates .....	3
Information sources .....	4
Unified Numbering System .....	4
American Iron and Steel Institute .....	4
American Society for Metals .....	5
Chemical elements .....	5
Element functions .....	5
Acknowledgments .....	6
Procedure .....	6
Method .....	6
Universal set .....	7
Chemical constituent specifications .....	7
AISI production set .....	8
Grade-to-type relationship .....	10
Uncertainty .....	10
Results .....	10
General .....	10
Production subcategory .....	11
Other .....	12
Element summary .....	15
Discussion .....	16
Elemental fraction definition .....	16
Uncertainty .....	16
Impact of Type 409 .....	17
Comparison of results .....	17
Alternative method .....	18
Chromium and nickel use .....	19
Conclusions .....	20
References .....	20
Appendix A.—Glossary of abbreviations .....	21
Appendix B.—Grade chemical specifications .....	22
Appendix C.—<E> definition .....	24
Appendix D.—Uncertainty .....	30
Appendix E.—Stainless and heat-resisting steel production .....	32
Appendix F.—<E' >, Type 409, 1977-83 time period .....	38
Appendix G.—<E'' > .....	40

## TABLES

1. Annual apparent consumption for several alloying elements, 1973-83 average .....	3
2. Elements referenced by UNS chemical specifications .....	7
3. Production set category names defined in terms of AISI type category names and period of use .....	8
4. Elemental fraction, uncertainty, and components specific and descriptive of uncertainty based on 1962-83 production .....	10
5. Average midpoint elemental fraction, by subcategories by element .....	11
6. Average midpoint elemental fraction, by selected production subcategory by element .....	12
7. Chromium content, fraction, and deviation for annual production .....	13

## TABLES—continued

	<i>Page</i>
8. Nickel content, fraction, and deviation for annual production .....	13
9. Molybdenum content, fraction, and deviation for annual production .....	14
10. Estimated elemental content of average stainless steel scrap receipts, average apparent consumption, and average metallurgical apparent consumption .....	14
11. Comparison of <E> and <E''> .....	19
B-1. Ambiguous UNS element specifications and interpretation .....	23
C-1. Association of UNS grades with descriptive AISI types .....	25
C-2. Chromium, nickel, molybdenum, and manganese minimum and maximum weight fraction in steel, by type .....	27
C-3. Columbium, vanadium, silicon, titanium, and tungsten minimum and maximum weight fraction in steel, by type .....	28
E-1. Stainless steel production for 1962-69, by type .....	32
E-2. Stainless steel production for 1970-77, by type .....	33
E-3. Stainless steel production for 1978-83, by type and by year, and 1962-83 average production, by type ....	35
E-4. Production of stainless steel, by specific and descriptive subcategories, by year .....	36
E-5. Production of stainless steel, by selected production subcategories, by year .....	36
F-1. Comparison of the estimated effect on elemental fraction due to Type 409 separation from "All other," with calculated change in elemental fraction .....	39
F-2. Elemental fraction, uncertainty, and components of total uncertainty .....	39
G-1. Scrap receipts and consumption, and element reported consumption for stainless steel production, by year .....	40
G-2. Alloy element consumption required per unit of stainless steel production .....	41

# CHROMIUM, NICKEL, AND OTHER ALLOYING ELEMENTS IN U.S.—PRODUCED STAINLESS AND HEAT-RESISTING STEEL

By John F. Papp<sup>1</sup>

---

## ABSTRACT

The objective of this U.S. Bureau of Mines study is to calculate an accurate, reliable estimate of chromium and nickel content of stainless and heat-resisting steel produced in the United States. The columbium, manganese, molybdenum, titanium, tungsten, and vanadium contents of this steel are also calculated. Such contents are required for estimating the quantity of alloying element recovered from recycled stainless steel and consumed by market sectors.

In this investigation, the elemental fraction of stainless and heat-resisting steel was calculated as the ratio of the weight of element contained in stainless steel to the weight of stainless steel produced. The elemental fraction has been calculated as a time-averaged, grade-averaged value. The elemental fraction was averaged from 1962 through 1983, and averaged over the grades for which production was reported by the American Iron and Steel Institute during that time period.

The 1962-83 average elemental fraction of U.S.-produced stainless and heat-resisting steel was calculated for chromium to be about  $0.17 \pm 0.01$ ; columbium,  $0.00014 \pm 0.00003$ ; manganese,  $0.015 \pm 0.005$ ; molybdenum,  $0.004 \pm 0.001$ ; nickel,  $0.07 \pm 0.01$ ; silicon,  $0.009 \pm 0.001$ ; titanium,  $0.0004 \pm 0.0001$ ; tungsten,  $0.0001 \pm 0.00003$ ; and vanadium,  $0.00003 \pm 0.00001$ .

---

<sup>1</sup>Physical scientist, Branch of Ferrous Metals, U.S. Bureau of Mines, Washington, DC.

## INTRODUCTION

### BUREAU OF MINES ROLE

The Bureau of Mines carries out its national defense responsibilities through the monitoring of critical and strategic mineral and material information and through metallurgical research (1).<sup>2</sup> In the areas of mineral information monitoring, (secondary) domestic resource identification, and conservation (including substitution), data about the use of minerals provide important information. Aggregated mineral import and export data are frequently obtainable through records collected by the U.S. Department of the Treasury and distributed by the U.S. Department of Commerce. For minerals with negligible domestic production, such import-export data yield aggregated use information at the national level. Information regarding strategic and critical mineral and material use is difficult to obtain, especially for categories that have not been greatly aggregated. The reasons for this difficulty include: (1) as aggregated mineral end use is disaggregated, the number of end uses increases dramatically; (2) as specific end uses are approached, mineral use becomes business proprietary information; and (3) end use of a material is sometimes reported in dollar value instead of material quantity, making analysis difficult if not impossible.

In order to project demand, assess conservation-substitution scenarios, or estimate stockpile requirements for critical and strategic materials, it is useful to first describe the usage of the material. Disaggregated material demand data may identify some uses with greater potential for substitution or conservation than other uses. Disaggregated demand data could help identify end-use categories most likely affected by material substitution based on a given set of physical properties. It is possible that demand projections based on disaggregated categories could be more accurate than those based on aggregated demand categories. Fortunately, data are available upon which disaggregated historical material consumption calculations can be based for steel end use.

### OBJECTIVE

An understanding of the concept and use of apparent consumption is critical to understanding the purpose and objective of this study. Apparent consumption will be defined, followed by an explanation of the significance of the chromium apparent consumption and an evaluation of the various possible approaches to determining elemental content required to calculate apparent consumption. Finally, the method used in this study will be summarized,

and previously published chromium elemental fractions will be compared.

Apparent consumption is an estimate of national consumption of a commodity based on a national materials balance adjusted for internal material flows. Apparent consumption is imports plus domestic production minus exports plus stock adjustments. Domestic production has two components, primary and secondary. Primary production comes from mining; i.e., the product, coproduct, or byproduct of a mining operation. Secondary production comes from a previously used material (nonmining sources); e.g., recovery from recycled metal scrap or reclaimed waste. Apparent consumption is measured in element contained weight.

Historical values of apparent consumption are extrapolated by planners to estimate future demand. This demand-estimating procedure may be carried out in great detail for one part of the commodity and market for the short term (1 to 5 years) by manufacturers who estimate demand for their product. A company plans its activities based on such estimates. Such extrapolation may be performed for the long term (20 years) in order to estimate long-term demand. National planners compare domestic reserves with accumulated future demand to anticipate shifts in foreign dependence. They compare market economy reserves with accumulated future demand to anticipate changes in dependence on resources from planned economy countries. National mineral resource policy results from these considerations. Other factors of these extrapolations being the same, the more accurate and reliable the apparent consumption, the more accurate and reliable will be the national dependence and adequacy of supply estimates upon which national policy is based.

The number of components that contribute to apparent consumption and their relative importance varies with commodity and time. Secondary production is generally recognized as a significant component of chromium and nickel apparent consumption. For chromium, secondary production from scrap is the only component of domestic production. Recycled stainless steel scrap containing chromium currently accounts for virtually all of chromium secondary production. Stainless steel, while being recognized as a significant source of demand for molybdenum, as scrap is not generally recognized as a significant source of secondary supply.

It is the objective of this report to determine an accurate and reliable estimate of the elemental content of stainless steel scrap in order to make the determination of apparent consumption as accurate as possible. For those commodities for which stainless steel scrap does not make a significant contribution, it is the objective of this report to quantify the amount currently disregarded.

<sup>2</sup>Italic numbers in parentheses refer to items in the list of references preceding the appendix at the end of this report.

Some possible strategies for determining the elemental content of scrap are as follows:

1. Survey the industry, scrap merchants, and consumers, seeking to reach a value by consensus.
2. Assume that all stainless scrap is the most commonly produced grade, and use the elemental content of that grade for all stainless steel scrap.
3. Calculate the elemental content of stainless steel based on the quantity of production by grade and the elemental composition of the grade, and assume scrap to be of the same composition.
4. Assume that scrap is 20 years old and apply strategy 3 above to production of 20 years ago to estimate today's elemental content of scrap.

Each of the strategies presented for developing an elemental content of stainless steel scrap has advantages and disadvantages, some of which depend on the purpose for which the calculation is made. In this study, the purpose is to obtain an elemental content of stainless steel scrap that can be applied to apparent consumption calculation extending over a historical time period of about 20 years. This is the time period from which future apparent consumption estimates are extrapolated. The future apparent consumption estimates are reported in the Bureau publication *Mineral Facts and Problems* (2).

In this study, the elemental fraction of stainless steel has been calculated as a time-averaged, grade-averaged value: time-averaged over the period 1962 through 1983 and grade-averaged over the grades for which production was reported by the American Iron and Steel Institute during that time period. The product of elemental fraction calculated here and production yields the elemental content necessary to calculate apparent consumption.

In fulfilling its national defense responsibilities, the Bureau has reported mineral production, consumption (2), and availability (2-12). The 1973 through 1983 average apparent consumption for several commodities is shown in table 1. Apparent consumption may be compared with availability to determine adequacy of supply.

**Table 1.—Annual apparent consumption for several alloying elements, 1973-83 average, thousand short tons**

Element	Content	Element	Content
Cr . . . . .	516	Si . . . . .	581
Cb . . . . .	3.2	Ti . . . . .	524
Mn . . . . .	1,189	W . . . . .	4.9
Mo . . . . .	30	V . . . . .	8.1
Ni . . . . .	235		

Source: *Mineral Facts and Problems*, BuMines B 675, 1985.

Recycled stainless steel scrap is the only component of domestic production (i.e., secondary production) used

to compute the apparent consumption of Cr. For the apparent consumption of Ni, recycled stainless steel scrap is the largest component of secondary production. To calculate the secondary production from stainless steel scrap, the elemental content of the scrap must be known. The elemental content of stainless steel scrap may be estimated from the weight fraction of element, elemental fraction, contained in stainless steel produced, hereafter called  $\langle E \rangle$  where the E stands for an element such as Cr or Ni. This dimensionless number may be used to calculate secondary production from recycled stainless steel.

The concept of  $\langle E \rangle$  is simple; its calculation is more complex. The difficulty arises from the need to conceptually define  $\langle E \rangle$  and to select and use available data consistent with the concept. The concept, the data and methods used, and the decisions made to calculate an accurate, reliable  $\langle E \rangle$  are detailed in this report. The elemental fraction was calculated by grade as the elemental content of stainless and heat-resisting steel<sup>3</sup> divided by production of that steel. The minimum and maximum elemental fraction of each stainless steel production category was calculated, then a midpoint elemental fraction was calculated from them. The midpoint elemental fraction was averaged over grades and years to get  $\langle E \rangle$ .

$\langle E \rangle$  can be used to estimate the elemental content of stainless steel for two purposes: to calculate secondary production from scrap data and to calculate elemental consumption by market sector from stainless steel consumption by market sector.  $\langle E \rangle$  can also be used to estimate the quantity of an element potentially recoverable by recycling or to estimate the quantity of an element required to produce stainless steel.  $\langle E \rangle$  is useful whenever engineering economic calculations of the elemental content of stainless steels are required. Use of  $\langle E \rangle$  to estimate elemental content of recycled scrap assumes the grade distribution of scrap to be similar to that of production.

## PREVIOUS ESTIMATES

Three estimates of the chromium elemental fraction of stainless steel have been previously published. None have been published for nickel, molybdenum, or any of the other alloying elements considered in this investigation. The first value reported was in a National Materials Advisory Board study (13). In that study, stainless steel was identified as containing 16.4% chromium. The method by which this number was derived and the uncertainty associated with it were not discussed. A second value was reported in a Bureau of Mines study on scrap availability (14). In that study, stainless steel was identified as containing 16.7% chromium by multiplying the median

<sup>3</sup>In this report, stainless and heat-resisting steel will hereafter be referred to as stainless steel.

chromium content per grade by production per grade in 1957 and 1977. The chromium content of collected categories (i.e., those that contain more than one grade) were apparently not considered, and the uncertainty associated with the recommended content was not discussed. Neither of the two studies addressed the applicability of the recommended chromium fraction of stainless steel over a long time period. A third value was reported by the author at a Bureau of Mines briefing on chromium (15). In that study, the chromium fraction of stainless steel was found to be  $0.1671 \pm 0.0097$ . This chromium fraction was calculated as the midpoint of the minimum and maximum chromium fractions per grade averaged annually over grades and averaged over time from 1962 through 1983. The uncertainty was defined as one-half of the difference between the average minimum and maximum chromium fractions. The uncertainty defined in this way disregards the uncertainty associated with time variation of elemental fractions.

The analysis presented in this report is an extension of that presented in reference 15, IC 9087. The uncertainty associated with the result of IC 9087 explains the similarity of the three previous results. IC 9087 showed that over a 22-year period the maximum chromium fraction variation was 10 parts per 100. Thus, the three previous results (which were based on data from that time period) should not vary by more than 10 parts per 100. Indeed, the three previous results vary by only 3 parts per 100. Analysis of the method used in IC 9087 was found to be potentially deficient owing to the choice of production categories and the chemical specifications associated with those categories. This report corrects the potential deficiencies of IC 9087, by not grouping production categories and by using a newer set of chemical specifications associated with production categories in a different way.

## INFORMATION SOURCES

The references used in the current study were the "Metals and Alloys in the Unified Numbering System" (16), the "Metals Handbook, Desk Edition" (17-18), and the "Quarterly Production of Stainless and Heat Resisting Raw Steel" (19).

### Unified Numbering System

The Unified Numbering System (UNS) for metals and alloys is the result of a collective effort among specification publishing organizations to define a common set of chemical specifications cross-referenced to the specifications of the participating organizations. Representative participating organizations are the American Iron and Steel Institute (AISI), Society of Automotive Engineers (SAE), American Society for Testing and Materials (ASTM), and the U.S. military. The chemical specifications of the UNS for an

elemental constituent of steel include a minimum or a maximum content value or both. For a few cases, the specification is a nominal content value. Although the set of UNS grades probably does not include all of the stainless and heat-resisting steels produced, it is more complete than any other set of specifications.

A UNS grade designation, hereafter called a grade, consists of a single-letter prefix followed by five digits. The letter prefix identifies a UNS material category, such as K for miscellaneous steels and ferrous alloys, N for nickel and nickel alloys, and S for heat- and corrosion-resistant steels (including stainless), valve steels, and iron-base superalloys. Hereafter "x" will be used for unspecified digits in a grade name. For example, Sxxxxx represents the UNS name of a heat- and corrosion-resistant steel.

### American Iron and Steel Institute

Stainless steel production was defined by AISI. AISI publishes Form AIS-104 (19), which details U.S. stainless steel production by AISI categories. The fourth quarter report was the source of production data for this report. AISI categorizes production by stainless steel type. Some of these categories are specific types, others are descriptive types. A specific type is an alphanumerically designated category that specifies a single steel classification (i.e., chemical specification), such as Types 304, 304N, or 409. A descriptive type is one whose name describes its content, such as "Other Chromium Nickel Stainless Steels With Nickel Under 8%." A specific type corresponds to a single grade, while a descriptive type may represent many grades. The specific type is easily associated with a grade because AISI labels production categories by both type and grade (since 1977) for specific type categories. Also, the UNS cross-references types with grades. Frequently, type and grade designations are similar. For example, Types 304, 304N, and 409 correspond to Grades S30400, S30451, and S40900, respectively.

Form AIS-104 is subdivided into three major sections: the first section includes chromium-nickel stainless steels, the second includes chromium stainless steels, and the third includes heat-resisting steels. Each section is further subdivided into specific types followed by descriptive types. The first section includes specific type 200's and 300's categories followed by "Other Chromium Nickel Stainless Steels With;" descriptive categories. The second section includes specific type 400's followed by "All Other" descriptive categories. The third section includes specific type 500's followed by "All Other High Chromium Heat Resisting Steels." The definition of stainless steel used by AISI appearing on Form AIS-104 is as follows: "Includes all stainless steels containing 10% or more of Chromium, with or without other alloys, or a minimum combined

content of 18% of Chromium and other alloys and heat resisting steels containing 4% or more but less than 10% Chromium." AISI now considers steel to be a ferrous alloy containing 50% or more iron. However, at least one alloy containing less than 50% iron appeared in AIS-104 before 1984. That one is Type 330 (Grade N08330).

### American Society for Metals

The "Metals Handbook, Desk Edition," published by the American Society for Metals (ASM), contains a section on stainless steels (chapter 15) and heat-resisting steels (chapter 16). The ASM categorized stainless steels by their microstructural and production characteristics (austenitic, martensitic, ferritic, precipitation-hardening, and duplex). ASM provides chemical composition data cross-referenced with grade designation. The ASM list of stainless steels was taken as representative of what the steel industry considers to be significant stainless steels and what the steel industry is likely to have reported to AISI as stainless steel production. Several stainless steels identified by ASM had no corresponding grade designation. For example, the common designation for some of those steels are Trim Lite, 18 SR, Nitronic 20, and DP3. The existence of such steels shows that the set of stainless steels defined from the set of UNS grades in this report is incomplete. Several Nxxxxx series grades identified by ASM were included among the stainless steel grades.

### CHEMICAL ELEMENTS

From among 19 elements appearing in the chemical specifications for stainless steels, 9 were selected for calculation of an <E>. Those nine included chromium, columbium, manganese, molybdenum, nickel, silicon, titanium, tungsten, and vanadium. They were selected for analysis because stainless steel scrap is an important component of the element's apparent consumption or because the element is one of the commodities surveyed and reported on by the Bureau of Mines. Some commodities surveyed and reported by the Bureau and contained in stainless steel chemical specifications were not included in this report because the use of that commodity in stainless steel was quantitatively insignificant or that element appeared in so few grades that the <E>, as calculated in this report, would likely not be accurate or reliable.

### ELEMENT FUNCTIONS

Alloying elements together with processing techniques are used to control the physical characteristics, handling properties, and oxidation and corrosion resistance of stainless steel. The functions of alloying elements are

numerous, diverse, and interdependent. Many of the properties and characteristics of steel (18) are likely to be affected by the addition of an alloying element. The magnitude of an effect depends on the quantity of the alloying element added and on the presence of other alloying elements. The addition of one alloying element to improve one of the steel's qualities may deteriorate another quality requiring a second additive to compensate for the deleterious effect of the first. The role of alloying elements can thus become quite complex and interdependent. The objective of this section is to identify the salient motives for using the alloying elements studied in this report (20-23).

The numerous stainless steel grades have evolved to meet special end-use demands. Thus, there are very specific reasons for the use of additives in each grade. The salient reason for an additive's use may not be the same as the reason for its addition to (or subtraction from) a particular grade.

Stainless steels are composed of five structurally different types: (1) austenitic (included among AISI Type 200 and 300 Series), (2) ferritic (AISI Type 400 Series), (3) martensitic (AISI Type 400 and 500 Series), (4) precipitation hardenable (AISI Type 100, 300, and 400 Series), and (5) duplex (AISI Type 300 Series). These names are derived from the steel's as-quenched microstructure (austenitic, ferritic, martensitic) and its processing method (precipitation hardenable). Duplex stainless steel contains a combination of austenite and ferrite. While important in specific uses, precipitation hardenable and duplex grades do not represent a large fraction of production and, therefore, will not be considered further as regards the role alloying elements. The microstructure is affected both by molecular structure and processing. The molecular structure of the steel is affected most importantly by alloying elements and physical conditions (temperature and pressure). Ferritic grades can be cold-worked and annealed, cannot be strengthened by heat treatment, and have good oxidation and corrosion resistance at high temperature. Austenitic grades are the most corrosion resistant, cannot be hardened by heat treatment, but can be hardened by cold working. Martensitic grades are hardenable by heat treatment and are less corrosion resistant than ferritics.

Chromium is alloyed with Fe to make stainless steel because Cr imparts oxidation and corrosion resistance. Both oxidation resistance and corrosion resistance are achieved through the development of a stable passive protective film of chromium oxide on the surface of the steel. Oxidation and corrosion resistance generally increases with Cr content. Chromium tends to stabilize a ferritic structure when alloyed with iron.

Nickel is alloyed with Cr and Fe because Ni causes the microstructure to be austenitic. Nickel also contributes

toughness to ferritic grades and contributes to the ability of high Cr steels to be transformed to martensite. The austenitic grades are generally more ductile.

Molybdenum is alloyed with Fe-Cr-Ni steels to improve corrosion resistance and elevated temperature properties of austenitic grades, to improve the corrosion resistance of ferritic grades, and to improve strength and resistance to tempering in martensitic grades.

Manganese is primarily a residual from the iron production process. Manganese is a strong austenitic former and has been used to substitute for Ni to make austenitic grades. The 200 series grades were developed to conserve Ni, using Mn instead to get austenite. Manganese is used with sulfur in free machining grades. Manganese promotes the dissolution of nitrogen, which increases strength and work-hardening characteristics.

Silicon is primarily a residual from iron production. In austenitic grades, Si increases resistance to carburizing. Silicon is needed during processing to assure adequate chromium recovery from chromium oxide created during carbon removal. Silicon also serves as a deoxidizer and/or controls inclusion type.

Tungsten enhances high-temperature strength in austenitic grades. Columbium improves corrosion resistance and imparts high-temperature strength in austenitic and ferritic grades. Titanium improves corrosion resistance in austenitic and ferritic grades. Columbium and titanium improve corrosion resistance indirectly. Each reacts with carbon to form carbides. If unreacted with Cb or Ti, that carbon would be available to react with Cr. That would cause depletion of Cr in the grain boundary and lead to intergranular corrosion. Vanadium increases hot hardness and wear resistance (24).

## ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance of other Bureau of Mines commodity specialists and express his appreciation for their assistance. In particular, Larry Cunningham, columbium and tantalum specialist, assisted with columbium data; Gerald E. Murphy, ferroalloys specialist, with ferroalloys and silicon data; Frederick J. Schottman, iron and steel specialist, with iron and steel data; Raymond E. Brown, iron and steel scrap specialist, with iron and steel scrap data; Thomas S. Jones, manganese specialist, with manganese data; John Blossom, molybdenum specialist, with molybdenum data; Peter G.

Chamberlain, nickel specialist, with nickel data; Langtry E. Lynd, titanium specialist, with titanium data; Phillip T. Stafford, tungsten specialist, and Gerald R. Smith, tungsten specialist, with tungsten data; and Peter H. Kuck, vanadium specialist, and Henry Hilliard, vanadium specialist, with vanadium data. These specialists assisted the author by explaining the unique characteristics of their commodities, by discussing the role of their commodity as used in stainless steel, and by technically reviewing this report. Mr. Schottman was also of assistance in analyzing the chemical specifications.

## PROCEDURE

### METHOD

Production was multiplied by chemical specification to get elemental content of production by type. Production and elemental content were summed over types to get annual gross weights.  $\langle E \rangle$  was calculated as the time-averaged ratio of annual elemental content divided by production gross weights. The procedure is conceptually straightforward but complex in application because:

- (1) Production categories (types) and chemical specification categories (grades) are different.
- (2) Chemical specification data are generally an upper and lower bound on the elemental content. However, many specifications must be restated as bounds.
- (3) A procedure to calculate  $\langle E \rangle$  as an average between upper and lower bounds, among types, and over time must be specified.

In this section the resolution of these complications are addressed.

A universal set of stainless steels was defined; i.e., a set assumed to contain all stainless steels by chemical specification. A production set of stainless steels was defined; i.e., a set representative of the production categories used by AISI from 1962 through 1983. Members of the universal set were associated with members of the production set and used to define the chemical composition of production set members. To calculate the elemental content of stainless steel, the product of chemical composition times production was calculated for each production set member on an annual basis. The annual values were then summed from 1962 through 1983 to get time-averaged values.  $\langle E \rangle$  was thus calculated as the ratio of elemental content to stainless steel production annually, then averaged over the 1962-83 time period.

## UNIVERSAL SET

The universal set of stainless steels defined here was composed of grades selected from UNS based on the AISI and ASM definitions of stainless steels. The universal set was composed of 252 grades of which 225 were from the Sxxxx series, 20 from the Kxxxx series, and 6 from the Nxxxx series, and 1 had no grade name.

### CHEMICAL CONSTITUENT SPECIFICATIONS

Table 2 lists the chemical elements found among the UNS grade specifications for stainless steels along with the number of grades for which that element was cited and a breakdown of the kind of citations. Table 2 shows the three kinds of citation observed.

Of the 19 elements listed in table 2, some are alloying elements; some are tramp (i.e., undesirable) elements; and most can be either, depending on the grade. An alloying element is one which is required to meet physical or processing requirements. In table 2, it may be inferred that an element with non-zero minimum content specification is an alloying element because its presence is required. It may be inferred that an element of specified

maximum content and no specified minimum content is a tramp element because its presence is limited. Actually, most of these elements are alloying elements within a certain content range and tramp elements otherwise. Carbon, manganese, and silicon are important alloying elements that, when appearing in excess, have a deleterious effect on desirable steel properties. These three elements are notable because they are introduced during the production process in amounts large compared with their alloying requirements. As a result of their ubiquitous presence in excessive amounts, chemical specifications only set limits on the content of these elements.

The UNS grade chemical specifications did not completely meet the needs of this study. As shown by table 2, many grades have unspecified bounds on some elements. For grades without a specified minimum elemental content, zero was generally used. The substitution of zero for an unspecified minimum limit may result in an underestimate of the elemental content. With the exception of W, every element chosen for analysis had some grades that have unspecified bounds. The resolution of the numerous unspecified elemental bounds counted in table 2 is discussed in detail in appendix B.

Table 2.—Elements referenced by the UNS chemical specifications with number of references,<sup>1</sup> by category and by element

Element <sup>2</sup>	Symbol	Elemental content boundary specifications			Total <sup>3</sup>
		Both minimum and maximum	Maximum only	Minimum only	
Aluminum . . . .	Al	18	17	0	35
Carbon . . . . .	C	64	178	3	245
Chromium . . . .	Cr	250	0	2	252
Cobalt . . . . .	Co	4	5	0	9
Columbium . . .	Cb	32	3	0	35
Copper . . . . .	Cu	15	61	0	76
Lead . . . . .	Pb	1	3	0	4
Manganese . . .	Mn	93	152	0	245
Molybdenum . .	Mo	109	39	0	148
Nickel . . . . .	Ni	174	32	1	207
Phosphorus . . .	P	3	241	0	244
Selenium . . . .	Se	1	1	5	7
Silicon . . . . .	Si	66	179	0	245
Sulfur . . . . .	S	8	230	6	244
Tantalum . . . .	Ta	6	4	0	10
Tin . . . . .	Sn	0	8	0	8
Titanium . . . .	Ti	28	5	0	33
Tungsten . . . .	W	11	0	0	11
Vanadium . . . .	V	12	4	0	16

<sup>1</sup>Number of references is the number of times the element is specified, as described in the column heading, among the set of stainless and heat-resisting steel grades used in this report.

<sup>2</sup>Included in the chemical specifications but not listed here are arsenic (As), boron (B), cerium (Ce), hydrogen (H), iron (Fe), nitrogen (N), oxygen (O), and zirconium (Zr).

<sup>3</sup>Total is the sum of the number of grades that cite a minimum or maximum element content.

NOTE.—Data base contains 252 grades.

## AISI PRODUCTION SET

The production set represents the 1962-83 AISI production categories. The production set contains 76 categories labeled by type designations. At most, production values for 52 categories appeared in 1 year (1979). From 1962 through 1976, 38 to 44 values per year were reported. From 1977 through 1983, 48 to 52 values per year were reported. The type categories used by AISI to report production changed from the 1962-76 to the 1977-83 time periods. In 1977, AISI introduced many new specific types, eliminated some specific and descriptive types, and changed some descriptive types. In 1977, AISI introduced specific Types 205, S30430, 304N, 316F, 316N, 317L, 329, 330, 384, 409, 420F, 422, 429, 434, and 436; Types 406 and 443 were eliminated. The eight descriptive categories under "Other chromium nickel stainless steels with:" were reduced to four descriptive categories under the name "Other Chromium Nickel Stainless Steels With:" The "All other" descriptive category was subdivided into "All Other 15% Chromium or Less," and "All Other Over 15%

Chromium." The descriptive category "501, 502, and all other high chromium heat resisting steels" was subdivided to specific categories "501" and "502," and descriptive category "All Other High Chromium Heat Resisting Steels," hereafter called AOHCHRS. The descriptive category "Production not reported by type" was changed to "Production Not Shown By Type." Hereafter, PNRBT will be used in place of "Production not reported by type," and PNSBT for "Production Not Shown By Type."

The objective in choosing a production set was to retain all detailed production data. This objective was achieved by defining the production set to contain a member for each production category used by AISI during the analysis period. The production set, so defined, contains 76 categories, of which 57 represent specific types and 19 represent descriptive types.

Table 3 summarizes the relationship between the abbreviated production set category names used in this report and the AISI type category names that they represent. Table 3 also identifies the time period over which AISI used a type to report production.

**Table 3.—Production set category names defined in terms of AISI type category names and period of use**

Type category	Use period	Production set category name
<b>CHROMIUM-NICKEL STAINLESS STEELS</b>		
<b>Specific types:</b>		
201	1962-83	201
202	1962-83	202
205	1977-83	205
301	1962-83	301
302	1962-83	302
302B	1962-83	302B
303	1962-83	303
303Se	1962-83	303Se
304	1962-83	304
S30430	1977-83	S30430
304N	1977-83	304N
304L	1962-83	304L
305	1962-83	305
308	1962-83	308
309	1962-83	309
309S	1962-83	309S
310	1962-83	310
310S	1962-83	310S
314	1962-83	314
316	1962-83	316
316F	1977-83	316F
316N	1977-83	316N
316L	1962-83	316L
317	1962-83	317
317L	1977-83	317L
321	1962-83	321
329	1977-83	329
330	1977-83	330
347	1962-83	347
348	1962-83	348
384	1977-83	384
<b>Descriptive types:</b>		
Other chromium nickel stainless steels with:		
Nickel under 8%, other alloys under 10%	1962-76	Ni < 8
Nickel under 8%, other alloys over 10%	1962-76	Ni < 8

**Table 3.—Production set category names defined in terms of AISI type category names and period of use—Continued**

Type category	Use period	Production set category name
<b>CHROMIUM-NICKEL STAINLESS STEELS-Continued</b>		
Other Chromium Nickel Stainless Steels With:		
Nickel Under 8% . . . . .	1977-83	Ni < 8
Other chromium nickel stainless steels with:		
Nickel 8% to 16%, other alloys under 10% . . .	1962-76	Ni = 8-16
Nickel 8% to 16%, other alloys over 10% . . .	1962-76	Ni = 8-16
Other Chromium Nickel Stainless Steel With:		
Nickel 8-16% . . . . .	1977-83	Ni = 8-16
Other chromium nickel stainless steel with:		
Nickel 16% to 24%, other alloys under 10% . .	1962-76	Ni > 16-24
Nickel 16% to 24%, other alloys over 10% . . .	1962-76	Ni > 16-24
Other Chromium Nickel Stainless Steel With:		
Nickel Over 16-24% . . . . .	1977-83	Ni > 16-24
Other chromium nickel stainless steels with:		
Nickel over 24%, other alloys under 10% . . . .	1962-76	Ni > 24
Nickel over 24%, other alloys over 10% . . . . .	1962-76	Ni > 24
Other Chromium Nickel Stainless Steels With:		
Nickel Over 24% . . . . .	1977-83	Ni > 24
<b>CHROMIUM STAINLESS STEELS</b>		
Specific types:		
403 . . . . .	1962-83	403
405 . . . . .	1962-83	405
406 . . . . .	1962-76	406
409 . . . . .	1977-83	409
410 . . . . .	1962-83	410
414 . . . . .	1962-83	414
416 . . . . .	1962-83	416
416Se . . . . .	1962-83	416Se
420 . . . . .	1962-83	420
420F . . . . .	1977-83	420F
422 . . . . .	1977-83	422
429 . . . . .	1977-83	429
430 . . . . .	1962-83	430
430F . . . . .	1962-83	430F
430FSe . . . . .	1962-83	430FSe
431 . . . . .	1962-83	431
434 . . . . .	1977-83	434
436 . . . . .	1977-83	436
440A . . . . .	1962-83	440A
440B . . . . .	1962-83	440B
440C . . . . .	1962-83	440C
442 . . . . .	1962-83	442
443 . . . . .	1962-76	443
446 . . . . .	1962-83	446
Descriptive types:		
All other . . . . .	1962-76	All other
All Other:		
15% Chromium or Less . . . . .	1977-83	≤15% Cr
Over 15% Chromium . . . . .	1977-83	>15% Cr
<b>HEAT-RESISTING STEELS</b>		
Specific types:		
501 . . . . .	1977-83	501
502 . . . . .	1977-83	502
Descriptive types:		
501, 502, and all other high chromium heat resisting steel . . . . .	1962-76	501, 502, +
All Other High Chromium Heat Resisting Steels . . . . .	1977-83	AOHCHRS
<b>ALL OTHER</b>		
Descriptive types:		
Production not reported by type . . . . .	1962-76	PNRBT
Production Not Shown By Type . . . . .	1977-83	PNSBT

## GRADE-TO-TYPE RELATIONSHIP

In order to define the chemical composition of the production set categories, the UNS grades were distributed over the AISI production set categories. The grade chemical compositions were used to define the type chemical compositions. The elemental fraction was calculated as the midpoint of the annual minimum and maximum elemental contents divided by production, averaged over the 1962-83 time period.  $\langle E \rangle$  is the type-averaged, time-averaged fraction of element contained in stainless steel production. The mathematical details of the definition of  $\langle E \rangle$  are described in appendix C.

## UNCERTAINTY

The quantitative value of  $\langle E \rangle$  is uncertain due to two factors:

(1) There is an uncertainty resulting from the chemical composition range permitted for each type.

(2) There is an uncertainty resulting from the time variation of the midpoint value of the chemical specification.

These are the chemical specification uncertainty and the time mean square uncertainty, respectively. The uncertainty associated with  $\langle E \rangle$  is the combination of these two uncertainties. Two characteristics of the chemical specifications, universality and uniformity, are defined, and their implications about the magnitude of the uncertainty are considered in appendix D. Appendix D details the mathematical definition of the uncertainty associated with  $\langle E \rangle$ , its components (chemical specifications and time mean square uncertainty), and the characteristics of the chemical specifications that affect uncertainty (universality and uniformity).

## RESULTS

### GENERAL

Over the 1962-83 period, the elemental content of stainless steel produced was calculated for each year based on minimum and maximum elemental specifications per AISI type. The minimum and maximum elemental contents were summed over types to obtain annual minimum and maximum elemental contents. These elemental contents were divided by annual stainless steel production to obtain the annual minimum elemental fraction and the annual maximum elemental fraction. The annual midpoint

elemental fractions were calculated from the minimum and maximum. The average elemental fraction,  $\langle E \rangle$ , was calculated as the time average of the annual midpoint elemental fractions. The  $\langle E \rangle$  uncertainty was calculated as the sum of the chemical specification uncertainty plus the time mean square uncertainty of the midpoint values. Table 4 summarizes the results. Table 4 shows  $\langle E \rangle$  by element, the uncertainty associated with that value, the uncertainty as a percentage of the value by element listed in decreasing order of  $\langle E \rangle$  magnitude, and the components of uncertainty.

Table 4.—Elemental fraction, uncertainty, and components of uncertainty (chemical specification and time mean square uncertainties) based on 1962-83 production

Constituents	Elemental fraction $\langle E \rangle^1$	Uncertainty <sup>2</sup> $E_t$	Uncertainty <sup>3</sup> %	Uncertainty bounds	
				Chemical specification $E_{cs}$	Time mean square $E_{tms}$
Major:					
Cr .....	0.1725	0.0102	5.906	0.0099	0.0003
Ni .....	.0675	.0098	14.58	.0094	.0004
Mn .....	.0147	.0051	35.04	.0051	.0001
Intermediate:					
Si .....	.0088	.0010	11.70	.0010	(4)
Mo .....	.0037	.0009	23.86	.0008	.0001
Minor:					
Ti .....	.00044	.00012	27.22	.00009	.00003
Cb .....	.00014	.00003	22.81	.00003	(5)
W .....	.00011	.00003	26.27	.00003	(5)
V .....	.00003	.00001	33.56	.00001	(5)

<sup>1</sup>Time-averaged midpoint elemental fraction.

<sup>2</sup>Sum of chemical specification and time mean square uncertainty.

<sup>3</sup>Percent of elemental fraction.

<sup>4</sup>Less than 0.00005.

<sup>5</sup>Less than 0.000005.

NOTE.—Components of uncertainty may not add to total shown owing to independent rounding.

## PRODUCTION SUBCATEGORY

The categories used by AISI in its production report were collected into major subcategories in two ways. First, the production categories were collected into categories labeled "specific" and "descriptive." The specific category contained all specific type production categories; descriptive, all descriptive type production categories. (Table 3 identifies specific and descriptive types.) Second, the production categories were collected into the major subcategories labeled "Cr-Ni Series," "400 Series," and "Heat-Resisting." The Cr-Ni Series was further subdivided into 200 Series, 300 Series, and Descriptive. The 400 Series was further subdivided into Martensitic, Ferritic, and Descriptive. With the exception of the Martensitic and Ferritic series, these categories are the same as those used in table 3. Martensitic series includes production categories 403, 410, 414, 416, 416Se, 420, 420F, 422, 431, 440A, 440B, 440C, and 442. Ferritic series includes production categories 405, 406, 409, 429, 430, 430F, 430FSe, 434, 436, 443, and 446. Tables 5 and 6 summarize the midpoint elemental fractions by element and production subcategory. These tables show the distribution of elements among the major production subcategories listed in decreasing order of  $\langle E \rangle$  magnitude.

Table 5.—Average midpoint elemental fraction,<sup>1</sup> by specific and descriptive subcategories by element

Constituent	Production subcategory	
	Specific	Descriptive
Major:		
Cr . . . . .	0.1747	0.1625
Ni . . . . .	.0700	.0577
Mn . . . . .	.0143	.0166
Intermediate:		
Si . . . . .	.0090	.0079
Mo . . . . .	.0026	.0086
Minor:		
Ti . . . . .	.00028	.00110
Cb . . . . .	.00006	.00051
W . . . . .	.00001	.00063
V . . . . .	(2)	.00016

<sup>1</sup>Time average of midpoint value between minimum and maximum annual element fractions.

<sup>2</sup>Less than 0.000005.

Two factors affect the uncertainty associated with  $\langle E \rangle$ : the difference between minimum and maximum elemental

specifications and the time variation of annual midpoint elemental fraction. Time variation of midpoint elemental fraction results from production shifts among types of differing chemical specification. Production may have shifted among types owing to changing demand or to changes in reporting. The variation in elemental requirement is affected by the universality and uniformity of that element's requirement. An element is universally required when each grade requires that element. An element is uniformly required when each production category's requirement is the same. Table C-2 details the elemental specifications per type. However, it is difficult to characterize universality and uniformity of an element by perusing the constituents of sets because there are so many of them. A measure of universality can be derived from the data in table 2. By dividing the total number of grades which specify an element ("Total" column) by 252, the total number of grades, one obtains the fraction of grades that require the element. So universality,  $U_v$ , is the number of grades that require an element divided by the total number of grades. If  $U_v$  is 1, the element is universally required. Some values for this fraction are 1.0 for Cr, 0.98 for Mn and Si, 0.82 for Ni, and 0.58 for Mo. A measure of uniformity,  $U_f$ , is the similarity of elemental fraction among the production subcategories, especially among the Cr-Ni Series and 400 Series. A small deviation in subcategory midpoint elemental fraction (table 6) from the  $\langle E \rangle$  (table 4) suggests a uniform requirement distribution. Table 6 shows that Cr, Mn, Ni, and Si are found in every production subcategory. Mo is missing only from the 200 Series. Cb, Ti, and V are each missing from three categories; W, from four. Comparing  $\langle E \rangle$  in table 4 with the average midpoint elemental fractions (AMEF) in table 6 shows wide deviations, even for major and intermediate constituents. Measuring the deviation as  $[(\langle E \rangle - \text{AMEF}) / \langle E \rangle] \cdot 100$  and excluding the heat-resisting category, the range of deviation of AMEF from  $\langle \text{Cr} \rangle$  expressed as a percent of  $\langle \text{Cr} \rangle$  was from 7% greater to 24% smaller; Si, 2% greater to 26% smaller; Ni, 88% greater to 99% smaller; Ti, 318% greater to 100% smaller; Mn, 347% greater to 65% smaller; Mo, 403% greater to 100% smaller; Cb, 417% greater to 100% smaller; V, 700% greater to 100% smaller; and W, 1409% greater to 100% smaller. Increasing maximum magnitude of deviation has the same effect on uncertainty as decreasing uniformity.

Table 6.—Average midpoint elemental fraction,<sup>1</sup> by selected production subcategory by element

Constituent	Cr-Ni Series			400 Series			Heat-resisting
	200 Series	300 Series	Descriptive	Martensitic	Ferritic	Descriptive	
Major:							
Cr .....	0.1703	0.1846	0.1761	0.1311	0.1589	0.1675	0.0594
Ni .....	.0452	.0950	.1273	.0010	.0005	.0020	.0008
Mn .....	.0658	.0151	.0215	.0053	.0051	.0135	.0140
Intermediate:							
Si .....	.0090	.0090	.0079	.0084	.0090	.0065	.0101
Mo .....	.0	.0032	.0151	.0019	.0005	.0063	.0089
Minor:							
Ti .....	.0	.00009	.00184	.0	.00118	.00126	.0
Cb .....	.0	.00007	.00080	.0	.00004	.00064	.0
W .....	.0	.0	.00166	.00008	.0	.0	.00092
V .....	.0	.0	.00024	.00002	.0	.00008	.00058

<sup>1</sup>Time average of midpoint value between minimum and maximum annual elemental fraction.

The elements order themselves in about the same way when listed in order of decreasing  $U_v$  or decreasing  $U_f$ : Cr, Si, Mn, Ni, and Mo by decreasing  $U_v$ ; and Cr, Si, Ni, Mn, Ti, and Mo by decreasing  $U_f$ . Because decreasing either of these characteristics potentially leads to greater magnitude of uncertainty, one would expect uncertainty as a percentage of  $\langle E \rangle$  to increase by the same order of elements. Table 4 shows this generally to be the case. In order of increasing percentage of uncertainty, the element order is Cr, Si, Ni, Mo, and Mn.

Chromium was found in every production subcategory because chromium is required for a steel to be categorized as stainless. Chromium is universally required among the grades. The limits of Cr fraction among the types specifically listed here range from 0.1050 for Type 409 to 0.2800 for Type 329. Typically, the specification range is 0.0200. (See tables C-2 and C-3.)

Table 5 shows that the specific production subcategory AMEF is greater for Cr, Ni, and Si; and the descriptive production subcategory is greater for Mn, Mo, Ti, Cb, W, and V. Table E-4 shows that the specific subcategory accounts for about six times more production than does the descriptive subcategory. The larger share of production and better definition of elemental content for the specific category suggests that  $\langle E \rangle$  for Cr, Ni, and Si were more reliably defined.

Table 6 shows the largest AMEF of Cr and Ni were in the 300 Series subcategory; Mn, 200 Series; Si and V, Heat-resisting; and Mo, Ti, Cb, and W in Cr-Ni Series Descriptive. Table E-5 shows the largest fraction of production was found in the 300 Series subcategory followed by Ferritic, Martensitic, and 400 Series Descriptive. Production in 300 Series was about five times that of the

second largest category. The large share of production associated with 300 Series suggests that Cr and Ni, found in largest quantity in those categories, are more reliably defined. Their  $\langle E \rangle$  was less likely to be affected by production shifts because they were part of the largest subcategory.

The absence of Cb, Ti, V, and W from several categories makes them susceptible to time mean square uncertainty; and their largest AMEF in Descriptive categories suggests uncertainty in knowing whether those grades were even produced.

Tables 7-9 show minimum, maximum, and midpoint elemental content, fraction, and midpoint deviation by year for Cr, Ni, and Mo. The deviations for Cr and, to a lesser degree, for Mo suggest declining specific use; although those for Ni suggest increasing specific use. (Specific element use is element use per unit of production.) It will be shown that the deviation for Cr results from the establishment of Type 409 as a specific category in 1977. (See discussion, 409 effect.)

## OTHER

Table 10 shows the average elemental content of stainless steel scrap receipts compared with average apparent consumption and metallurgical apparent consumption. The detailed data upon which the summarized results of table 10 were based are in appendix F. Large elemental content of scrap relative to apparent consumption or metallurgical apparent consumption for Cr and Ni implies significant secondary production.

Table 7.—Chromium content, fraction, and deviation for annual production

[<Cr> = 0.172491; uncertainty (0.010187) = chemical specification uncertainty (0.009881) plus time mean square uncertainty (0.000307)]

Year	Stainless steel production, st	Chromium					
		Minimum		Maximum		Midpoint	
		Content, st	Fraction	Content, st	Fraction	Fraction	Deviation
1962	1,080,113	176,759	0.163648	198,449	0.183730	0.173689	+0.001198
1963	1,202,624	198,000	.164640	222,127	.184702	.174671	+0.002180
1964	1,439,112	238,609	.165803	267,485	.185868	.175836	+0.003345
1965	1,490,274	244,286	.163920	274,132	.183947	.173934	+0.001443
1966	1,646,172	270,539	.164344	303,530	.184386	.174365	+0.001874
1967	1,450,376	236,361	.162965	265,318	.182931	.172948	+0.000457
1968	1,407,449	228,724	.162509	256,853	.182496	.172503	+0.000012
1969	1,561,275	255,424	.163600	286,604	.183570	.173585	+0.001094
1970	1,280,037	207,796	.162336	233,349	.182298	.172317	-0.000174
1971	1,257,708	204,875	.162896	229,993	.182867	.172881	+0.000390
1972	1,557,280	253,707	.162917	284,696	.182816	.172866	+0.000375
1973	1,890,278	310,382	.164199	348,171	.184191	.174195	+0.001704
1974	2,152,523	351,330	.163218	394,348	.183203	.173210	+0.000719
1975	1,114,651	179,712	.161227	201,962	.181188	.171208	-0.001283
1976	1,658,209	274,577	.165586	307,727	.185578	.175582	+0.003091
1977	1,865,874	295,870	.158569	331,573	.177704	.168136	-0.004355
1978	1,941,668	308,178	.158718	345,432	.177905	.168312	-0.004179
1979	2,100,163	334,391	.159222	374,785	.178455	.168838	-0.003652
1980	1,692,933	273,276	.161422	306,111	.180817	.171119	-0.001372
1981	1,744,070	281,953	.161664	315,700	.181013	.171339	-0.001152
1982	1,233,546	199,405	.161652	223,131	.180886	.171269	-0.001222
1983	1,751,801	284,438	.162369	318,172	.181626	.171997	-0.000494
Total	34,518,130	5,608,591	NA	6,289,648	NA	NA	NA
Average	1,569,006	254,936	.162610	285,893	.182372	.172491	NA

NA Not applicable.

Table 8.—Nickel content, fraction, and deviation for annual production

[<Ni> = 0.067480; uncertainty (0.009842) = chemical specification uncertainty (0.009412) plus time mean square uncertainty (0.000430)]

Year	Stainless steel production, st	Nickel					
		Minimum		Maximum		Midpoint	
		Content, st	Fraction	Content, st	Fraction	Fraction	Deviation
1962	1,080,113	60,054	0.055599	78,564	0.072737	0.064168	-0.003312
1963	1,202,624	68,975	.057354	90,580	.075319	.066336	-0.001143
1964	1,439,112	85,487	.059403	112,887	.078442	.068922	+0.001443
1965	1,490,274	86,377	.057961	113,783	.076350	.067156	-0.000324
1966	1,646,172	103,255	.062724	135,299	.082190	.072457	+0.004978
1967	1,450,376	84,123	.058001	110,347	.076081	.067041	-0.000439
1968	1,407,449	78,823	.056004	103,802	.073752	.064878	-0.002602
1969	1,561,275	86,490	.055397	114,303	.073212	.064304	-0.003175
1970	1,280,037	71,931	.056195	95,421	.074545	.065370	-0.002110
1971	1,257,708	67,477	.053651	89,531	.071186	.062418	-0.005061
1972	1,557,280	87,683	.056305	115,631	.074252	.065279	-0.002201
1973	1,890,278	114,771	.060717	151,302	.080042	.070379	+0.002900
1974	2,152,523	126,161	.058611	167,380	.077760	.068185	+0.000706
1975	1,114,651	63,637	.057091	84,687	.075976	.066534	-0.000946
1976	1,658,209	92,453	.055755	123,361	.074394	.065074	-0.002405
1977	1,865,874	104,309	.055903	139,268	.074639	.065271	-0.002208
1978	1,941,668	109,421	.056354	145,961	.075173	.065764	-0.001716
1979	2,100,163	123,828	.058961	165,032	.078581	.068771	+0.001291
1980	1,692,933	105,225	.062156	140,081	.082745	.072450	+0.004970
1981	1,744,070	106,168	.060873	141,517	.081142	.071008	+0.003528
1982	1,233,546	75,935	.061559	101,440	.082234	.071896	+0.004417
1983	1,751,801	106,713	.060916	141,663	.080867	.070892	+0.003412
Total	34,518,130	2,009,297	NA	2,661,841	NA	NA	NA
Average	1,569,006	91,332	.058068	120,993	.076892	.067480	NA

NA Not applicable.

Table 9.—Molybdenum content, fraction, and deviation for annual production

[< Mo > = 0.003664; uncertainty (0.000874) = chemical specification uncertainty (0.000812) plus time mean square uncertainty (0.000062)]

Year	Stainless steel production, st	Molybdenum					
		Minimum		Maximum		Midpoint	
		Content, st	Fraction	Content, st	Fraction	Fraction	Deviation
1962	1,080,113	2,744	0.002541	4,358	0.004034	0.003288	-0.000377
1963	1,202,624	2,944	.002448	4,618	.003840	.003144	-.000520
1964	1,439,112	3,617	.002513	5,659	.003932	.003223	-.000441
1965	1,490,274	4,384	.002941	6,893	.004625	.003783	+0.00119
1966	1,646,172	5,058	.003073	7,913	.004807	.003940	+0.00276
1967	1,450,376	4,140	.002855	6,525	.004499	.003677	+0.00013
1968	1,407,449	3,932	.002794	6,212	.004413	.003604	-.000060
1969	1,561,275	4,313	.002763	6,843	.004383	.003573	-.000091
1970	1,280,037	4,004	.003128	6,260	.004891	.004009	+0.000345
1971	1,257,708	3,370	.002680	5,289	.004205	.003443	-.000222
1972	1,557,280	4,084	.002623	6,422	.004124	.003373	-.000291
1973	1,890,278	5,512	.002916	8,599	.004549	.003733	+0.00068
1974	2,152,523	6,881	.003197	10,811	.005022	.004110	+0.000445
1975	1,114,651	4,127	.003703	6,470	.005805	.004754	+0.001089
1976	1,658,209	5,141	.003100	8,152	.004916	.004008	+0.000344
1977	1,865,874	5,118	.002743	8,057	.004318	.003530	-.000134
1978	1,941,668	5,371	.002766	8,483	.004369	.003568	-.000096
1979	2,100,163	6,284	.002992	9,814	.004673	.003833	+0.000168
1980	1,692,933	5,799	.003426	8,963	.005294	.004360	+0.000696
1981	1,744,070	4,944	.002835	7,678	.004402	.003618	-.000046
1982	1,233,546	3,027	.002454	4,693	.003804	.003129	-.000535
1983	1,751,801	3,957	.002259	6,253	.003570	.002914	-.000750
Total	34,518,130	98,754	NA	154,963	NA	NA	NA
Average	1,569,006	4,489	.002852	7,044	.004476	.003664	NA

NA Not applicable.

Table 10.—Estimated elemental content (ECS) of average stainless steel scrap receipts,<sup>1</sup> average apparent consumption (AAC), and average metallurgical apparent consumption (AMC), thousand short tons of element content unless noted otherwise

Constituents	ECS		AAC <sup>2</sup>	ECS/AAC <sup>3</sup>	AMC <sup>4</sup>	ECS/AMC <sup>5</sup>
	Quantity	Uncertainty				
Major:						
Cr	69.4	±4.1	523	13	368	19
Ni	27.2	±4.0	231	12	206	13
Mn	5.9	±2.1	1,228	.5	1,189	.5
Intermediate:						
Si	3.5	±.4	533	.7	489	.7
Mo	1.5	±.4	28	5	26	6
Minor:						
Ti	.18	±.05	509	.03	18	1
Cb	.06	±.01	2.8	2	2.8	2
W	.05	±.01	8.6	.5	8.3	.5
V	.01	( <sup>6</sup> )	7.4	.2	6.9	.2

<sup>1</sup>1964-83 average annual stainless steel scrap receipts (402,412 st) times <E>.<sup>2</sup>1964-83 average annual apparent consumption reported as industrial demand in Mineral Facts and Problems, BuMines B 675, 1985, and B 671, 1980.<sup>3</sup>Average annual content of scrap as a percentage of average annual apparent consumption.<sup>4</sup>1964-83 average annual metallurgical apparent consumption estimated as industrial demand less nonmetallurgical demand for Cr, Mn, Mo, Ni, Si, V, and W. Nonmetallurgical demand includes chemical and refractory demand for Cr; chemical, battery, and 10% of other demand for Mn; and chemical demand for Mo, Ni, Si, V, and W. Metallurgical apparent consumption estimated as industrial demand for Cb. Metallurgical apparent consumption estimated as metallurgical demand for Ti.<sup>5</sup>Average annual elemental content of stainless steel scrap as a percentage of average annual metallurgical apparent consumption.<sup>6</sup>Less than 0.005.

NOTE.—All data independently rounded.

## ELEMENT SUMMARY

<Cr> was found to be 0.1725 with an uncertainty of  $\pm 0.0102$  or 6% of the <Cr>. The uncertainty was primarily from chemical specification uncertainty. The universality of chromium was 1. The requirement for Cr was distributed among all production subcategories. The production subcategory midpoint elemental fractions deviated from <Cr> by 24% at most, except for the 500's, which had a midpoint elemental fraction of about one-third to one-half that of the other subcategories. On the average, from 1962 through 1983, Cr contained in stainless steel scrap receipts was about 13% of Cr average (1962-83) annual apparent consumption.

<Ni> was found to be 0.0675 with an uncertainty of  $\pm 0.0098$  or 15% of the <Ni>. The uncertainty was primarily from chemical specification uncertainty. The universality of Ni was 0.82. The requirement for Ni was heavily concentrated in the Cr-Ni Series and, within there, under Descriptive. The production subcategory midpoint elemental fractions deviated from <Ni> by a range of from -89% to +99%. Nickel was one to two orders of magnitude more abundant in the Cr-Ni Series than in 400 Series or Heat-resisting. On the average, from 1962 through 1983, Ni contained in stainless steel scrap receipts was about 12% of Ni annual apparent consumption.

<Mn> was found to be 0.0147 with an uncertainty of  $\pm 0.0051$  or 35% of the <Mn>. The uncertainty was primarily from chemical specification uncertainty. Universality of Mn was 0.98. The requirement for Mn was distributed among all production subcategories. The production subcategory midpoint elemental fractions deviated from <Mn> by a range of from -347% to +65%. The largest deviation was for the 200 Series, where Mn was used as a substitute for Ni. Excluding the 200 Series, deviations ranged from -46% to +65%. There was two or more times less Mn in the Martensitic and Ferritic than in the other subcategories. The Cr-Ni Series and 400 Series Descriptive categories had the largest Mn midpoint elemental fraction requirement. On the average, from 1962 through 1983, Mn contained in stainless steel scrap receipts was about 0.5% of Mn annual apparent consumption.

<Si> was found to be 0.0088 with an uncertainty of  $\pm 0.0010$  or 12% of the <Si>. The uncertainty was virtually all from chemical specification uncertainty. Universality of Si was 0.98. The requirement for Si varied little among production subcategories. The production subcategory midpoint elemental fractions deviated from <Si> by a range of from -2% to +26%. Excluding the 400 Series Descriptive that accounted for the 26% deviation, the deviation range was only -2% to +10%. On the average, from 1962 through 1983, Si contained in stainless steel scrap receipts was about 0.7% of Si annual apparent consumption.

<Mo> was found to be 0.0037 with an uncertainty of  $\pm 0.0009$  or 24% of the <Mo>. The uncertainty was

about 90% chemical specification and 10% time mean square. Universality of Mo was 0.58. The requirement for Mo was distributed among all production subcategories, except the 200 Series, with a larger fraction required in the Cr-Ni Series Descriptive subcategory. The production subcategory midpoint elemental fraction deviated from <Mo> by a range of from -403% to 100%, a wide range of large deviations. On the average, from 1962 through 1983, Mo contained in stainless steel scrap receipts was about 5% of Mo annual apparent consumption.

<Ti> was found to be 0.00044 with an uncertainty of  $\pm 0.00012$  or 27% of the <Ti>. The uncertainty was about 64% chemical specification and 36% time mean square uncertainty. Universality of Ti was 0.13. The requirement for Ti was distributed over the 300 Series, Cr-Ni Series Descriptive, Ferritic, and the 400 Series Descriptive subcategories. Ti was absent from the 200 Series, Martensitic, and Heat-resisting. The largest fraction was required in Ni-Cr Series Descriptive, followed closely by 400 Series Descriptive and Ferritic subcategories. For those subcategories requiring Ti, the production subcategory midpoint elemental fractions deviated from <Ti> by a range of from -318% to 100%, a wide range of large deviations. On the average, from 1962 through 1983, Ti contained in stainless steel scrap receipts was about 0.03% of Ti annual apparent consumption.

<Cb> was found to be 0.00014 with an uncertainty of  $\pm 0.00003$  or 23% of the <Cb>. The uncertainty was about 80% chemical specification and 20% time mean square. Universality of Cb was 0.14. The requirement for Cb was distributed over 300 Series, Cr-Ni Series Descriptive, Ferritic, and 400 Series Descriptive. Cb was absent from 200 Series, Martensitic, and Heat-resisting. The largest fraction was required in Cr-Ni Series Descriptive, followed closely by 400 Series Descriptive. For those subcategories containing Cb, the production subcategory midpoint elemental fractions deviated from <Cb> by a range from -417% to 100%, a wide range of large deviations. On the average, from 1962 through 1983, Cb contained in stainless steel scrap receipts was about 2% of Cb annual apparent consumption.

<W> was found to be 0.00011 with an uncertainty of  $\pm 0.00003$  or 26% of the <W>. The uncertainty was virtually all chemical specification. Universality of W was 0.04. W was required only in the Cr-Ni Series Descriptive, Martensitic, and Heat-resisting production subcategories. W requirement was largest in Cr-Ni Series Descriptive. For those subcategories requiring W, the production subcategory midpoint elemental fraction deviated from <W> by from -1409% to 100%, a wide range of large deviations. On the average from 1962 through 1983, W contained in stainless steel scrap was 0.5% of W annual apparent consumption.

<V> was found to be 0.00003 with an uncertainty of  $\pm 0.00001$  or 34% of the <V>. The uncertainty was virtually all chemical specification. Universality of V was 0.06. The requirement for V was distributed over Cr-Ni Series

Descriptive, Martensitic, 400 Series Descriptive, and Heat-resisting.

The largest fraction was required in heat-resisting, followed by Cr-Ni Series Descriptive. For those subcategories requiring V, the production subcategory midpoint

elemental fractions deviated from  $\langle V \rangle$  by  $-700\%$  to  $100\%$ , a wide range of large deviations. On the average, from 1962 through 1983, V contained in stainless steel scrap receipts was about  $0.2\%$  of V annual apparent consumption.

## DISCUSSION

### ELEMENTAL FRACTION DEFINITION

The minimum and maximum elemental fractions of stainless steel are calculable from chemical specification and production data. Indeed they have here been calculated for several alloying elements. It is not obvious how the calculated minimum and maximum fractions should be combined to form an "elemental fraction" representative of stainless steel production practice. The author has chosen to represent the elemental fraction as the midpoint value between the minimum and maximum fractions and to specify an uncertainty for that midpoint value. The midpoint elemental fraction may be high or low relative to production practice, but the elemental fraction achieved in practice is virtually certain to lie within the specified bounds. Tables 7, 8, and 9 show that all of the annual midpoint elemental fractions lie within the bounds of  $\langle E \rangle$  for Cr and Ni. One value (that of 1975) lies outside the bounds for Mo. (Rounding of  $\langle E \rangle$  and its bounds did not change the number of values that exceed the bounds.) For Mn, Si, and W, all of the annual midpoint elemental fractions lay within the bounds specified for both the exact and rounded results. For V, one value lay outside the exact result; three, the rounded. For Cb, seven values lay outside the exact and rounded results. For Ti, 19 values lay outside the exact result; 17, the rounded.

Analysis over the 1977-83 time period showed no annual midpoint elemental fractions lay outside the bounds of  $\langle E \rangle$ . (See appendix F.)

It is generally the practice that the alloy content of a heat (i.e., one furnace load) of steel is on the low side of the chemical specification for that steel. The alloy content of steel produced in a refining vessel is controllable to margins less than those of the chemical specifications. For economic reasons, alloy content favors the low end of the specification requirement. Because the effect of favoring the low end of the chemical specification on elemental fraction was not quantitatively known, it could not be quantitatively accounted for here. The situation is further complicated by the fact that steel companies typically produce and market company-specified or consumer-specified products that do not match the standard categories. The products are allocated to AISI production categories for the purpose of reporting production. Because the distribution of such products within an AISI type was unknown,

even if the preference for alloy contents to the low end of the specification were quantitatively known for all commercial products, those quantitative preferences would not be directly applicable to AISI production categories.

### UNCERTAINTY

The uncertainty used here is the sum of the chemical specification ( $e_s$ ) and the time mean square (tms) uncertainties. The chemical specification uncertainty was chosen so that the true value lies within the  $E_{cs}$  with 100% confidence and the time mean square uncertainty with 50% confidence. The chemical specification uncertainty reflects the uncertainty of the elemental fraction between the chemical specification limits. The time mean square uncertainty reflects the uncertainty of the midpoint elemental fraction due to variation of that quantity with time. The time variation of the midpoint elemental fraction results from shifting production among types and changes in the type categories.

The chemical specification uncertainty is a lower bound to the  $\langle E \rangle$  uncertainty in the sense that, at best, the time mean square uncertainty could be zero. The uncertainty measured as a percentage of the  $\langle E \rangle$  varies widely among elements, even though the difference between the maximum and minimum elemental content is the same. This effect is shown by the chemical specification of Type 304, the production category accounting for the single largest fraction of production. For Type 304, chemical specification ranges are Cr,  $\pm 0.0100$ ; Mn,  $\pm 0.0025$ ; Ni,  $\pm 0.0125$ ; and Si,  $\pm 0.0010$ . The midpoint chemical specifications are Cr, 0.1900; Ni, 0.0925; Mn, 0.0175; and Si, 0.0090. The resulting chemical specification ranges as a percent of the midpoint chemical specifications are Cr,  $\pm 11\%$ ; Ni,  $\pm 27\%$ ; Mn,  $\pm 29\%$ ; and Si,  $\pm 22\%$ . Thus, even though the ranges are comparable in magnitude for Cr and Ni, the resulting uncertainties are significantly different.  $E_{cs}$  dominates the uncertainty for each element.

Appendix E shows the major production categories to have been first 301, 304, and 409 (1977-83), and All other (1962-76). Then 304N, 316, 316L, Ni<8, and 403 followed. A check of these categories in table C-3 shows that V and W did not appear in major production categories. Cb was contained only in Ni<8, and Ti was contained only in 409 and Ni<8.

The Si uncertainty was dominated by  $E_{cs}$ , with  $E_{tms}$  small in comparison. Table 2 shows that Si, along with Mn, is the second most referenced element of those here analyzed. Table C-3 shows that the chemical specification element minimum of Si (Si.min) and the chemical specification element maximum of Si (Si.max), are nearly unchanging among the production categories. The major production categories all have the specification  $0.0080 \leq Si \leq 0.0100$ . Thus, even shifting production among major production categories would not affect  $\langle Si \rangle$ . Si.min and Si.max are constant over virtually all of the major production categories and Si is chemically specified for virtually all production categories. Together, these factors result in a small  $E_{tms}$ . The constancy of Si.min and Si.max result in a small  $E_{cs}$ . Together, the small  $E_{cs}$  and  $E_{tms}$  result in an atypically small Si uncertainty.

### IMPACT OF TYPE 409

Tables 7, 8, and 9 show the midpoint elemental fractions (MEF) from which  $\langle E \rangle$  was calculated for Cr, Ni, and Mo, respectively, and the deviation of MEF from  $\langle E \rangle$ . The change in sign of the Cr deviations from predominantly positive during the 1962-76 time period to predominantly negative during the 1977-83 time period suggests that something happened in 1977 to cause the decline in specific Cr use. (See table 7.) (Specific element use is element used per unit of stainless steel produced. For the purpose of discussion here,  $\langle Cr \rangle$  and specific Cr use are the same.) The Ni deviations suggest that specific Ni use increased in the 1977-83 time period compared with that of the 1962-76 time period. The Mo deviations do not suggest a changing pattern of Mo use from the 1962-76 time period to the 1977-82 time period.

The effect of Type 409 introduction on the annual Cr fraction is shown in table 7. The introduction of Type 409 lowered the annual Cr fraction relative to the 1962-83 average value as shown by the predominantly negative deviations after 1976. Appendix F shows that the decrease of annual Cr fraction from 1976 to 1977 is explicable by Type 409 introduction. The lower than average annual midpoint Cr fraction after 1977 presumably resulted from the same cause, the presence of Type 409 as a specific category representing a significant fraction of production. Cr use has changed as a result of increased use of Type 409. However, the abrupt change shown by the negative deviations appearing in 1977 reflects a change in reporting pattern.

The observed effect of Type 409 becoming a specific production category in 1977 suggested that the  $\langle E \rangle$  may also have been affected by this change of production categories. Appendix F shows the  $\langle E' \rangle$ .  $\langle E' \rangle$  was calculated in the same way as  $\langle E \rangle$  except that the analysis was carried out over only the 1977-83 time period.

Except for Ti,  $\langle E' \rangle$  lies within the uncertainty bounds of  $\langle E \rangle$ .  $\langle Ti' \rangle$  is nearly double  $\langle Ti \rangle$ .

The cause of declining specific Cr use was the increased use of Type 409. Type 409 is the stainless steel of lowest Cr chemical specification with a range of 10.50% to 11.75%. In 1977, Type 409 production was 11% of stainless steel production, the largest 400 Series production, and the second (to Type 304) largest production category. Until about 1970, Type 409 was only used for parts in automobile exhaust system components. Its use then increased when automobile manufacturers chose to comply with the Federal Clean Air Act of 1970 by equipping automobiles with catalytic converters. Type 409 provided the desired lifetime for these converters at the high operating temperatures resulting from converter use. By 1979, the majority of automobiles were equipped with catalytic converter exhaust systems (25). Because its use has been extended to exhaust pipes and manifolds in order to extend the service life of those components, Type 409 continues to be used in large amounts.

### COMPARISON OF RESULTS

Previous estimates of the  $\langle Cr \rangle$  include 0.164 (13), 0.167 (14), and  $0.1671 \pm 0.0097$  (15).  $\langle Cr \rangle$  calculated here ( $0.1725 \pm 0.0102$ ) agrees with previous estimates to within the specified uncertainty range.

The National Materials Advisory Board (NMAB) (13) suggested 0.164 for  $\langle Cr \rangle$ . That value was presented without reference and without explanation as to how it was derived. It is not possible to evaluate the NMAB value for applicability or uncertainty. The value was presented as an average content with a footnote identifying the Cr content of austenitic grades as 17.9%; ferritic grades, 15.2%; and martensitic grades, 12%, based on data from AISI in 1975. The NMAB average Cr fraction of stainless steel thus appears to be a grade-averaged value for 1 year. It is unclear how descriptive types, heat-resisting steels, and PNRBT were treated. The certainty with which the recommended  $\langle Cr \rangle$  was estimated was unspecified. The purpose of calculating  $\langle Cr \rangle$  in the NMAB report was to permit the conversion of stainless steel commodity data into Cr equivalent, thereby determining Cr use by economic sectors.

A Bureau study (14) suggested 0.167 for  $\langle Cr \rangle$ . That value was determined by multiplying the median content per production category by production and averaging for the years 1957 and 1977. That study did not account for descriptive categories and used elemental contents different from those used in this study for some specific categories.  $\langle Cr \rangle$  presented in that study was an average over 2 years and over the specific types. The certainty with which the suggested  $\langle Cr \rangle$  was determined was

unspecified. Also, the purpose of calculating  $\langle \text{Cr} \rangle$  was to estimate the Cr available in stainless steel for recycling.

Another Bureau study (15) suggested  $0.167 \pm 0.0097$  for  $\langle \text{Cr} \rangle$ . That value was determined by multiplying the Cr fraction per production category by production and averaging over the 1962-83 time period. The recommended  $\langle \text{Cr} \rangle$  was the midpoint value between the minimum and maximum Cr fractions, and the uncertainty was one-half the difference between the minimum and maximum Cr fraction. An uncertainty associated with time fluctuations was not estimated.  $\langle \text{Cr} \rangle$  recommended in the study was an average over a 22-year time period and over production categories. A result of that analysis was that the production categories were unsatisfactorily chosen, and a better association of UNS specifications with AISI production categories was recommended. The purposes of calculating  $\langle \text{Cr} \rangle$  in the study were to estimate the Cr content of stainless steel scrap and to estimate Cr consumed by market sectors.

The data base and procedures used in this analysis and that study were similar. The major differences between this analysis and that one include:

1. The uncertainty bound for the previously calculated  $\langle \text{Cr} \rangle$  included only the chemical specification uncertainty.  $\langle \text{Cr} \rangle$  calculated here included both chemical and time mean square uncertainty components and is therefore larger.
2. The universe of stainless steel grades was here derived primarily from "Metals & Alloys in the Unified Numbering System, Third Edition," and other sources while that of IC 9087 was derived entirely from the second edition. The Cr chemical specification of only one specific type (Type 305) changed (from a range of from 0.17 to 0.19 to a range of from 0.19 to 0.21). All of the descriptive type Cr chemical specifications changed.
3. The method for allocating grades to types differed. No grades were here assigned to the PNRBT and PNSBT categories. These categories were included in production, but the elemental fraction of these categories was assumed to be that of the average of the other categories.
4. The analysis in this report was applied to Cr, Ni, Mo, and six other elements. IC 9087 analyzed only Cr.

The difference between the previously calculated  $\langle \text{Cr} \rangle$  and the one calculated here shows that the elemental contents assigned to the descriptive categories affect the calculated elemental content. The effect is well within the uncertainty bounds of the calculation.

#### ALTERNATIVE METHOD

An alternate method of estimating the elemental content of stainless steel is to compare elemental consumption (as reported by the Bureau of Mines) with stainless steel

production (as reported by AISI). The comparison of reported scrap and ferroalloy consumption with stainless steel production yields the quantity of element consumed, hereafter called  $\langle E'' \rangle$ . This method (method 2) may be less reliable than the chemical specification-production by type method (method 1) used in this report. Method 1 accuracy depends on the stainless steel grade and reported production by type being representative of what was produced, but is independent of report completeness. Method 2 accuracy depends on "relative" completeness of reporting; i.e., the result of method 2 is accurate when the same fraction of production and ferroalloy and scrap consumption are reported. For example, if many more companies report production than consumption or, say, more ferroalloy than scrap consumption was reported, method 2 error would be increased. In addition, method 2 requires the estimation of process losses to get the elemental fraction. The quantity of alloying element lost from ferroalloy and scrap feed materials varies with element and production technique.  $\langle E'' \rangle$  was unmodified for process losses, so it represents the quantity of element required to produce stainless steel, not element contained in the stainless steel product. These factors suggest that method 1 is more accurate than method 2. Owing to these factors, the method 2 results may serve as an order of magnitude check on results of method 1.

Table 11 shows  $\langle E \rangle$  and  $\langle E'' \rangle$  and compares them. All  $\langle E'' \rangle$  were larger than  $\langle E \rangle$ . Because stainless steel scrap is used primarily for its Ni and Cr content, only the Ni and Cr  $\langle E'' \rangle$  and  $\langle E \rangle$  should be expected to be comparable. Owing to material losses during stainless steel production, the ratio  $\langle E'' \rangle$  to  $\langle E \rangle$  must be greater than 1. Owing to the Ni efficiency of the stainless steel production process during the time period of analysis (less than 10% of alloying Ni added was lost), the ratio of  $\langle \text{Ni}'' \rangle$  to  $\langle \text{Ni} \rangle$  should be less than about 1.1. Indeed,  $\langle \text{Ni}'' \rangle / \langle \text{Ni} \rangle$  is 1.1. The Cr efficiency of the stainless steel production process during the time period of analysis changed. The AOD (argon-oxygen-decarburization) stainless steel production process replaced the double slag process during the analysis period. The AOD process is Cr efficient losing less than 10% of alloying Cr added. The double slag process, however, was much less efficient losing 40%-50% of alloying Cr added. Thus the  $\langle \text{Cr}'' \rangle / \langle \text{Cr} \rangle$  should be in the range of from 1.1 to 2.0. The large value of the ratio of  $\langle \text{Cr}'' \rangle$  to  $\langle \text{Cr} \rangle$  indicates inconsistency in the data used to calculate  $\langle \text{Cr}'' \rangle$  and not inefficiency in the stainless steel production process. The method 2 results could be made to approach those of method 1 by accounting for (1) efficiency of element transfer from ferroalloy to product, (2) efficiency of element transfer from scrap to product, and (3) the fraction of stainless steel scrap consumed to make other than stainless steel. The quantitative data upon which the results of method 2 were based are found in appendix G.

Table 11.—Comparison of  $\langle E \rangle$  and  $\langle E'' \rangle$ 

Constituents	$\langle E \rangle^1$		$\langle E'' \rangle^2$		$\langle E'' \rangle / \langle E \rangle$
	Quantity	Uncertainty	Quantity	Uncertainty	
<b>Major:</b>					
Cr .....	0.1725	0.0102	0.2674	0.0347	1.6
Ni .....	.0675	.0098	.0776	.0092	1.1
Mn .....	.0147	.0051	.0290	.0058	2.0
<b>Intermediate:</b>					
Si .....	.0088	.0010	.0281	.0055	3.2
Mo .....	.0037	.0009	.0053	.0009	1.4
<b>Minor:</b>					
Ti .....	<sup>4</sup> .00077	<sup>4</sup> .00018	.00118	.00044	1.5
Cb .....	.00014	.00003	.00047	.00009	3.4
W .....	.00011	.00003	.00016	.00007	1.4
V .....	.00003	.00001	.00005	.00002	1.8

<sup>1</sup>Calculated from production and chemical specification by stainless steel type, (1962-83). See table 4.

<sup>2</sup>Calculated as element reported consumption divided by stainless steel production minus stainless steel scrap consumed for stainless steel production by year from 1962 through 1984, and averaged over the time period. Stainless steel scrap consumed for stainless steel production assumed to be 95% of reported stainless steel scrap consumption. See table G-2.

<sup>3</sup>Mean square uncertainty from time average value.

<sup>4</sup>1977-83 value.

## CHROMIUM AND NICKEL USE

Given the annual rate of 967,000 st (1962-83 average) of scrap consumed to produce 1,567,000 st (1962-83 average) of stainless steel, primary sources must have contributed the alloying element to produce the difference, 600,000 st. Thus, about two-thirds of alloying element required for raw stainless steel production may have been supplied by secondary sources (purchased and prompt scrap) and one-third by primary sources. About 40% of this average annual scrap consumption was accounted for by scrap receipts (402,000 st).

FeCr is the source of primary Cr and charge-grade FeCr (55% Cr) is the predominantly traded grade. Thus, on average, the Cr content of one unit of charge-grade FeCr is adequate to produce about three units of stainless steel when FeCr is the sole source of Cr. However, with scrap accounting for more than two-thirds of Cr feedstock, only one-third of raw stainless steel production required primary Cr. Thus, one unit of charge-grade FeCr has been required, on average, to produce nine units of raw stainless steel.

Ni metal, ferronickel (FeNi), and nickel oxide (NiO) are the sources of primary Ni. For the purpose of calculating the quantity of Ni required from primary sources, we assume—

1. Typical Ni fractions for primary Ni sources (i.e., 1.00 Ni in Ni metal, 0.75 Ni in FeNi, and 0.77 in NiO).

2. 1985 supply distribution for sources of primary Ni in the production of stainless steel (i.e., about 50% from Ni metal, 30% from FeNi, and 10% from NiO).

3.  $\langle \text{Ni} \rangle = 0.0675$ .

4. Scrap accounted for two-thirds of Ni requirements.

Based on the above assumptions, it is estimated that about 0.034 tons of Ni metal, 0.024 tons of FeNi, and 0.009 tons of NiO have been required to produce a ton of stainless steel.

It is of interest to some economic analysts to know whether the use of a particular alloying element is increasing or decreasing per unit of production. This intensity of use can be determined from the time series of data presented here. A small time mean square uncertainty suggests constant intensity of use; large time mean square uncertainty, varying intensity of use. The production set change from 1976 to 1977 affected the annual elemental fraction, and, therefore, the annual deviations of elemental fraction from  $\langle E \rangle$ . These deviations cannot be distinguished from intensity-of-use changes. Thus, intensity-of-use analysis should be done over time periods of unchanging production categories.

$\langle E \rangle$  has been precisely determined for Cb, Cr, Mn, Mo, Ni, Si, Ti, V, and W. A 22-year average value was calculated in order to get an accurate, reliable factor. The accuracy of  $\langle E \rangle$  was limited primarily by chemical specification uncertainty with a significant contribution from time mean square uncertainty for Cb, Mo, and Ti. Accuracy has been limited by constraints of the data base. In particular, those constraints included incomplete descriptive type chemical specification information and a change in production categories from 1976 to 1977. Another constraint was a low universality factor for some elements in descriptive types. A low universality factor here implies

that an element is contained in only one or two of the grades used to define the chemical specification of a

descriptive type, leaving in doubt whether that grade was actually produced.

## CONCLUSIONS

For the purpose of estimation, the Cr, Ni, Mo, Mn, or Si fraction of stainless steel, or scrap resulting from that steel, and uncertainty bounds were calculated. Factors and uncertainty bounds for Cb, Ti, V, and W were also calculated. However, the uncertainty bounds for the latter elements are broad, suggesting an alternative method may be appropriate.

For the major and intermediate constituent elements, the 1962-83 average elemental fraction and uncertainty was

calculated for Cr to be about  $0.17 \pm 0.01$ ; Ni,  $0.07 \pm 0.01$ ; Mn,  $0.015 \pm 0.005$ ; Mo,  $0.004 \pm 0.001$ ; and Si,  $0.009 \pm 0.001$ . For the minor constituent elements, the 1962-83 average elemental fraction and uncertainty was calculated for Cb to be about  $0.00014 \pm 0.00003$ ; Ti,  $0.0004 \pm 0.0001$ ; V,  $0.00003 \pm 0.00001$ ; and W,  $0.0001 \pm 0.00003$ . The use of Ti changed significantly over the analysis period. The elemental fraction and uncertainty for Ti calculated over the 1977-83 time period was  $0.0008 \pm 0.0001$ .

## REFERENCES

1. Morgan, J. D. U.S. and the World Mineral Positions, 1985 to the Year 2000. *Min. Eng.*, v. 38, No. 4 (Littleton, CO), Apr. 1986, pp. 245-248.
2. U.S. Bureau of Mines, Mineral Facts and Problems, 1985 Edition. B 675, 1985, 956 pp.
3. Thomas, P. R., and E. H. Boyle, Jr. Chromium Availability—Market Economy Countries. BuMines IC 8977, 1984, 86 pp.
4. Coffman, J. S., and C. M. Palencia. Manganese Availability—Market Economy Countries. BuMines IC 8978, 1984, 26 pp.
5. Bleiwas, D. I. Nickel Availability—Market Economy Countries. BuMines IC 8995, 1984, 33 pp.
6. Anstett, T. F., D. I. Bleiwas, and R. J. Hurdelbrink. Tungsten Availability—Market Economy Countries. BuMines IC 9025, 1985, 51 pp.
7. Palencia, C. M. Molybdenum Availability—Market Economy Countries. BuMines IC 9044, 1985, 30 pp.
8. Fantel, R. J., D. A. Buckingham, and D. E. Sullivan. Titanium Minerals Availability—Market Economy Countries. BuMines IC 9061, 1986, 48 pp.
9. Miller, F. W., R. J. Fantel, and D. A. Buckingham. Columbium Availability—Market Economy Countries. BuMines IC 9085, 1986, 20 pp.
10. Kilgore, C. C., and P. R. Thomas. Manganese Availability—Domestic. BuMines IC 8889, 1982, 14 pp.
11. Lemons, J. F., E. H. Boyle, Jr., and C. C. Kilgore. Chromium Availability—Domestic. BuMines IC 8895, 1982, 14 pp.
12. Buckingham, D. A., and J. F. Lemons, Jr. Nickel Availability—Domestic. BuMines IC 8988, 1984, 27 pp.
13. National Materials Advisory Board. Contingency Plans for Chromium Utilization. Natl. Acad. Sci., Washington, DC, NMAB-335, 1978, p. 128.
14. Kusik, C. L., H. V. Makar, and M. R. Mounier. Availability of Critical Scrap Metals Containing Chromium in the United States. Wrought Stainless Steels and Heat-Resisting Alloys. BuMines IC 8822, 1980, pp. 38-44.
15. Papp, J. F. Chromium Contained in U.S. Produced Stainless and Heat-Resisting Steels. Paper in Chromium-Chromite: Bureau of Mines Assessment and Research. Proceedings of Bureau of Mines Briefing held at Oregon State University, Corvallis, OR, June 4-5, 1985, comp. by C. B. Daellenbach. BuMines IC 9087, 1986, pp. 5-11.
16. Society of Automotive Engineers. Metals & Alloys in the Unified Numbering System. SAE, 3d ed., 1983, pp. 122, 173-181, 197-217.
17. Boyer, H. E., and T. L. Gall (eds.). Heat-Resistant Materials. Ch. in Metals Handbook, Desk Edition. ASM, Nov. 1984, pp. 16.1-16.22.
18. Redmond, J. D. Corrosion-Resistant Materials. Ch. in Metals Handbook, Desk Edition, ed. by H. E. Boyer and T. L. Gall. ASM, Nov. 1984, pp. 15.1-15.30.
19. American Iron and Steel Institute. Quarterly Production of Stainless and Heat Resisting Raw Steel, Fourth Quarter 1963 Through 1983. AISI Form AIS-104.
20. Peckner, D., and I. M. Bernstein (eds.). Handbook of Stainless Steels. McGraw-Hill, 1977, p. 39-11.
21. Lula, R. A. Manganese Stainless Steel. The Manganese Centre (Paris), 1986, 83 pp.
22. \_\_\_\_\_. Stainless Steel. ASM, 1986, 173 pp.
23. Deeley, P. D., K. J. A. Kundig, and H. R. Spendelow. Ferroalloys and Alloying Additives Handbook. Shieldalloy Corp., 1981, 124 pp.
24. American Society for Metals. Assessment of Quality and Material Form of Vanadium for the National Defense Stockpile. ASM, June 1986, p. 52.
25. Peckner, D., and I. M. Bernstein (eds.). Handbook of Stainless Steels. McGraw-Hill, 1977, pp. 11.1-11.19, 12.1-12.40, 13.1-13.15, and 14.1-14.14.

## APPENDIX A.—GLOSSARY OF ABBREVIATIONS

cs	Chemical specification.	M	Subscript representing maximum.
<E>	Average element fraction of stainless steel. E represents an element. Time period 1962-83.	max	Maximum.
<E' >	Average element fraction of stainless steel calculated by the same method as <E> but for the time period 1977-83. E represents an element.	MEC	Midpoint element content.
<E'' >	Average element fraction of stainless steel using alternative method. E represents an element.	min	Minimum.
ECC	Element content change.	N	An integer number representing the total number of something indicated by a subscript.
El.min	Chemical specification element minimum, where El represents an element.	P	Production of stainless steel.
El.max	Chemical specification element maximum, where El represents an element.	PD	Percent difference.
EPD	Estimated percent difference.	R	Magnitude of the difference between upper and lower bound element fraction specification divided by element fraction.
F	Fraction of element contained in stainless steel.	RC	Reported consumption.
FeCr	Ferrochromium	SC	Scrap consumption.
G	Fraction of element contained in a stainless steel grade.	st	Short tons.
<i>i</i>	Subscript index representing steel type.	T	Fraction of element contained in a stainless steel type.
<i>j</i>	Subscript index representing year.	tms	Time mean square.
<i>k</i>	Subscript index representing stainless steel grade.	Uf	Uniformity.
<i>l</i>	Subscript index representing an alloying element.	Uv	Universality.
<i>m</i>	Subscript index representing minimum and maximum.	yr	Year.
<i>m</i>	Subscript representing minimum.	$\sigma^2$	Statistical variance.
		$\Sigma$	Summation symbol.

## APPENDIX B.—GRADE CHEMICAL SPECIFICATIONS<sup>1</sup>

A minimum and maximum elemental content for each element for each grade is required to calculate  $\langle E \rangle$ . As indicated in table 2, numerous grades do not have both a chemical element minimum and maximum specification. In this appendix, the reasons for a lack of boundary values are categorized and the interpretation of boundary values is resolved.

In order to make table 2, interpretation of the UNS chemical specifications was necessary. In some specifications, the elemental contents were ambiguous. The ambiguous content specifications were categorized as follows:

1. Optional—An elemental content is optional.
2. Shared—A content specification is shared between elements.
3. Conditional—The content for one element is dependent on that of one or two other elements.

The conditional case is subdivided into two parts: conditional A, where there is no maximum elemental content specified and conditional B, where a maximum elemental content is specified. Table B-1 details the conditional chemical specifications and the choice of minimum and maximum content. S30300 is an example of the optional case. In each optional case, the maximum content is specified; minimum unspecified; and content is optional. The minimum content was defined to be zero for each optional case. S17480 is an example of the shared case. In each shared case, elemental content limits apply to a combination of two elements. The elemental content limits were applied independently to each element that shared the limit for each shared case. S32100 is an example of conditional A case. In each conditional A case, no maximum content is specified, and the minimum content is a constant times the C content. The minimum content was calculated assuming maximum C content. The maximum was set equal to the minimum value for each conditional A case. S30940 is an example of conditional B case. In each conditional B case, the maximum elemental content is specified; but the minimum is a function of one other element (carbon) or two other elements (carbon and nitrogen). The specified maximum was used and the minimum was calculated assuming maximum C or C and N content for each conditional B case. Most of the conditional chemical specifications detailed in table B-1 are a combination of the shared and conditional B cases described above.

No maximum specification appears in two grades for Cr and in one grade for Ni. For Cr, those grades are S30483

and S30560. Because all other S304xx and S305xx series grades have a 2% spread between Cr minimum and maximum, that spread was assumed to apply to these grades as well. Thus, the maximum Cr content for these grades was defined to be 2% greater than the minimum percent content. For Ni, that grade is S30483. Based on an expected average Ni content of 8.25%, the maximum Ni content was defined to be 8.5%.

No minimum specification appears for Cb in 3 grades, Mn in 152 grades, Mo in 39 grades, Ni in 32 grades, Si in 179 grades, Ti in 5 grades, and V in 4 grades. For Cb and Ti, the grades containing an unspecified minimum appear only in descriptive production categories. Because of this, the impact of any choice regarding the unspecified minimum is diluted by the other grades that appear in the descriptive category.

For Cb, the unspecified minimum Cb contents were assumed to be zero. The only three grades affected are S37000, S38660, and S42100. In each case, the upper bound Cb content is 0.05% and the grade is part of a descriptive production category. The maximum Cb content of these grades is only one-fourth the magnitude of the smallest maximum Cb content of the 32 grades that specify both a minimum and maximum content. For these reasons, the assumption of zero value for the unspecified minimum of these three grades is likely to have little effect on the calculated  $\langle Cb \rangle$ .

For Mn, the unspecified minimum contents were estimated for the grades associated with major production categories. Those grades are the S301xx, S304xx, S316xx, S409xx, and S430xx Series. Based on an anticipated average Mn content for these grades, the minimum content was chosen to be zero for S301xx, S409xx, and S430xx Series; 1.5% for the S304xx Series; and 1.0% for S316xx series. These series represent 26 of the 152 Grades (17%) for which there are unspecified Mn minima. However, in terms of production, these 26 grades represented 74% of total production in 1983. The unspecified minimum Mn content was assumed to be zero for the remaining grades that did not specify a minimum.

For Mo, the unspecified minimum contents were estimated for the grades associated with specific types that were used by AISI as production categories. Those grades (types) were S30300 (303), S41600 (416), S42040 (420F), S43020 (430F), S44002 (440A), S44003 (440B), and S44004 (440C). Based on an expected typical Mo content, the minimum content chosen was 0.40 for S41600 and 0.25 for S44002, S44003, and S44004. The minimum contents for S30300, S42020, and S43020 were chosen to be zero because those grades are produced Mo free.

<sup>1</sup>Symbols used in this appendix are defined in appendix A.

Table B-1.—Ambiguous UNS element specifications and interpretation

Grade	Element	UNS specification, %	Bound interpretation, %	
			Minimum	Maximum
K91800	Ti	Ti: 5C to 0.60, 0.08% C max	0.40	0.60
N08020	Cb	Cb: 8C to 1.00, 0.07% C max	.56	1.00
N08700	Cb	Cb: 8C to 0.50, 0.04% C max	.32	.50
S17480	Cb	Cb + Ta: 0.15 to 0.30	.15	.30
S30300	Mo	Mo: 0.60 max (Optional)	.0	.60
S30940	Cb	Cb: 10C to 1.00, 0.08% C max	.8	1.00
S31040	Cb	Cb + Ta: 10C min to 1.10 max, 0.08% C max	.8	1.10
S31635	Ti	Ti: 5(C + N) to 0.70, 0.08% C max, 0.10% N max	.45	.7
S31640	Cb	Cb + Ta: 10C to 1.10, 0.08% C max	.8	1.10
S31980	Cb	Cb + Ta: 8C to 1.0, 0.08% C max	.64	1.0
S32100	Ti	Ti: 5C min, 0.08% C max	.4	.4
S32109	Ti	Ti: 4C to 0.06, C: 0.04 to 0.10	.16	.60
S32180	Ti	Ti: 9C to 1.0, 0.08% C max	.72	1.0
S34700	Cb	Cb: 10C min, 0.08% C max	.8	.8
S34709	Cb	Cb: 8C to 1.00, C: 0.04 to 0.10	.32	1.00
S34720	Cb	Cb: 10C to 1.10, 0.08% C max	.8	1.10
S34723	Cb	Cb: 10C to 1.10, 0.08% C max	.80	1.10
S34780	Cb	Cb: 10C to 1.0, 0.08% C max	.80	1.00
S34781	Cb	Cb + Ta: 12C to 0.50, 0.07% C max	.30	.50
S34788	Cb	Cb + Ta: 10C to 1.0, 0.08% C max	.80	1.00
S34800	Cb	Cb: 10C min, 0.08% C max	.80	.80
S34809	Cb	Cb: 8C to 1.00, C: 0.04 to 0.10	.32	1.00
S40800	Ti	Ti: 12C to 1.10, 0.08% C max	.96	1.10
S40900	Ti	Ti: 6C to 0.75, 0.08% C max	.48	.75
S41600	Mo	Mo: 0.60 max (Optional)	.0	.60
S42020	Mo	Mo: 0.60 max (Optional)	.0	.60
S43020	Mo	Mo: 0.60 max (Optional)	.0	.60
S43035	Ti	Ti: 12C to 1.10, 0.07% C max	.84	1.10
S43036	Ti	Ti: 5C to 0.75, 0.10% C max	.50	.75
S43600	Cb	Cb + Ta: 5C to 0.70, 0.12% C max	.60	.70
S44100	Cb	Cb: [0.3 + (9C)] to 0.9, 0.03% C max	.57	.90
S44400	Cb	Ti + Cb: [0.20 + 4(C + N)] to 0.80, 0.025% C max, 0.025% N max	.40	.80
	Ti		.40	.80
S44635	Cb	Cb + Ti: [0.20 + 4(C + N)] to 0.80, 0.025% C max, 0.035% N max	.44	.80
	Ti		.44	.80
S44660	Cb	Cb + Ti: [0.20 + 4(C + N)] to 0.80, 0.025% C max, 0.035% N max	.44	.80
	Ti		.44	.80
S44687	Ni	Ni + Cu: 0.50 max, 0.20% Cu max	.00	.50
S44735	Cb	Cb + Ti: [0.2 + 6(C + N)] to 1.0, 0.03% C max, 0.045% N max	.20	1.00
	Ti		.20	1.00
S45000	Cb	Cb: 8C min, 0.05% C max	.40	.40
S66009	Mo	Mo: 0.20 to 0.50, W: 1.50 to 3.00	.20	.50
	W	If Mo not used, W: 2.00-3.00	1.5	3.0

## APPENDIX C.—<E> DEFINITION<sup>1</sup>

The procedure set forth in the "Grade-to-type relationship" section is here applied to get the type chemical specifications and <E> is defined.

This procedure resulted in the association of each universal set grade with one production set type. With this procedure for distributing grades over types, a problem was encountered for the category Ni<8Σ<10 ("Other chromium nickel stainless steel with: Nickel under 8%, other alloys under 10%"). There are no grades assigned to this category. To understand this problem, recall the AISI definition of reported stainless and heat-resisting steel production (See "Information Sources" section). AISI's definition says that the AIS 104 reports production of stainless steel containing (1) 10% or more Cr or (2) 18% Cr plus other alloys. The Ni<8Σ<10 category requires the sum of non-nickel-alloying elements, and therefore Cr, to be less than 10%. Such a steel does not meet part 1 of the reported stainless steel production definition. This category requires less than 8% Ni and less than 10% of other alloy elements combined. Therefore, the sum of all alloying elements must be less than 18%. Such a steel does not meet part 2 of the reported stainless steel production definition. Thus, the Ni<8Σ<10 definition and the reported stainless steel production definition are logically mutually exclusive. In fact, there was no grade that requires less than 8% Ni and a sum of other alloys less than 10%, not even a heat-resisting grade. For 4 years (1966-69), production was reported independently for this category. For the remaining 18 years, however, production was reported only for the combined category, Ni<8%.

An additional problem with this allocation of grades was the sparsity of grades in the remaining "Other nickel chromium stainless steels with: ...other alloys under 10%." (See table C-1.) The Ni=8-16Σ<10 category has two grades; and Ni>16-24Σ<10 has one grade; and Ni>24Σ<10 has two grades. One purpose for using UNS grades was to have a representative chemical elemental content definition of the descriptive categories. So few grades per descriptive category suggests that the variety of steels which make up production in that descriptive category are not represented. If so, the chemical elemental contents inferred from those constituent grades may be inaccurate, especially for chemical elements other than Cr and Ni.

Because of the potential for error resulting from the limited or lack of grade constituents and the limited quantity of resolved production data for these categories, the "Other alloys under 10%" and "Other alloys over 10%" categories were combined for each specified Ni category.

Thus, the eight 1962-76 "Other nickel chromium stainless steels with:" categories were reduced to four categories equivalent to the four 1977-82 "Other Nickel Chromium Stainless Steels With:" categories of the same description. The chemical elemental content of these categories for the 1962-76 period differs from that of the 1977-82 period because the grade constituents vary between those time periods. The constituent grade variation resulted from the change in specific types used to report production.

Table C-1 summarizes the association of UNS grades with AISI types. Tables C-2 and C-3 summarize the AISI type minimum and maximum elemental fractions calculated from the associated grades listed in table C-1. The production values used to calculate elemental contents are listed in appendix E.

The descriptive type elemental fraction was calculated as the unweighted average of the constituent grade elemental fractions. Let  $T_{lmi}$  be the fractional elemental content for  $l$ th element of the  $i$ th type, where  $m$  represents minimum or maximum. Let  $G_{lmk}$  be the fractional elemental content of  $l$ th element of the  $k$ th grade. Then,

$$T_{lmi} = \left[ \sum_{k(i)} G_{lmk} \right] / K \quad (C-1)$$

where  $k(i)$  means those  $k$  grades associated with the  $i$ th type and  $K$  is the number of those grades. For example, suppose there are three grades, say,  $k = 1, 3,$  and  $7$ , associated with type  $i = 2$ , then

$$T_{lm2} = G_{lm1} + G_{lm3} + G_{lm7} / 3. \quad (C-2)$$

Ideally, one would like to combine the chemical specifications of the grades in a way that is proportional to the production of that grade; that is, use a production-weighted average. Then the chemical specification of the type would represent production within that type. Unfortunately, we do not know the production distribution among grades within a type. So, we must use the unweighted average method. Potentially, production within a type could be virtually nil for one grade that requires an element uncommon to stainless steel; while another grade not requiring that element accounts for a large fraction of that type's production. The method used here would overestimate the "uncommon" element. There is less danger of making erroneous estimates for those elements that are required in every grade within a type, such as for Cr or Ni in those descriptive categories that specify Ni limits.

Having defined the type elemental fraction via grades, one can calculate the annual minimum and maximum

<sup>1</sup>The symbols used in this appendix are defined in appendix A.

elemental fraction averaged over types,  $F_{lmj}$ . Let  $P_{ij}$  be the production of type  $i$  in year  $j$ . Then  $F_{lmj}$  is

$$F_{lmj} = \left[ \sum_{i=1}^{76} T_{lmi} \cdot P_{ij} \right] / \left[ \sum_{i=1}^{76} P_{ij} \right] \quad (C-3)$$

The annual midpoint elemental fraction then is

$$F_{lj} = (F_{lMj} + F_{lmj})/2 \quad (C-4)$$

in year  $j$ , where  $M$  represents maximum;  $m$ , minimum. The time-averaged midpoint elemental fraction,  $F_l$ , is

$$F_l = \left[ \sum_{j=1962}^{1983} F_{lj} \right] / N_{yr} \quad (C-5)$$

where  $N_{yr}$  is the number of years over which  $F_{lj}$  is summed.  $N_{yr} = 22$  for  $j$  summed from 1962 through 1983.

$\langle E \rangle$  is defined as the midpoint value,  $F_l$ .

$$\langle E \rangle = F_l \quad (C-6)$$

Table C-1.—Association of UNS grades with descriptive AISI types

AISI name	Production category name	Constituent UNS grade(s)
1962-76 TIME PERIOD		
Other chromium nickel stainless steel with:		
Nickel under 8%, other alloys under 10% . . . . .	Ni < 8Σ < 10 . . . . .	--
Nickel under 8%, other alloys over 10% . . . . .	Ni < 8Σ > 10 . . . . .	K91352, S15500, S15700, S15780, S15789, S16600, S17400, S17480, S17600, S17700, S17780, S20300, S20500, S21460, S21600, S21603, S21900, S21904, S21980, S23980, S24000, S24100, S31100, S31200, S31500, S31803, S32550, S32900, S35000, S35080, S35500, S35580, S36200, S41026, S41050, S41086, S41500, S41780, S41800, S41880, S42100, S42200, S42201, S42400, S44635, S44660, S44800, S45000, S63005, S63007, S63008, S63011, S63012, S63015, S64152, S65006, S65770
Nickel 8% to 16%, other alloys under 10% . . . . .	Ni = 8-16Σ < 10 . . . . .	K91890, K91940
Nickel 8% to 16%, other alloys over 10% . . . . .	Ni = 8-16Σ > 10 . . . . .	K91555, K91930, S13800, S13889, S14800, S16800, S16880, S20910, S20980, S21500, S21800, S21880, S30115, S30210, S30260, S30310, S30330, S30345, S30360, S30409, S30430, S30451, S30452, S30453, S30454, S30483, S30560, S30780, S30815, S30880, S30881, S30882, S30883, S30884, S30886, S30888, S30940, S30980, S30981, S30983, S31609, S31620, S31635, S31640, S31651, S31653, S31654, S31680, S31681, S31683, S31688, S31703, S31780, S31783, S31980, S32109, S32180, S34709, S34720, S34723, S34780, S34781, S34788, S34809, S37000, S38660, S45500, S63014, S63016, S63017, S63198, S63199, S64299, S66009
Nickel 16% to 24%, other alloys under 10% . . . . .	Ni > 16-24Σ < 10 . . . . .	S33100
Nickel 16% to 24%, other alloys over 10% . . . . .	Ni > 16-24Σ > 10 . . . . .	S31040, S31080, S31254, S38100, S38400
Nickel over 24%, other alloys under 10% . . . . .	Ni > 24Σ < 10 . . . . .	K92350, K94760
Nickel over 24%, other alloys over 10% . . . . .	Ni > 24Σ > 10 . . . . .	N06333, N08020, N08026, N08028, N08330, N08366, N08700, S66220, S66286, S66545
All other . . . . .	All other . . . . .	K91470, K91670, K91800, K91870, K92400, K92500, K92801, S18200, S21400, S28200, S40800, S40900, S41001, S41008, S41025, S41040, S41041, S41080, S41081, S41610, S42020, S42023, S42080, S42300, S42900, S43035, S43036, S43080, S43400, S43600, S44020, S44023, S44025, S44100, S44400, S44625, S44626, S44627, S44687, S44700, S44735, S63013, S65150

Table C-1.—Association of UNS grades with descriptive AISI types—Continued

AISI name	Production category name	Constituent UNS grade(s)
1962-76 TIME PERIOD—Continued		
501, 502, and all other high chromium heat-resisting steels .....	501, 502, + .....	K41245, K41545, K51545, K90941, K90987, K91955, S50100, S50180, S50181, S50200, S50280, S50281, S50300, S50400, S50480, S64005, S64006, S65007
Production not reported by type .....	PNRBT <sup>1</sup> .....	--
1977-83 TIME PERIOD		
Other Chromium Nickel Stainless Steels With:		
Nickel Under 8% .....	Ni < 8 .....	K91352, S15500, S15700, S15780, S15789, S16600, S17400, S17480, S17600, S17700, S17780, S20300, S21460, S21600, S21603, S21900, S21904, S21980, S23980, S24000, S24100, S31100, S31200, S31500, S31803, S32550, S35000, S35080, S35500, S35580, S36200, S41026, S41050, S41086, S41500, S41780, S41800, S41880, S42100, S42201, S42400, S44635, S44660, S44800, S45000, S63005, S63007, S63008, S63011, S63012, S63015, S64152, S65006, S65770
Nickel 8-16% .....	Ni=8-16 .....	K91555, K91890, K91930, K91940, S13800, S13889, S14800, S16800, S16880, S20910, S20980, S21500, S21800, S21880, S30115, S30210, S30260, S30310, S30330, S30345, S30360, S30409, S30452, S30453, S30454, S30483, S30560, S30780, S30815, S30880, S30881, S30882, S30883, S30884, S30886, S30888, S30940, S30980, S30981, S30983, S31609, S31635, S31640, S31653, S31654, S31680, S31681, S31683, S31688, S31780, S31783, S31980, S32109, S32180, S34709, S34720, S34723, S34780, S34781, S34788, S34809, S37000, S38660, S45500, S63014, S63016, S63017, S63198, S63199, S64299, S66009
Nickel Over 16-24% .....	Ni > 16-24 .....	S31040, S31080, S31254, S33100, S38100
Nickel Over 24% .....	Ni > 24 .....	K92350, K94760, N06333, N08020, N08026, N08028, N08366, N08700, S66220, S66286, S66545
All Other:		
15% Chromium or Less .....	≤15% Cr .....	K91470, K91670, NONE, <sup>2</sup> S40800, S41001, S41008, S41025, S41040, S41041, S41080, S41081, S41610, S42023, S42080, S42300
Over 15% Chromium .....	> 15% Cr .....	K91800, K91870, K92400, K92500, K92801, S18200, S21400, S28200, S43035, S43036, S43080, S44020, S44023, S44025, S44100, S44300, S44400, S44625, S44626, S44627, S44687, S44700, S44735, S63013, S65150
All Other High Chromium Heat Resisting Steels .....	AOHCHRS <sup>3</sup> .....	K41245, K41545, K51545, K90941, K90987, K91955, S50180, S50181, S50241, S50281, S50300, S50400, S50480, S64005, S64006, S65007
Production Not Shown By Type .....	PNSBT <sup>4</sup> .....	--

<sup>1</sup>PNRBT represents Production not reported by type. See table 3.

<sup>2</sup>AISI Type 406 composition was defined in reference 16.

<sup>3</sup>AOHCHRS represents All Other High Chromium Heat Resisting Steels. See table 3.

<sup>4</sup>PNSBT represents Production Not Shown By Type. See table 3.

NOTE.—Dashes represent absence of data.

Table C-2.—Chromium, nickel, molybdenum, and manganese minimum and maximum weight fraction in steel, by type

Production type	Chromium		Nickel		Molybdenum		Manganese	
	Min	Max	Min	Max	Min	Max	Min	Max
201	0.1600	0.1800	0.0350	0.0550	--	--	0.0550	0.0750
202	.1700	.1900	.0400	.0600	--	--	.0750	.1000
205	.1600	.1800	.0100	.0175	--	--	.1400	.1550
301	.1600	.1800	.0600	.0800	--	--	--	.0200
302	.1700	.1900	.0800	.1000	--	--	--	.0200
302B	.1700	.1900	.0800	.1000	--	--	--	.0200
303	.1700	.1900	.0800	.1000	--	0.0060	--	.0200
303Se	.1700	.1900	.0800	.1000	--	--	--	.0200
304	.1800	.2000	.0800	.1050	--	--	.0150	.0200
S30430	.1700	.1900	.0800	.1000	--	--	.0150	.0200
304N	.1800	.2000	.0800	.1050	--	--	.0150	.0200
304L	.1800	.2000	.0800	.1200	--	--	.0150	.0200
305	.1700	.1900	.1000	.1300	--	--	--	.0200
308	.1900	.2100	.1000	.1200	--	--	--	.0200
309	.2200	.2400	.1200	.1500	--	--	--	.0200
309S	.2200	.2400	.1200	.1500	--	--	--	.0200
310	.2400	.2600	.1900	.2200	--	--	--	.0200
310S	.2400	.2600	.1900	.2200	--	--	--	.0200
314	.2300	.1900	.1900	.2200	--	--	--	.0200
316	.1600	.1800	.1000	.1400	0.0200	.0300	.0100	.0200
316F	.1700	.1900	.1200	.1400	.0175	.0250	.0100	.0200
316N	.1600	.1800	.1000	.1400	.0200	.0300	.0100	.0200
316L	.1600	.1800	.1000	.1400	.0200	.0300	.0100	.0200
317	.1800	.2000	.1100	.1500	.0300	.0400	--	.0200
317L	.1800	.2000	.1100	.1500	.0300	.0400	--	.0200
321	.1700	.1900	.0900	.1200	--	--	--	.0200
329	.2300	.2800	.0250	.0500	.0100	.0200	--	.0100
330	.1700	.2000	.3400	.3700	--	--	--	.0200
347	.1700	.1900	.0900	.1300	--	--	--	.0200
348	.1700	.1900	.0900	.1300	--	--	--	.0200
384	.1500	.1700	.1700	.1900	--	--	--	.0200
1962-76:								
Ni < 8	.1637	.1832	.0371	.0490	.0090	.0134	.0243	.0357
Ni = 8-16	.1684	.1897	.0946	.1194	.0085	.0138	.0119	.0248
Ni > 16-24	.1792	.1992	.1833	.2042	.0100	.0121	.0025	.0172
Ni > 24	.1655	.1893	.2992	.3277	.0230	.0308	.0010	.0160
1977-83:								
Ni < 8	.1635	.1823	.0385	.0503	.0092	.0135	.0231	.0344
Ni = 8-16	.1681	.1895	.0943	.1189	.0081	.0135	.0121	.0251
Ni > 16-24	.1850	.2050	.1860	.2070	.0120	.0145	.0300	.0166
Ni > 24	.1651	.1883	.2955	.3238	.0250	.0336	.0011	.0157
403	.1150	.1300	--	--	--	--	--	.0100
405	.1150	.1450	--	--	--	--	--	.0100
406	.1300	.1300	--	--	--	--	--	--
409	.1050	.1175	--	.0050	--	--	--	.0100
410	.1150	.1350	--	--	--	--	--	.0100
414	.1150	.1350	.0125	.0250	--	--	--	.0100
416	.1200	.1400	--	--	.0040	.0060	--	.0125
416Se	.1200	.1400	--	--	--	--	--	.0125
420	.1200	.1400	--	--	--	--	--	.0100
420F	.1200	.1400	--	--	--	.0060	--	.0125
422	.1150	.1350	.0050	.0100	.0075	.0125	--	.0100
429	.1400	.1600	--	--	--	--	--	.0100
430	.1600	.1800	--	--	--	--	--	.0100
430F	.1600	.1800	--	--	--	.0060	--	.0125
430FSe	.1600	.1800	--	--	--	--	--	.0125
431	.1500	.1700	.0125	.0250	--	--	--	.0100
434	.1600	.1800	--	--	.0075	.0125	--	.0100
436	.1600	.1800	--	--	.0075	.0125	--	.0100
440A	.1600	.1800	--	--	.0050	.0075	--	.0100

**Table C-2.—Chromium, nickel, molybdenum, and manganese minimum and maximum weight fraction in steel, by type—Continued**

Production type	Chromium		Nickel		Molybdenum		Manganese	
	Min	Max	Min	Max	Min	Max	Min	Max
440B .....	0.1600	0.1800	--	--	0.0050	0.0075	--	0.0100
440C .....	.1600	.1800	--	--	.0050	.0075	--	.0100
442 .....	.1800	.2300	--	--	--	--	--	.0100
443 .....	.1800	.2300	--	0.0050	--	--	--	.0100
446 .....	.2300	.2700	--	--	--	--	--	.0150
All other .....	.1642	.1841	--	.0040	.0050	.0086	0.0108	.0190
All Other:								
≤15% Cr ...	.1180	.1360	--	.0038	.0019	.0048	.0019	.0083
>15% Cr ...	.1966	.2184	--	.0047	.0069	.0106	.0175	.0260
501, 502, + .....	.0512	.0686	--	.0017	.0070	.0113	.0109	.0181
501 .....	.0400	.0600	--	--	.0040	.0065	--	.0100
502 .....	.0400	.0600	--	--	.0040	.0065	--	.0100
AOHCHRS <sup>1</sup> ...	.0526	.0697	--	.0019	.0074	.0119	.0123	.0191
PNRBT <sup>2</sup> .....	--	--	--	--	--	--	--	--
PNSBT <sup>3</sup> .....	--	--	--	--	--	--	--	--

<sup>1</sup>AOHCHRS represents All Other High Chromium Heat Resisting Steels. See table 3.

<sup>2</sup>PNRBT represents Production not reported by type. See table 3.

<sup>3</sup>PNSBT represents Production Not Shown By Type. See table 3.

NOTE.—Dashes represent absence of data.

**Table C-3.—Columbium, vanadium, silicon, titanium, and tungsten minimum and maximum weight fraction in steel, by type**

Production type	Columbium		Vanadium		Silicon		Titanium		Tungsten	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
201 .....	--	--	--	--	0.0080	0.0100	--	--	--	--
202 .....	--	--	--	--	.0080	.0100	--	--	--	--
205 .....	--	--	--	--	.0080	.0100	--	--	--	--
301 .....	--	--	--	--	.0080	.0100	--	--	--	--
302 .....	--	--	--	--	.0080	.0100	--	--	--	--
302B .....	--	--	--	--	.0200	.0300	--	--	--	--
303 .....	--	--	--	--	.0080	.0100	--	--	--	--
303Se .....	--	--	--	--	.0080	.0100	--	--	--	--
304 .....	--	--	--	--	.0080	.0100	--	--	--	--
S30430 .....	--	--	--	--	.0080	.0100	--	--	--	--
304N .....	--	--	--	--	.0080	.0100	--	--	--	--
304L .....	--	--	--	--	.0080	.0100	--	--	--	--
305 .....	--	--	--	--	.0080	.0100	--	--	--	--
308 .....	--	--	--	--	.0080	.0100	--	--	--	--
309 .....	--	--	--	--	.0080	.0100	--	--	--	--
309S .....	--	--	--	--	.0080	.0100	--	--	--	--
310 .....	--	--	--	--	.0120	.0150	--	--	--	--
310S .....	--	--	--	--	.0120	.0150	--	--	--	--
314 .....	--	--	--	--	.0150	.0300	--	--	--	--
316 .....	--	--	--	--	.0080	.0100	--	--	--	--
316F .....	--	--	--	--	.0080	.0100	--	--	--	--
316N .....	--	--	--	--	.0080	.0100	--	--	--	--
316L .....	--	--	--	--	.0080	.0100	--	--	--	--
317 .....	--	--	--	--	.0080	.0100	--	--	--	--
317L .....	--	--	--	--	.0080	.0100	--	--	--	--
321 .....	--	--	--	--	.0080	.0100	0.0040	0.0040	--	--
329 .....	--	--	--	--	.0060	.0075	--	--	--	--

Table C-3.—Columbium, vanadium, silicon, titanium, and tungsten minimum and maximum weight fraction in steel, by type—Continued

Production type	Columbium		Vanadium		Silicon		Titanium		Tungsten	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
330 .....	--	--	--	--	0.0075	0.0150	--	--	--	--
347 .....	0.0080	0.0080	--	--	.0080	.0100	--	--	--	--
348 .....	.0080	.0080	--	--	.0080	.0100	--	--	--	--
384 .....	--	--	--	--	.0080	.0100	--	--	--	--
1962-76:										
Ni <8 .....	.0003	.0006	0.0002	0.0004	.0066	.0087	0.0004	0.0008	0.0014	0.0020
Ni=8-16 ...	.0010	.0017	--	.0001	.0067	.0099	.0004	.0008	.0005	.0009
Ni >16-24 ..	.0013	.0018	--	--	.0091	.0131	--	--	--	--
Ni >24 .....	.0007	.0013	.0001	.0004	.0059	.0088	.0051	.0064	.0021	.0033
1977-83:										
Ni <8 .....	.0003	.0006	.0002	.0004	.0066	.0087	.0004	.0008	.0013	.0019
Ni=8-16 ...	.0011	.0018	--	.0001	.0067	.0099	.0004	.0009	.0005	.0009
Ni >16-24 ..	.0016	.0022	--	--	.0093	.0137	--	--	--	--
Ni >24 .....	.0008	.0014	.0001	.0005	.0057	.0083	.0056	.0070	.0023	.0036
403 .....	--	--	--	--	.0040	.0050	--	--	--	--
405 .....	--	--	--	--	.0080	.0100	--	--	--	--
406 .....	--	--	--	--	--	--	--	--	--	--
409 .....	--	--	--	--	.0080	.0100	.0048	.0075	--	--
410 .....	--	--	--	--	.0080	.0100	--	--	--	--
414 .....	--	--	--	--	.0080	.0100	--	--	--	--
416 .....	--	--	--	--	.0080	.0100	--	--	--	--
416Se .....	--	--	--	--	.0080	.0100	--	--	--	--
420 .....	--	--	--	--	.0080	.0100	--	--	--	--
420F .....	--	--	--	--	.0080	.0100	--	--	--	--
422 .....	--	--	.0015	.0030	.0060	.0075	--	--	.0075	.0125
429 .....	--	--	--	--	.0080	.0100	--	--	--	--
430 .....	--	--	--	--	.0080	.0100	--	--	--	--
430F .....	--	--	--	--	.0080	.0100	--	--	--	--
430FSe .....	--	--	--	--	.0080	.0100	--	--	--	--
431 .....	--	--	--	--	.0080	.0100	--	--	--	--
434 .....	--	--	--	--	.0080	.0100	--	--	--	--
436 .....	.0060	.0070	--	--	.0080	.0100	--	--	--	--
440A .....	--	--	--	--	.0080	.0100	--	--	--	--
440B .....	--	--	--	--	.0080	.0100	--	--	--	--
440C .....	--	--	--	--	.0080	.0100	--	--	--	--
442 .....	--	--	--	--	.0080	.0100	--	--	--	--
443 .....	--	--	--	--	.0080	.0100	--	--	--	--
446 .....	--	--	--	--	.0080	.0100	--	--	--	--
All other .....	.0005	.0010	--	.0001	.0059	.0076	.0009	.0018	--	--
All Other:										
≤15% Cr ...	.0001	.0004	.0001	.0002	.0051	.0063	.0006	.0008	--	--
>15% Cr ...	.0005	.0012	--	--	.0058	.0077	.0011	.0023	--	--
501, 502, + .....	--	--	.0004	.0008	.0085	.0119	--	--	.0006	.0014
501 .....	--	--	--	--	.0080	.0100	--	--	--	--
502 .....	--	--	--	--	.0080	.0100	--	--	--	--
AOHCHRS <sup>1</sup> ...	--	--	.0005	.0009	.0086	.0121	--	--	.0006	.0016
PNRBT <sup>2</sup> .....	--	--	--	--	--	--	--	--	--	--
PNSBT <sup>3</sup> .....	--	--	--	--	--	--	--	--	--	--

<sup>1</sup>AOHCHRS represents All Other High Chromium Heat Resisting Steels. See table 3.

<sup>2</sup>PNRBT represents Production not reported by type. See table 3.

<sup>3</sup>PNSBT represents Production Not Shown By Type. See table 3.

NOTE.—Dashes represent absence of data.

## APPENDIX D.—UNCERTAINTY<sup>1</sup>

The kinds of uncertainty, chemical specification and time variation, are described and mathematically defined. The chemical specification characteristics, universality and uniformity, are defined and their influence on chemical specification uncertainty discussed.

### UNCERTAINTY

Two uncertainty bounds were calculated: (1) the chemical specification uncertainty and (2) the time mean square uncertainty. The chemical specification uncertainty resulted from knowing only the minimum and maximum elemental fraction. The actual elemental fraction could lie anywhere between the extremes. The chemical specification uncertainty,  $E_{cs}$ , was defined as one-half of the maximum minus the minimum elemental fraction or

$$E_{cs,l} = \pm [F_{lM} - F_{lm}] / 2. \quad (D-1)$$

The time mean square uncertainty,  $E_{tms}$ , results from the time variation of the  $\langle E \rangle$ .  $E_{tms}$  represents the uncertainty incurred as a result of the time variance of  $F_{lj}$  about  $F_l$ .  $E_{tms}$  is defined in terms of the statistical standard error. The time mean square deviation is the mean square deviation over time based on the deviation of the annual midpoint elemental fraction,  $F_{lj}$ , defined in equation C-4, from the time-averaged elemental fraction,  $F_l$ , defined in equation C-5. The time variance of  $F_{lj}$  about  $F_l$ ,  $\sigma^2$ , is expressed by the equation

$$\sigma_l^2 = \left[ \sum_{j=1962}^{1983} (F_{lj} - F_l)^2 \right] / (N_{yr} - 1). \quad (D-2)$$

The standard error is  $S_l$

$$S_l = \sigma_l / N_{yr}, \quad (D-3)$$

and  $E_{tms,l}$  is the probable error

$$E_{tms,l} = 0.68 S_l. \quad (D-4)$$

Assuming  $F_{lj}$  is normally distributed, there is 95% certainty that the error is no more than  $2S_l$ . For Cr, this translates into a standard error of 0.00045 of 95% probability that the error does not exceed 0.0009 and a probable error of 0.00031.

The uncertainty used in this report,  $E_l$ , is the sum of the chemical specification and time mean square uncertainties

$$E_l = E_{cs,l} + E_{tms,l}. \quad (D-5)$$

Since the elemental fraction of each type is constant (except for those changes that resulted from the change of production categories in 1977), the time mean square deviation should represent variations of production among types of different elemental fractions. In terms of specific use (i.e., the number of units of element per unit of production), a small time mean square deviation indicates a constant specific use. A large time mean square deviation indicates time varying specific use.

Two characteristics of the chemical specification affect the uncertainty associated with a single  $\langle E \rangle$  representing the 1962-83 time period. These two characteristics are the relative size of the chemical specification and the variation of chemical specifications among production categories. The relative size of the chemical specification translates directly into  $E_{cs}$ . It is the uncertainty in  $F_l$  resulting from the difference between  $F_l$  and  $F_{lm}$  and  $F_{lM}$ . Denoting this characteristic by  $R$  and quantifying it as

$$R_l = (F_{lM} - F_{lm}) / F_l, \quad (D-6)$$

the average over all grades then becomes

$$R_l = \left[ \sum_{i'} (F_{lMi'} - F_{lmi'}) / F_{li'} \right] / N_l, \quad (D-7)$$

where  $i'$  indicates those grades that require element  $l$  and  $N_l$  is the number of grades that require element  $l$ . Note that for the same difference  $(F_{lM} - F_{lm})$ ,  $R_l$  is smaller when  $F_l$  is larger. This effect is reflected most clearly in  $E_l$  when  $E_l$  is measured as a percentage of  $\langle E \rangle$ . Because  $R_l$  is an average over a large number of grades, some of which are collected into production categories, and the actual value of  $E_{cs}$  depends on  $P_{ij}$  as well as on  $F_{lmi}$ ,  $R_l$  is an indicator or measure of potential for uncertainty. As  $R_l$  increases, the potential for greater  $E_{cs,l}$  increases. Whether or not  $E_{cs,l}$  changes as  $R_l$  does depends on the distribution of production. It is possible that, from one element to another, production varies in such a way that  $R_l$  increases while  $E_{cs,l}$  decreases. Such a case is considered unlikely owing to the large number of production categories. It is because of this possibility that  $R_l$  must be interpreted as an indicator of the magnitude of  $E_{cs}$ .

The second characteristic, variation of chemical specifications among production categories, is more complex. The idea in this instance is that, as production changes from year to year among production categories, the annual  $F_{lmj}$  vary owing to the difference in chemical specification and the variations in production. Here the variation of chemical requirements has two components: the difference of elemental requirements between those categories that require the element and the number of categories that

<sup>1</sup>Symbols used in this appendix are defined in appendix A.

require the element. Call these components "uniformity" and "universality" of an element's chemical specifications and define them in terms of the set of grades. An element is uniformly specified when every grade that requires that element has the same specification. That is

$$F_{lmi'} = F_{lm}, \quad (D-8)$$

where  $i'$  denotes those grades that require element  $l$ . An element is universally required when every grade requires that element. That is

$$F_{lMi} > 0 \quad (D-9)$$

for all  $i$ . The minimum possible uncertainty results (i.e.,  $E_{tms} = 0$  and  $E = E_{cs}$ ) when an element is universally required and uniformly specified. The magnitude of  $E_{tms}$  depends on the distribution of  $P_{ij}$ ; so, the variation of chemical specifications must be viewed as an indicator for the potential of greater (or lesser) uncertainty.

Quantitative measures of universality and uniformity could be made for  $R_l$  as defined in order to compare the potential for increasing uncertainty among elements in  $\langle E \rangle$  resulting from these characteristics of the chemical specifications. Universality of elemental  $l$ ,  $Uv_l$ , is the number of grades that require element  $l$ ,  $N_l$ , divided by the total number of grades,  $N_t$ . Then

$$Uv_l = N_l/N_t. \quad (D-10)$$

There are two aspects of uniformity to be accounted for. They are the variations of the lower and upper bounds of the chemical specification. A usual measure of the variation of a population is the standard deviation's. One can use as a measure of uniformity,  $Uf_l$ , the sum of the standard deviation of the lower and upper bound chemical specifications. Then

$$Uf_l = D_{lM} + D_{lm} \quad (D-11)$$

where

$$D_{lm} = \sum_{i'} (F_{lmi'} - \langle F_{lm} \rangle)^2 / (N_l - 1), \quad (D-12)$$

and where  $i'$  represents those grades which require element  $l$  and

$$\langle F_{lm} \rangle = \left( \sum_{i'} F_{lmi'} \right) / N_l. \quad (D-13)$$

Chromium would be expected to have a small time mean square deviation relative to that of the other elemental constituents because chromium is required in all stainless steel types. The use of other elements is more varied. Raw material and processing costs and consumer demand could result in changes of other element use over time and thereby result in a time mean square deviation greater than that of chromium.





Table E-2.—Stainless steel production for 1970-77, by type, short tons—Continued

Type	1970	1971	1972	1973	1974	1975	1976	1977
316	68,141	53,773	63,476	102,175	129,079	58,057	72,100	87,752
316F	--	--	--	--	--	--	--	2,532
316N	--	--	--	--	--	--	--	--
316L	30,155	20,603	28,035	46,467	64,296	44,146	46,390	55,998
317	639	1,357	756	1,237	1,993	2,579	2,213	1,981
317L	--	--	--	--	--	--	--	--
321	18,994	14,866	19,669	24,835	30,993	15,431	12,877	19,251
329	--	--	--	--	--	--	--	3,972
330	--	--	--	--	--	--	--	--
347	5,325	4,088	5,299	7,657	8,558	7,292	4,450	5,094
348	723	682	565	1,984	808	--	--	--
384	--	--	--	--	--	--	--	640
Ni < 8Σ < 10	37,549	31,177	36,131	42,741	52,418	33,918	40,997	--
Ni < 8Σ > 10	--	--	--	--	--	--	--	--
Ni = 8-16Σ < 10	4,271	8,199	16,322	22,802	21,823	10,892	17,161	--
Ni = 8-16Σ > 10	--	--	--	--	--	--	--	--
Ni > 16-24Σ < 10	999	2,170	3,166	4,437	2,199	3,725	6,487	--
Ni > 16-24Σ > 10	--	--	--	--	--	--	--	--
Ni > 24Σ < 10	18,745	16,787	24,578	29,382	24,562	16,966	13,430	--
Ni > 24Σ > 10	--	--	--	--	--	--	--	--
Ni < 8	--	--	--	--	--	--	--	54,139
Ni = 8-16	--	--	--	--	--	--	--	15,010
Ni > 16-24	--	--	--	--	--	--	--	3,091
Ni > 24	--	--	--	--	--	--	--	15,406
403	19,974	19,814	50,392	30,374	21,698	14,653	7,242	10,998
405	3,468	3,243	1,269	3,322	4,218	3,670	1,087	1,369
406	--	--	--	--	--	--	--	--
409	--	--	--	--	--	--	--	210,994
410	51,666	45,839	59,999	74,840	136,770	56,827	43,505	41,354
414	327	773	360	609	754	344	521	526
416	31,216	26,236	34,778	38,352	49,406	20,731	29,866	39,131
416Se	--	186	--	--	--	2,371	--	--
420	4,960	4,150	5,721	6,021	6,568	3,551	3,573	4,199
420F	--	--	--	--	--	--	--	2,016
422	--	--	--	--	--	--	--	2,674
429	--	--	--	--	--	--	--	--
430	112,984	137,946	140,256	164,818	138,821	44,809	91,238	94,440
430F	2,750	4,561	5,134	5,533	7,244	15,788	3,210	4,478
430FSe	--	--	--	--	1,036	--	--	--
431	3,792	3,955	5,204	2,917	2,336	1,677	1,358	1,236
434	--	--	--	--	--	--	--	52,649
436	--	--	--	--	--	--	--	7,531
440A	2,554	1,536	1,429	2,963	3,098	3,654	535	2,556
440B	--	--	--	--	--	289	199	--
440C	6,110	6,016	8,122	10,303	9,965	5,933	6,422	7,806
442	667	807	723	1,214	1,184	423	796	260
443	--	--	--	--	--	--	--	--
446	2,352	1,707	2,570	2,174	1,725	1,385	1,159	1,477
All other	115,642	121,749	131,584	118,331	196,961	130,715	275,973	--
All Other:								
≤ 15% Cr	--	--	--	--	--	--	--	45,035
> 15% Cr	--	--	--	--	--	--	--	7,746
501, 502, +	36,520	28,853	27,114	32,426	43,746	36,986	26,049	--
501	--	--	--	--	--	--	--	3,554
502	--	--	--	--	--	--	--	--
AOHCHRS <sup>1</sup>	--	--	--	--	--	--	--	11,709
PNRBT <sup>2</sup>	64,303	48,642	51,904	56,923	48,715	36,541	31,141	--
PNSBT <sup>3</sup>	--	--	--	--	--	--	--	50,279

<sup>1</sup>AOHCHRS represents All Other High Chromium Heat Resisting Steels. See table 3.

<sup>2</sup>PNRBT represents Production not reported by type. See table 3.

<sup>3</sup>PNSBT represents Production Not Shown By Type. See table 3.

NOTE.—Dashes indicate that American Iron and Steel Institute did not report production for that type and year.

Source: American Iron and Steel Institute (which combined production of some types in some years; combinations are not indicated in table).

Table E-3.—Stainless steel production for 1978-83, by type and by year, and 1962-83 average production, by type, short tons

Type	1978	1979	1980	1981	1982	1983	Average 1962-83
201	40,607	37,578	25,353	32,993	21,959	36,011	38,072
202	1,137	1,229	438	339	221	153	1,343
205	--	--	--	--	--	--	--
301	177,140	171,437	117,164	141,165	93,835	162,920	128,804
302	14,446	16,945	14,173	17,800	12,639	19,853	24,185
302B	--	--	--	--	--	--	2
303	41,544	50,266	38,996	36,095	20,493	41,111	35,082
303Se	1,449	18,842	--	--	--	--	2,726
304	638,442	714,203	596,743	632,545	484,819	717,990	514,862
S30430	13,222	12,356	--	10,490	--	--	2,093
304N	690	622	348	656	333	68,250	3,392
304L	62,633	76,399	79,945	80,512	60,387	--	49,547
305	13,040	11,885	9,360	7,945	6,272	9,315	10,488
308	2,455	3,227	1,951	2,797	1,199	1,388	2,976
309	5,834	6,204	5,056	5,988	2,211	3,111	6,152
309S	5,605	6,028	4,216	5,170	3,139	6,590	4,007
310	7,087	5,100	3,261	2,984	2,920	4,395	5,266
310S	--	1,970	2,322	2,568	1,072	--	862
314	--	--	--	--	--	--	--
316	88,240	107,812	98,332	76,704	47,475	60,572	74,307
316F	1,434	1,899	2,259	1,903	866	1,140	547
316N	--	--	--	--	--	--	--
316L	52,856	67,480	65,824	56,691	35,002	52,915	39,829
317	418	1,534	642	322	2,636	3,317	1,465
317L	2,379	5,026	4,687	6,888	--	--	863
321	21,877	24,097	16,144	17,693	11,846	14,067	20,775
329	4,018	4,266	2,360	3,017	1,740	3,191	1,026
330	--	--	--	--	--	--	--
347	6,353	6,882	5,297	5,103	4,333	5,070	7,222
348	863	804	487	610	746	871	704
384	--	--	--	--	--	--	29
Ni<8Σ<10	--	--	--	--	--	--	21,322
Ni<8Σ>10	--	--	--	--	--	--	4,269
Ni=8-16Σ<10	--	--	--	--	--	--	7,000
Ni=8-16Σ>10	--	--	--	--	--	--	1,521
Ni>16-24Σ<10	--	--	--	--	--	--	1,964
Ni>16-24Σ>10	--	--	--	--	--	--	501
Ni>24Σ<10	--	--	--	--	--	--	11,319
Ni>24Σ>10	--	--	--	--	--	--	3,092
Ni<8	66,762	74,841	65,590	52,739	39,216	55,689	18,590
Ni=8-16	22,394	24,229	23,153	22,214	9,224	14,414	5,938
Ni>16-24	3,348	5,487	8,393	7,536	4,756	7,220	1,811
Ni>24	17,321	18,249	17,485	13,095	11,154	8,826	4,615
403	9,889	13,162	11,520	15,276	6,578	5,483	16,665
405	1,425	1,311	1,384	587	676	647	2,512
406	--	--	--	--	--	--	--
409	205,771	217,429	132,359	146,855	119,592	172,012	54,773
410	48,868	50,370	46,201	50,172	32,889	33,013	51,377
414	601	316	--	--	20,718	31,104	2,680
416	39,265	45,294	36,804	38,171	--	--	32,162
416Se	--	--	--	--	--	--	145
420	4,513	5,977	5,622	4,732	3,971	3,586	5,128
420F	1,619	1,464	938	1,222	759	961	408
422	1,925	5,025	3,321	2,589	2,027	2,242	900
429	--	93,295	--	--	--	--	4,241
430	90,921	--	70,516	64,130	36,014	58,694	117,875
430F	4,336	5,173	4,247	3,395	2,898	3,038	4,712
430FSe	--	--	--	--	--	--	47
431	1,676	1,920	2,153	1,335	1,146	1,102	2,574
434	45,652	41,295	26,255	28,028	11,388	19,864	10,233

**Table E-3.—Stainless steel production for 1978-83, by type and by year, and 1962-83 average production, by type, short tons—Continued**

Type	1978	1979	1980	1981	1982	1983	Average 1962-83
436 .....	7,903	5,108	5,079	4,493	5,622	5,990	1,897
440A .....	2,072	2,348	4,383	4,407	4,704	4,315	3,896
440B .....	--	--	216	--	85	7,210	372
440C .....	9,141	10,537	9,223	7,115	4,613	--	6,775
442 .....	1,546	1,147	1,220	--	--	--	825
443 .....	--	--	--	--	--	--	24
446 .....	--	--	--	1,351	587	759	1,612
All other .....	--	--	--	--	--	--	81,255
All Other:							
≤15% Cr .....	55,050	24,119	15,959	18,863	17,161	26,599	9,218
> 15% Cr .....	14,616	19,140	9,950	13,617	8,548	14,900	4,024
501, 502, + .....	--	--	--	--	--	--	20,617
501 .....	4,317	6,397	3,231	4,583	981	2,172	1,147
502 .....	760	214	--	--	--	--	44
AOHCHRS <sup>1</sup> .....	14,166	11,014	15,357	8,973	6,528	6,727	3,385
PNRBT <sup>2</sup> .....	--	--	--	--	--	--	48,518
PNSBT <sup>3</sup> .....	62,042	61,211	77,016	79,614	65,568	53,004	20,397

<sup>1</sup>AOHCHRS represents All Other High Chromium Heat Resisting Steels. See table 3.

<sup>2</sup>PNRBT represents Production not reported by type. See table 3.

<sup>3</sup>PNSBT represents Production Not Shown By Type. See table 3.

NOTE.—Dashes indicate that American Iron and Steel Institute did not report production for that type and year.

Source: American Iron and Steel Institute (which combined production of some types in some years; combinations are not indicated in table).

**Table E-4.—Production of stainless steel by specific and descriptive subcategories, by year, short tons**

Year	Specific	Descriptive	Year	Specific	Descriptive
1962 .....	864,753	215,360	1974 .....	1,762,099	390,424
1963 .....	967,881	234,743	1975 .....	844,908	269,743
1964 .....	1,146,821	292,291	1976 .....	1,246,971	411,238
1965 .....	1,192,585	297,689	1977 .....	1,659,905	205,969
1966 .....	1,345,478	300,694	1978 .....	1,680,892	260,776
1967 .....	1,148,786	301,590	1979 .....	1,855,262	244,901
1968 .....	1,121,384	286,065	1980 .....	1,456,799	236,134
1969 .....	1,264,255	297,020	1981 .....	1,522,836	221,234
1970 .....	1,002,008	278,029	1982 .....	1,070,410	163,136
1971 .....	1,000,131	257,577	1983 .....	1,562,250	189,551
1972 .....	1,266,481	290,799	Average ..	1,298,460	270,546
1973 .....	1,583,236	307,042			

**Table E-5.—Production of stainless steel by selected production subcategories, by year, short tons**

Year	Cr-Ni Series			400 Series			Heat-resisting
	200 Series	300 Series	Descriptive	Martensitic	Ferritic	Descriptive	
1962 .....	38,982	561,419	57,450	80,690	183,662	63,172	20,661
1963 .....	49,097	649,257	65,785	73,530	195,997	53,925	20,674
1964 .....	44,191	825,177	61,887	86,581	190,872	69,923	16,873
1965 .....	25,579	842,203	67,033	132,715	192,088	100,244	23,538
1966 .....	23,209	1,003,987	98,304	148,582	169,700	80,808	32,845
1967 .....	28,041	818,356	83,263	138,013	164,376	89,077	33,618
1968 .....	36,729	789,483	70,679	140,057	155,115	100,579	37,536
1969 .....	43,425	906,652	73,297	131,934	182,244	138,932	36,126
1970 .....	45,164	714,024	61,564	120,599	122,221	115,642	36,520
1971 .....	65,267	678,095	58,333	108,505	148,264	121,749	28,853
1972 .....	56,125	894,399	80,197	166,005	149,952	131,584	27,114
1973 .....	49,631	1,190,165	99,362	166,379	177,061	118,331	32,426

Table E-5.—Production of stainless steel by selected production subcategories, by year, short tons—Continued

Year	Cr-Ni Series			400 Series			Heat-resisting
	200 Series	300 Series	Descriptive	Martensitic	Ferritic	Descriptive	
1974 .....	39,276	1,338,000	101,002	230,595	154,228	196,961	43,746
1975 .....	30,797	638,006	65,501	110,030	66,075	130,715	36,986
1976 .....	46,082	1,010,178	78,075	93,221	97,490	275,973	26,049
1977 .....	47,525	1,126,686	87,646	112,496	373,198	52,781	15,263
1978 .....	41,744	1,162,025	109,825	119,569	357,554	69,666	19,243
1979 .....	38,807	1,315,284	122,806	136,413	364,758	43,259	17,625
1980 .....	25,791	1,069,567	114,621	120,381	241,060	25,909	18,588
1981 .....	33,332	1,115,646	95,584	125,019	248,839	32,480	13,556
1982 .....	22,180	793,963	64,350	77,490	176,777	25,709	7,509
1983 .....	36,164	1,176,066	86,149	89,016	261,004	41,499	8,899
Average ..	39,415	937,211	81,942	123,083	198,752	94,496	25,193

## APPENDIX F.—<E' >, TYPE 409, 1977-83 TIME PERIOD<sup>1</sup>

It was observed that the deviations of Cr and Ni annual midpoint elemental fraction from <E> showed significant changes from the 1962-76 time period to the 1977-83 time period. Cr deviation showed a significant change from 1976 to 1977. The deviation change coincided with the change of report production categories. The salient production category change was the introduction of Type 409, since it accounted for a major share of production in its year of introduction, and probably in earlier years.

In this appendix, the impact of transferring production from "All other" in 1976 to Type 409 in 1977 is evaluated. It was conjectured that the observed change in deviation from 1976 to 1977 was the result of making Type 409 a specific type.

To test this conjecture, we calculate the effect a change in production categories would have had in 1976 and compare that to the actual effect of the change in production categories from 1976 to 1977. If the effects are comparable, the change in production categories was sufficient to account for the observed changes.

To calculate the effect a change in production categories would have had in 1976, we must estimate the production of the new categories. From 1976 to 1977, the category change of interest here was from "All other," which included Type 409 in 1976, to "All Other" and Type 409 in 1977. Assume that production of Type 409 and the other grades that made up "All other" in 1976 were relatively the same as those of 1977. Then we can assume that Type 409 and the remainder of "All other" production in 1976 was in the same proportion as Type 409 and "All Other" production in 1977. The estimated element content change in 1976 resulting from the change in production categories, ECC, is

$$ECC_i = (T_{i,409} - T_{i,"All\ other"}) \cdot P_{409,1976} \quad (F-1)$$

where

$$P_{409,1976} = (P_{409,1977} / (P_{409,1977} + P_{"All\ Other",1977})) \cdot P_{"All\ Other",1976} \quad (F-2)$$

The midpoint element content, MEC, in 1976 was

$$MEC_i = \sum_j F_{ij} \cdot P_{i,1976} \quad (F-3)$$

The estimated percent difference, EPD, in 1976 due to a supposed change in production categories is

$$EPD_i = ECC_i / MEC_i \quad (F-4)$$

The actual percent difference, PD, in element fraction resulting from the production category change was

$$PD_i = ((F_{i,1976} - F_{i,1977}) / F_{i,1976}) \quad (F-5)$$

If  $EPD_i$  is comparable to  $PD_i$ , the change in production categories from 1976 to 1977 is sufficient to account for the observed variation in deviation from the 1962-76 period to the 1977-83 period. Table F-1 shows the results of this calculation.

The greatest impact (as measured by magnitude of PD) was on (in order of decreasing impact) Ti, V, Mn, Cr, Si, and Ni. In each case, EPD was comparable to PD. So, for these elements, the change in deviation from the 1962-76 period to the 1977-83 period may be accounted for by the change in production categories. However, comparison of PD and EPD for Cb, Mo, and W, (and possibly Ti) suggests the change in production categories does not completely account for the estimated change for these elements.

The change in elemental fractions from 1976 to 1977 suggested that the average elemental fraction may be significantly different from the 1977-83 time period and the 1962-83 time period. The elemental fraction of stainless steel averaged over the 1977-83 time period is hereafter called <E' >. <E' >, uncertainty, and uncertainty components were calculated for the 1977-83 time period in the same way that they were calculated for the 1962-83 time period. Table F-2 shows the results of that calculation and those for the 1962-83 time period.

Comparison of the results of the 1977-83 calculation (table F-2) with those of the 1962-83 calculation (table 4) shows that, except for Ti, there is no difference in elemental fractions to within the uncertainty bounds specified. For Ti, the results were not the same to within the specified uncertainty. A significant increase in Ti use in stainless steel occurred as a result of increased Type 409 production.

<sup>1</sup>Symbols used in this appendix are defined in appendix A.

**Table F-1.—Comparison of the estimated effect on elemental fraction due to Type 409 separation from "All other," with calculated change in elemental fraction**

[Estimated element content change (ECC) as percent of midpoint element content (MEC) is the estimated effect of separation; percent difference (PD) is the comparable measure of the change in calculated fraction]

Element	Estimated Type 409 effect					Calculated change in elemental fraction		
	MEC <sup>1</sup> st	Midpoint chemical specification		ECC <sup>2</sup> st	EPD <sup>3</sup> %	F <sub>L,1976</sub>	F <sub>L,1977</sub>	PD <sup>4</sup> %
		All other	Type 409					
Cb .....	306.5	0.00075	0	-165.6	-54.0	0.00019	0.00010	-47.4
Cr .....	291,152.	.17415	0.11125	-13,885.	-4.8	.17558	.16814	-4.2
Mn .....	25,895.	.0149	.005	-2,185.	-8.4	.01562	.01392	-10.9
Mo .....	6,646.5	.0068	0	-1,501.	-22.6	.00401	.00353	-12.0
Ni .....	107,907.	.002	.0025	+110.	+1	.06507	.06527	+0.3
Si .....	14,235.5	.00675	.009	+496.7	+3.5	.00859	.00884	+2.9
Ti .....	549.5	.00135	.00615	+1,059.6	+193.	.00033	.00086	+160.6
V .....	51.	.00005	0	-11.0	-22.	.000031	.000024	-22.6
W .....	144.5	0	0	0	0	.000087	.000100	+14.9

<sup>1</sup>Midpoint element content in 1976.

<sup>2</sup>Estimated element content change.

<sup>3</sup>(ECC/MEC)·100.

<sup>4</sup>Percent difference is  $[(F_{L,1977} - F_{L,1976})/F_{L,1976}] \cdot 100$ .

**Table F-2.—Elemental fraction, uncertainty, and components of total uncertainty**

(Chemical specification and time mean square uncertainty based on 1977-83 stainless steel production)

Constituents	Elemental Fraction <E> <sup>1</sup>	Uncertainty bounds			
		Uncertainty <sup>2</sup> E	Uncertainty <sup>3</sup> %	Uncertainty components	
				Chemical speci- fication E <sub>cs</sub>	Time mean square E <sub>tms</sub>
<b>Major:</b>					
Cr .....	0.1701	0.0101	5.907	0.0096	0.0004
Ni .....	.0694	.0107	15.34	.0099	.0007
Mn .....	.0143	.0049	34.62	.0049	.0001
<b>Intermediate:</b>					
Si .....	.0089	.0010	11.48	.0010	(4)
Mo .....	.0036	.0009	25.34	.0008	.0001
<b>Minor:</b>					
Ti .....	.00077	.00018	23.12	.00016	.00003
Cb .....	.00011	.00002	19.27	.00002	(5)
W .....	.00011	.00003	26.03	.00002	(5)
V .....	.00002	.00001	33.78	.00001	(5)

<sup>1</sup>Time-averaged midpoint elemental fractions.

<sup>2</sup>E = E<sub>cs</sub> + E<sub>tms</sub>.

<sup>3</sup>E as a percentage of <E>.

<sup>4</sup>Less than 0.00005.

<sup>5</sup>Less than 0.000005.

NOTE.—Components of uncertainty may not add to total shown owing to independent rounding.

APPENDIX G.—<E"><sup>1</sup>

Supporting data for the calculation of the quantity of alloying element required to produce stainless steel per unit of production is reported in this appendix.

The quantity of alloying element required to produce stainless steel per unit of production, <E">, is based on

element contained in master alloy and scrap consumed per unit of production. Calculation of elemental content per unit of stainless steel production requires the same data plus estimates of (1) stainless steel scrap consumed in stainless steel production, (2) quantity of element in scrap that reports to product, and (3) quantity of element in master alloy that reports to product.

<sup>1</sup>Symbols used in this appendix are defined in appendix A.

Table G-1.—Scrap receipts and consumption (gross weight), and element reported consumption for stainless steel production, by year, thousand short tons

Year	Scrap <sup>1</sup>		Reported consumption, <sup>2</sup> element contained weight								
	Receipts	Consumption	Cb	Cr <sup>3</sup>	Mn <sup>4</sup>	Mo	Ni <sup>5</sup>	Si <sup>6</sup>	Ti <sup>7</sup>	V	W
1962	229	644	0.291	69	12.1	2.16	29.7	9.05	0.240	0.019	NA
1963	252	716	.225	128	14.2	2.50	34.1	9.38	.196	.034	NA
1964	265	839	.263	162	17.9	3.42	48.3	10.97	.337	.035	NA
1965	359	840	.301	169	17.0	3.67	51.7	13.03	.448	.032	NA
1966	355	969	.284	181	18.1	3.78	65.9	12.58	1.219	.038	NA
1967	307	863	.219	150	15.9	3.05	52.9	NA	.290	.039	NA
1968	376	878	.211	155	16.5	3.03	44.9	10.97	.256	.050	0.101
1969	610	1,189	.269	161	19.0	3.13	39.5	15.20	.281	.037	.173
1970	481	950	.261	143	17.6	2.87	40.8	12.90	.300	.048	.126
1971	507	966	.294	129	17.1	2.47	33.2	10.29	.241	.030	.094
1972	438	969	.322	165	19.5	2.93	45.4	16.28	.257	.030	.086
1973	459	1,074	.356	227	24.0	4.24	65.8	17.84	.680	.026	.106
1974	552	1,333	.282	266	26.5	5.02	73.8	23.39	1.673	.038	.129
1975	290	787	.226	119	13.1	3.17	38.2	11.70	.783	.020	.079
1976	424	1,091	.230	170	18.1	3.17	48.6	16.81	1.408	.021	.063
1977	424	1,090	.284	188	17.7	3.90	53.2	21.03	1.437	.028	.088
1978	395	1,073	.403	204	19.0	3.94	60.5	29.41	1.679	.032	.118
1979	425	1,205	.414	224	20.8	4.30	69.6	34.75	1.661	.045	.153
1980	383	1,001	.412	175	15.2	3.94	54.7	27.92	1.136	.040	.089
1981	428	1,015	.298	175	15.5	3.26	50.6	28.14	1.088	.035	.051
1982	402	782	.225	111	10.2	1.66	32.2	20.84	.904	.015	.028
1983	492	1,005	.331	184	27.5	2.27	47.0	31.13	1.226	.014	.051
1984	NA	NA	.476	179	24.9	2.57	75.2	35.03	1.298	.020	.089
Average	402	967	.299	166	18.1	3.24	50.3	19.03	.824	.032	.095
Uncertainty <sup>8</sup>	NAp	NAp	±.009	±6	±.6	±.11	±1.8	±1.16	±.078	±.001	±.006

NA Not available. NAp Not applicable.

<sup>1</sup>As reported in the Minerals Yearbook, Iron and Steel Scrap chapter, 1962-77, and as recorded in Bureau of Mines computer files, 1978-83.

<sup>2</sup>Consumed to produce stainless steel as reported in the Minerals Yearbook, commodity chapter.

<sup>3</sup>1963-66 and 1968-84 data in contained weight calculated as gross weight times the ratio of total contained to gross weight for each category. 1967 contained weight was calculated as an average content factor times the gross weight for each category. The average content factor was the average of the content factors from 1963 through 1966. The content factors used were Low-carbon FeCr, 0.6905; High-carbon FeCr, 0.6502; FeCrSi, 0.4093; Exothermic FeCrSi, 0.3133; Cr Briquettes, 0.5408; and Other, 0.5600.

<sup>4</sup>1962-82 contained weight data calculated as gross weight times a content factor for each category. The content factors used were High-carbon FeMn, 0.78; Medium-carbon FeMn, 0.80; SiMn, 0.66; Spiegeleisen, 0.20; and Mn metal, 1.00. 1983-84 contained weight data calculated as gross weight times the ratio of total contained to gross weight for each category.

<sup>5</sup>Exclusive of scrap.

<sup>6</sup>1962-66 and 1968-74 content data calculated from gross weight using a content factor for each category. 1962-66 content factors used were as follows. Silvery pig iron: 5-13, 0.09; 14-20, 0.17. Ferrosilicon: 21-55, 0.38; 56-70, 0.65; 71-80, 0.76; 81-89, 0.85; 90-95, 0.93. Silicon metal, 0.98. Ferrosilicon briquette, 0.45. Miscellaneous, 0.5. 1969-74 content factors used were as follows. Silvery pig iron, 0.18. Ferrosilicon: 22-55, 0.48; 56-70, 0.65; 71-80, 0.76; 81-95, 0.85. Silicon metal, 0.98. Miscellaneous, 0.50. 1968 content factors used were as follows. Silvery pig iron, 0.125. Ferrosilicon: 21-55, 0.39; 56-80, 0.68; 81-95, 0.85. Silicon metal, 0.98. Miscellaneous, 0.50. 1978-84 content data calculated from gross weight times the ratio of total content to gross for each category.

<sup>7</sup>Contained weight calculated as gross weight times a content factor. The content factor was calculated as the 1981-85 average of the ratio of total Ti content to gross weight. Content was calculated by category from confidential data. The Ti content used for each category was as follows: ferrotitanium less than 50%, 0.40; greater than 50%, 0.70; Ti scrap, 0.90, and Other, 0.95. The average content was calculated to be 0.701±0.026.

<sup>8</sup>Uncertainty calculated as probable error of time variation.

Let  $P_j$  represent production of stainless steel in year  $j$ ;  $SC_j$  scrap consumption in year  $j$ ; and  $RC_{lj}$ , reported consumption of element  $l$  in year  $j$ .  $\langle E'' \rangle$ , the fraction of element consumed to produce stainless steel, is

$$\langle E'' \rangle = \sum_{j=1962}^{1983} [RC_{lj}/(P_j - SC_j)]/N_{yr}, \quad (G-1)$$

where  $N_{yr}$  is the number of years. Here  $RC_{lj}$  are non-scrap element sources. Thus,  $\langle E'' \rangle$  is the time averaged

ratio of reported consumption to the difference between production and scrap consumption from 1962 through 1983. The elemental content of scrap was assumed to be the same as that of stainless steel production. This assumption seems reasonable because a large fraction of scrap consumption is prompt scrap. (Scrap is generally divided into two main groups, prompt and purchased. Prompt scrap is generated by the steel producer. Purchased scrap is purchased by the steel producer.) It was assumed that 95% of reported stainless steel scrap consumption was utilized for stainless steel production.

**Table G-2.—Alloy element consumption required per unit of stainless steel production, thousand-short-ton contained weight**

Element	Averaged reported consumption		$\langle E'' \rangle$	
	Quantity	Uncertainty	Quantity <sup>1</sup>	Uncertainty <sup>2</sup>
Cb .....	0.2990	0.1296	0.000474	0.000092
Cr .....	168.4818	80.7714	.267392	.034653
Mn .....	18.1464	8.7200	.028980	.005823
Mo .....	3.2375	1.6548	.005253	.000926
Ni .....	50.2546	25.9896	.077587	.009246
Si .....	19.0294	16.7612	.028072	.005545
Ti .....	.8277	1.1429	.001176	.000442
V .....	.0316	.0208	.000054	.000017
W .....	.0953	.0816	.000163	.000067

<sup>1</sup>Annual stainless steel production minus annual stainless scrap consumed for stainless steel production divided into annual reported element consumption for stainless production, averaged over the 1962-84 time period, where data were available. Annual stainless steel scrap consumed for stainless steel production assumed to be 95% of reported stainless steel scrap consumption.

<sup>2</sup>Quantity times standard error divided by average annual stainless steel production.

