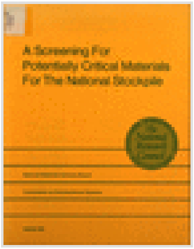


A Screening for Potentially Critical Materials for the National Stockpile (1977)

Pages
73

Size
8.5 x 10

ISBN
0309346320

Committee on Technical Aspects of Critical and Strategic Materials; National Materials Advisory Board; Commission on Sociotechnical Systems; National Research Council

NATIONAL RESEARCH COUNCIL
COMMISSION ON SOCIOTECHNIAL SYSTEMS
NATIONAL MATERIALS ADVISORY BOARD

Chairman:

Mr. Julius J. Harwood
Director, Materials Science Laboratory
Engineering and Research Staff
Ford Motor Company
P.O. Box 2053
Dearborn, Michigan 48121

Past Chairman:

Dr. Seymour L. Blum
Director, Energy and Resources Management
The MITRE Corporation
P.O. Box 208
Bedford, Massachusetts 01730

Members

Dr. James Boyd
Consultant
Materials Associates
Suite 250
600 New Hampshire Ave., N.W.
Washington, D.C. 20037

Dr. Alan G. Chynoweth
Executive Director, Electronic Device, Process and Materials Division
Bell Laboratories
Murray Hill, New Jersey 07974

Dr. Arthur C. Damask
Professor, Physics Department
Queens College of New York City
Flushing, New York 11367
(Mail Address)
29 Brewster Lane
Bellport, New York 11713

Dr. Herbert I. Fusfeld
Director of Research
Kennecott Copper Corporation
161 E. 42nd Street
New York, New York 10017

Dr. John B. Goodenough
Professor of Inorganic Chemistry
Inorganic Chemistry Lab.
University of Oxford
South Park Rd.
Oxford OXI 3QR, England

Mr. Lawrence Levy
President
Interprise Corporation
Box 947
Framingham, Massachusetts 01701

Mr. William D. Manly
Group Vice President
Engineered Products
Cabot Corporation
1020 West Park Avenue
Kokomo, Indiana 46901

Dr. Frederick T. Moore
Economist Advisor
Industrial Project
WORLD BANK
Room F 1010
1818 H Street, N.W.
Washington, D.C. 20431

Dr. Walter S. Owen
Head, Materials Science Department
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Dr. Harold W. Paxton
Vice President-Research
U.S. Steel Corporation
600 Grant Street
Pittsburgh, Pennsylvania 15219

Dr. Eli M. Pearce
Head, Department of Chemistry
Prof. of Polymer Chemistry & Engineering
Polytechnic Institute of New York
333 Jay Street
New York, New York 11201

Dr. David V. Ragone
Dean, College of Engineering
University of Michigan
Ann Arbor, Michigan 48104

Dr. Raymond L. Smith
President
Michigan Technological University
1400 College Avenue
Houghton, Michigan 49931

Dr. Morris A. Steinberg
Director, Technology Applications
Lockheed Aircraft Corporation
Burbank, California 91520

Dr. Giuliana C. Tesoro
Adjunct Professor
Massachusetts Institute of Technology
278 Clinton Avenue
Dobbs Ferry, New York 10522

Dr. John E. Tilton
Commodities Division
United Nations Conference on Trade and Development
Palais des Nations
CH-1211 Geneva 10, Switzerland

Dr. John B. Wachtman, Jr.
Division Chief
Inorganic Materials Division
National Bureau of Standards
Room B306, Materials Building
Washington, D.C. 20234

Dr. Max L. Williams
Dean, School of Engineering
University of Pittsburgh
Pittsburgh, Pennsylvania 15261

NMAB Staff

W. R. Prindle, Executive Director
J. V. Hearn, Executive Secretary

1/1/77

A SCREENING FOR POTENTIALLY CRITICAL MATERIALS FOR THE NATIONAL STOCKPILE

Report of

The Committee on the Technical Aspects of
Critical and Strategic Materials

NATIONAL MATERIALS ADVISORY BOARD
. Commission on Sociotechnical Systems
National Research Council

Publication NMAB-329

National Academy of Sciences

Washington, D. C.

1977

NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This study by the National Materials Advisory Board was conducted under Contract No. GS-00-DS-(P)-94008 with the General Services Administration on behalf of the General Services Administration, the U.S. Department of Commerce, and the U.S. Bureau of Mines.

The National Research Council was established in 1916 by the National Academy of Sciences to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy by authority of its Congressional charter of 1863, which establishes the Academy as a private, non-profit, self-governing membership corporation. Administered jointly by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine (all three of which operate under the charter of the National Academy of Sciences), the Council is their principal agency for the conduct of their services to the government, the public, and the scientific and engineering communities.

This report is for sale by the National Technical Information Service, Springfield, Virginia 22151.

Printed in the United States of America.

Order from
National Technical
Information Service,
Springfield, Va.
22161
Order No. PB 267-214

COMMITTEE ON THE TECHNICAL ASPECTS OF CRITICAL AND STRATEGIC MATERIALS

Chairman

MILTON E. WADSWORTH, Professor and Chairman, Department of Mining, Metallurgical and Fuels Engineering, The University of Utah, Salt Lake City

Members

SAMUEL R. CALLAWAY, Chief Materials Engineer, Electro-Motive Division, General Motors Corporation, La Grange, Illinois
HERBERT I. FUSFELD, Director of Research, Kennecott Copper Corporation, New York, New York
HOWARD L. GERHART, Professor of Chemical Engineering, Chemical Engineering Department, Carnegie-Mellon University, Pittsburgh, Pennsylvania
DOUGLAS G. HARVEY, Assistant Director of Buildings and Industry Conservation, Energy Research and Development Administration, Washington, D.C.
RICHARD T. NEWCOMB, Professor of Mineral Economics and Chairman, Department of Resources and Energy Economics, University of West Virginia, Morgantown
ALFRED PETRICK, Jr., Coulter Professor of Mineral Economics, Colorado School of Mines, Golden
ALLEN S. RUSSELL, Vice President, ALCOA Laboratories, Pittsburgh, Pennsylvania

Liaison Representatives

MICHAEL BOZZELLI, Economic Preparedness Division, Federal Preparedness Agency, General Services Administration, Washington, D.C.
RICHARD E. DONNELLY, Office of Assistant Secretary of Defense (I&L), The Pentagon, Washington, D.C.
HAROLD KIRKEMO, Chief, Office of Minerals Exploration, U.S. Geological Survey, National Center, Reston, Virginia
JAMES J. MORRIS, U.S. Army Materiel Command, Alexandria, Virginia
ROBERT J. MROCZEK, Federal Preparedness Agency, General Services Administration, Washington, D.C.
JAMES W. OWENS, Director, Materials Division, Bureau of Domestic Commerce, U.S. Department of Commerce, Washington, D.C.
RUSSELL L. RICHARDS, Mining Engineer, Market and Technical Services Division, Office of Stockpile Disposal, General Services Administration, Washington, D.C.
*ROBERT A. WEEKS, formerly Assistant Chief, Office of Minerals Exploration, U.S. Geological Survey, Reston, Virginia
PAUL F. YOPES, Chief Minerals Specialist, U.S. Bureau of Mines, U.S. Department of the Interior, Washington, D.C.

NMAB Staff

BEN A. KORNHAUSER, Staff Engineer

---

* Retired.

PREFACE

Strategic and critical materials have been accumulated by the General Services Administration under the authority of several statutes. The National Stockpile was established under the Strategic and Critical Materials Stock Piling Act (Public Law 520, 79th Congress, July 1946 -- a revision of Public Law 117 passed by the 76th Congress in 1939). The purpose of the national stockpile, as described in the 1946 Act, is as follows:

> ". . . it is the policy of the Congress and the purpose and intent of this Act to provide for the acquisition and retention of stocks of materials within the United States and thereby decrease and prevent wherever possible a dangerous and costly dependence of the United States upon foreign nations for supplies of materials in times of national emergency. This is accomplished by effective management of the strategic and critical materials stockpiling program, including the determination of stockpile objectives, the acquisition of materials, storage, upgrading, and rotation of inventories, and the disposal of obsolescent or excess materials."

To attain this goal, stockpile objectives were established after study of the estimated availability of U.S. production and imports as against requirements for materials in times of emergency for military, defense supporting, and civilian needs essential to endure the emergency. At this time, stockpile objectives (refer to Appendix A) represent the shortfall between estimated available supply and estimated requirements for the first year of a war. Zero stockpile objectives indicate that estimated supply is equal to or greater than estimated requirements. Changes in technology and supply affect the types and amounts of materials required for the stockpiling. These aspects are continually monitored by the Federal Preparedness Agency, which has been assigned the responsibility for stockpile policy, acquisition, maintenance, and disposal.

This study of potentially critical materials was performed by the National Materials Advisory Board Committee on the Technical Aspects of Critical and Strategic Materials to examine the implications of technological change and use trends on materials in the national stockpile and materials that are not stockpiled currently, but may be in short supply under future emergency conditions. The study is based on information collected through July 1976.

Critical and strategic materials, insofar as the national stockpile is concerned, are defined as follows:

> Critical materials are those that are necessary to manufacture the products required for a national emergency and its accompanying essential civilian needs. The market imbalance, within the

Committee's overall purpose, was not considered a "critical" area. Strategic materials are those that are not in sufficient natural abundance within the United States to provide the above critical materials in the necessary time frame and are located in foreign countries that, in an emergency, are considered unreliable sources with respect to quantities of supply, ideology, and/or interdiction of shipments. Inasmuch as the strategic aspects of the materials in the national stockpile are determined by the National Security Council and the Federal Preparedness Agency based on undivulged classified factors, their strategic position was taken as a "given" and not assessed by the Committee. Understandably, if the strategic factors were known, the conclusions and recommendations might be different.

Supply estimates reflect known U. S. and foreign sources that are assumed accessible, based on the guidance of the National Security Council. These estimates include scheduled and in-progress mine and plant expansions and closures consistent with available information. The projected available quantities of foreign supplies are adjusted to reflect the risks involved in transporting materials during wartime.

The strategic and critical materials requirements are derived from Department of Defense data on planned military strength and munitions requirements that provide estimates of essential military and military-supporting material requirements and from projections of essential requirements for the total economy (as related to emergency needs) based on various components of the gross national product estimated for the period under review. The government inventories, objectives, excesses, and balance of disposal authorizations for the stockpile are summarized in Appendix A (Federal Preparedness Agency, 1975).

ACKNOWLEDGMENTS

Various systems of defense, energy, transport, and communications were reviewed and individuals from the involved agencies were invited to brief the Committee on their current and expected materials problems. The Committee is particularly grateful to the U. S. Army, Navy, and Air Force, the National Aeronautics and Space Administration, the U. S. Bureau of Mines, the U. S. Geological Survey, the General Services Administration (Federal Preparedness Agency), the U. S. Department of State, the Energy Research and Development Administration, and the Department of Defense, all of whom provided the Committee with very useful information on their material needs for their future systems, and to the following individuals, who graciously contributed their time and efforts to make presentations to enlighten the Committee:

LOCKE BOGART, Energy Research and Development Administration
SYDNEY M. COHEN, Headquarters, U. S. Air Force
GEORGE DEUTSCH, Director, Materials and Structures, National Aeronautics and Space Administration
HENRY E. FRANKEL, Energy Research and Development Administration
KENNETH B. HIGBIE, Chief, Division of Solid Wastes, U. S. Bureau of Mines
KENNETH HORTON, Energy Research and Development Administration
LOUIS IANNIELLO, Division of Physical Research, Energy Research and Development Administration
J. J. INGERSOLL, Director, Office of International Commodities, U. S. State Department
HAROLD F. KELLEY, Defense Supply Agency, Department of Defense
HAROLD KIRKEMO, Chief, Office of Minerals Exploration, U. S. Geological Survey
ALEX MILLS, Director, Division of Advanced Research and Supporting Technology, Energy Research and Development Administration
JAMES J. MORRIS, U. S. Army Materiels Command, Department of Defense
DENNIS L. PLACE, Office of Preparedness, General Services Administration
LELAND N. SPARKS, Logistics Staff, Energy Research and Development Administration
PAUL F. YOPES, Chief Minerals Specialist, U. S. Bureau of Mines

CONTENTS

LIST OF TABLES AND FIGURES

ABSTRACT

Inorganic and organic source materials were reviewed in an attempt to identify materials of greatest potential criticality. Their strategic nature was not reviewed since the classifying factors were determined by the National Security Council and the Federal Preparedness Agency. While primary criticality was based upon short-term stockpiling needs, other aspects such as the impact of new energy developments, alternate sources, alternate materials or design, and conservation were considered. Surprisingly few additional materials could be identified clearly as being critical on a worldwide basis within the context of this study; however, after screening a broad spectrum of source materials, chromium, germanium, iridium, rhenium, vanadium, and zirconium and hafnium were identified for a more detailed examination. Of these commodities, chromium stands out in importance on the basis of criticality. The study emphasizes the importance of continual updating of need in the light of rapidly changing technology and abrupt changes in sources of U. S. supply.

Chapter One

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations herein relate only to U. S. objectives in stockpiling critical and strategic materials. These objectives are based upon supply estimates reflecting known U. S. and foreign sources that are assumed accessible, based on the guidance of the National Security Council, and upon projected available foreign supplies that reflect the risks in transporting materials in wartime. The study reviewed commodities in the July 1975 national stockpile and data inputs from various government agencies to identify changes that should be made in view of possible new demands related to broad technological developments, alternative materials, and conservation. The identified commodities were those that were not listed in the national stockpile, or whose stockpile objectives appeared low based on projected needs, or where provisional systems might alter requirements.

A. CONCLUSIONS

1. Critical shortages of metallic materials do not appear imminent in the near term (one to three years). This conclusion is based on the supply-demand situations of the last 10 or 15 years, which are presumed to reflect the needs of the wartime stockpile; however, new constraints imposed by the supply interruptions, energy development, and advancing technology can alter this picture rapidly if such constraints are not anticipated accurately.

2. After surveying a broad spectrum of inorganic and organic source materials, the Committee identified the following as being worthy of more detailed evaluation: chromium, germanium, iridium, rhenium, vanadium, and zirconium (and hafnium), among the potentially critical and strategic metals.

3. No acceptable alternate materials now exist for chromium in many corrosion- and heat-resisting alloys. Domestic resources of chromium are negligible; therefore, the United States and most of the world will continue to depend on chromite supplies, outside their borders, that are estimated to be adequate for several decades, albeit there may be problems of accessibility during a national emergency such as war, and the probability of curtailment of import during peacetime.

4. Stockpiling of germanium is unnecessary because there are acceptable alternate materials and sources of supply.

5. The current government stockpile of iridium appears adequate.

6. Seven-eighths of the presently recoverable rhenium is being lost; however, its conservation costs may be relatively reasonable if weighed against its promising potential uses. It is important not because of present criticality but rather because it is an important future natural reserve now being irretrievably lost.

7. Vanadium, although currently removed from the stockpile objective, may be in considerable demand if nuclear and aerospace requirements grow very rapidly.

8. The small potential market imbalances foreseeable for zirconium and hafnium do not warrant their stockpiling because no criticality is apparent in the reserve or resource position of either metal.

B. RECOMMENDATIONS

1. The technical and economic (which includes availability) aspects of chromium supply should be evaluated continuously. In this regard, a primary objective should be the preparation of updated projections for new and expanding uses, particularly as influenced by the development of alternate or expanded energy sources. In addition, an analysis of alternative materials for chromium in specific applications should be made, * and alternative methods of fabrication such as metal cladding and electroplating for corrosion-resisting and some high-temperature applications should be evaluated repeatedly.

2. The cost of conserving the present by-product rhenium -- currently being dissipated -- should be explored. Inasmuch as rhenium has great potential in alloys used for high-temperature-resisting applications, the U. S. Bureau of Mines, Department of Defense, National Aeronautics and Space Administration, and Energy Research and Development Administration, may be interested government agencies.

3. Further analysis of the future demand for vanadium in nuclear and aerospace applications and of other domestic sources of vanadium is justified.

4. The technology for economic extraction of germanium from coal fly ash should be developed if major uses for germanium should develop.

---

* The National Materials Advisory Board has an ongoing study on Contingency Plans for Chromium Utilization.

Chapter Two

INTRODUCTION

A. PURPOSE

The purpose of this study, requested by its sponsors, was to review materials, currently stockpiled, to determine omissions or changes that should be made in light of possible new demands related to broad technological developments, alternative materials and conservation. The overall purpose of this continuing committee is to assess the implications of technological change and usage trends on the supply-demand balance in applications utilizing, or likely to utilize, various essential materials from the viewpoint of necessary civilian needs and military requirements.

It should be noted that stockpiling is a means for eliminating or mitigating the adverse effects of temporary material imbalances resulting from supply interruptions or a sharp increase in demand. In such cases, stockpiling provides the time to implement one or more possible solutions (such as substitution, conservation, alternative supply source), or weather the disruption with minimal change.

The study is based on data collected up to July 1976 at which time the stockpile objective was based on an emergency of one year.

B. CONDUCT OF THE STUDY

Critical* and strategic* materials with serious potential excess demands were considered to be those with major strategic applications for which there are no acceptable alternative materials or technologies and for which the United States depends upon other hemisphere sources for a significant portion of its needs.

Since stockpile policy is based upon inputs to the Federal Preparedness Agency from government agencies such as the Departments of Commerce, Defense, and Interior, these agencies were asked to identify the materials that they considered potentially critical. The materials and related pertinent information were gathered as follows:

---

* Defined on page v, Preface.

1. Information regarding materials necessary in a national emergency was obtained from questionnaires sent to the U. S. Army, U. S. Navy, U.S. Air Force, National Aeronautics and Space Administration, U.S. Bureau of Mines, U. S. Geological Survey, General Services Administration (Federal Preparedness Agency), Department of State, and Energy Research and Development Administration.

2. Representatives from the agencies receiving questionnaires were invited to appear before the Committee to present information pertinent to the study and to answer questions from the Committee.

3. Extensive background information on selected commodities was obtained, primarily through the efforts of the liaison members of the Committee, to provide the Committee with substantive data on past, current, and anticipated demand.

The list from the first two sources above included: aluminum, aluminum oxide, asbestos, barium chromate, bauxite, beryllium, boron-10, calcium chromate, chromium, cobalt, columbium, copper, industrial diamonds, fluorine, gold, graphite, helium, heptanoic acid, iridium, iron ore, isophrone diisocyanate, kaolin, lead, lithium, magnesium powder, manganese, mercury, molybdenum, nickel, nitroform, platinum group, potassium, rubber, rutile, silicon-electronic grade, silver, tantalum, tin, titanium, tungsten, turbine fuel, vanadium, zinc, and zirconium powder.

It should be noted that in addition to the national stockpile, the Office of the Assistant Secretary of the Department of Defense for Installations and Logistics maintains stocks of finished components or products to prevent interruption in the flow of their vital products or systems. The national stockpile, however, is concerned with maintaining commodities in the form most useful for general contingencies, i.e., forms such as ore concentrates and ferroalloys. Accordingly, some items listed by the Armed Services were dropped immediately. Then, data on several commodities were arranged in a matrix that included supply and demand, percentage imported, major foreign sources of supply, possibility of cartelization, characteristics that made the materials necessary and useful, principal uses, functional and material requirements and factors affecting suitability, present possible substitutes, and general comments. In addition, a chart was compiled listing horizontally the goals and/or needs of the systems for defense (aerospace, marine, land, and communications and guidance), energy (coal gasification and liquefaction, liquid metal fast breeder reactor, fission and fusion, solar, and geothermal) and transport (jet engines and gas turbines, high strength/weight ratio materials, joining, and safety inspection). For these items, there were listed the projected functional requirements and the limitations and/or requirements for their materials of construction.

This information was examined to determine the commodities required for materials limiting the development of various anticipated systems for defense, energy, transport and communications. These identified materials were checked against the stockpile commodities and their existing objectives. If these identified commodities were not in the current list of critical materials, if the objectives appeared too low based upon projected needs, or if doubts were raised regarding the material demand in provisional systems, the commodities were considered potentially critical and are discussed in the subsequent chapters.

Based on the material reviewed, the elements listed in Table 1 were selected for detailed study for the following reasons:

1. Chromium because of possible interruptions of chromite and ferrochromium supplies due to international changes.

2. Germanium because of expected greater-than-normal growth in special applications (Table 1).

3. Iridium because of its use in thermal batteries (e.g., as spacecraft and standby missile power supplies).

4. Rhenium because of expected greater-than-normal growth in its use in catalysts and high-temperature alloys.

5. Zirconium and hafnium because of their use in nuclear reactors.

6. Vanadium because of expected increased use in high-strength low-alloy steels and its use in fast breeder nuclear reactors.

The Committee also considered certain petrochemicals to be potentially critical or strategic with respect to the availability of crude oil and/or specific hydrocarbon fractions derived from petroleum refining; however, the question of stockpiling hydrocarbon feedstock was beyond the Committee's scope* and is discussed in appendix B.

It should be noted that the commodity studies hereinafter are not in-depth. This study was a screening process to indicate materials that might become more critical in the future. If in-depth studies of any of these commodities were conducted, panel members would be selected with particular expertise to insure their proper assessment.

C. ORGANIZATION OF THIS REPORT

Each of the materials studied in detail by the Committee is discussed separately in the remainder of this report in terms of its critical and strategic aspects, present use and projected use, and current starting materials (amount, future supply and substitutes). Specific conclusions and recommendations also are presented.

---

* In addition, petrochemicals represent an average of only 5 percent of total crude consumption.

TABLE 1 Basis for Selecting the Reviewed Commodities.

Commodity	Principal Uses	Characteristics That Make It Necessary and Useful	Stockpile Objective (short, dry tons of material)	Availability	Substitutability
Chromium (Cr)	Corrosion- and heat-resisting steels and superalloys; plating for wear-, corrosion-, and heat-resistance; refractories	Imparts corrosion- and heat-resistance to alloys; passive film formation; plating provides a wear- and rust-proof surface; in refractories, produces neutral reaction with acidic or basic slags	Chromite--high Al (refractory) grade, 54,000; high Fe (chemical) grade, 8,400; high Cr (metallurgical) grade, 444,710 Ferrochromium--high C, 11,476; low C, none; Si, none Chromium Metal--3,763	Republic of South Africa, Rhodesia, USSR, and Turkey; refractory grade from the Philippines	In some applications, none; elsewhere, Ti for stainless steel, Al for chrome plating and other decorative, and Ni, Mo, V, Cb and Mn in alloy steels; MgO in refractories
Germanium (Ge)	Nuclear radiation detection devices; special optical glass (i.e., infrared transmitting lens); electronic devices for communication and guidance	Optimum electrical properties for electronic devices, rectifiers, and infra-red beam and thermal electric devices	None	Minor byproduct of ores mined for zinc and in some domestic fly ash	Silicon, tellurium, selenium, indium, and gallium
Iridium (Ir)	Thrusters for spacecraft propulsion; catalyst in chemical and petroleum industries; encapsulation of plutonium	Catalytic activity; mechanical properties and corrosion resistance at high temperatures	None	Byproduct of platinum group; 90 percent from USSR and Republic of South Africa	In some applications
Rhenium (Re)	Catalyst; used with W in thermocouples and high-temperature control systems; used as a non-agglomerating dispersoid in high-temperature alloys	High temperature and corrosion resistance	None	Recovered from molybdenite in porphyry copper ores	Possibly technetium; also possibly iridium in catalysts
Vanadium (V)	High-quality, high-strength alloy titanium and steels; tool steels; high-strength low-alloy steels; projected construction material for fast breeder nuclear reactors	Low thermal-neutron absorption alloying additions; catalyst; noncorrosive; heat resistance	None	Mainly a coproduct of other metals; Republic of South Africa, Chile, and USSR	Columbium, tungsten, molybdenum
Zirconium (Zr)	Corrosion and erosion resisting tubing; tubing for fusion and fission uses in nuclear reactors; batteries; high-density propellants and thermal batteries; foundry sand facing; refractories	Low neutron absorption; instantaneous reaction to create electrical potential	Essentially none	Byproduct or coproduct of mining titanium minerals from placer deposits; could be obtained wholly in U.S. under proper economic inducement	Chromite sand in foundry molds and facings; titanium in corrosion-resisting applications
Hafnium (Hf)	Control rods in nuclear reactors; high-strength, oxidation-resisting alloys	High neutron absorption	None	Byproduct of making reactor-grade zirconium	Alternate metals for control rod material are silver-indium-cadmium, boron stainless steel, and rare-earth stainless steel alloys

Chapter Three

CHROMIUM

A. CRITICAL AND STRATEGIC ASPECTS

Domestic resources of chromium-bearing minerals are low in grade and so limited that even in the most critical situation, domestic production could supply only 5 to 10 percent of the nation's chromium needs for a limited number of years. Worldwide reserves and deposits of chromite are considered adequate for many decades. World chromite ore reserves and resources are discussed later in this section.

In recent years, the United States has consumed about 17 to 19 percent of world chromite production. This material comes essentially from the Eastern Hemisphere (with 25 percent coming from the USSR); therefore, the possibility of supply interruptions resulting from government instability in the producing countries as well as the problems of price fluctuation and transportation must be recognized.

Historically, approximately two-thirds of the chromium consumed by the United States has been used for the production of corrosion- and heat-resisting alloys; 15 percent for the production of chemicals, pigments, and electroplating materials; and the balance for refractories. Over the past decade, however, the use of chromium in refractories has declined while its use in metallurgical applications has increased.

No practical substitute exists for chromium in the production of stainless steels and heat-resisting alloys. Certain copper, nickel, titanium, and aluminum alloys have properties that make them potential alternatives for stainless steels in some applications; however, such alloys are not available commercially for the total spectrum of steel uses involving chromium.* For high-temperature applications where oxidation resistance alone is desired, chromium might be conserved through use of aluminum coatings, porcelain enamel, or diffused chromium surface layers; however, the mechanical strength of such structures is the same as that of the base metal and, almost without exception, is inferior to that of stainless steel. Other elements can be used in place of chromium to achieve the desired hardenability in heat-treatable

---

* Alternatives for chromium currently are being addressed in an NMAB study, Contingency Plans for Chromium Utilization.

grades of engineering alloy steels with the possible exception of ball and roller bearing steels. Replacement of chromium in high-speed tool steels, however, poses a much more difficult problem because of their specialized application but, fortunately, only one percent of chromium enters high-speed tool steel uses.

B. PRESENT USE

U.S. Bureau of Mines statistics on demand for chromium and chromium-bearing materials in 1964 and in 1974 are presented in Table 2 and indicate that the demand pattern remained fairly constant during the 10-year period with the exception of refractory usage which decreased by about 5 percent due to the reduction in use of open hearth steel furnaces requiring large amounts of chromite refractories and the trend toward basic oxygen refining practice requiring little chromite. Data on the total consumption of ferrochromium by end use are given in Table 3 and show that ferrochrome usage increased by about 6 percent per year. These data further indicate that the proportion used for stainless steel rose from approximately 71 to 75 percent and that this increase was countered by a corresponding decrease in the usage of chromium in

TABLE 2 Demand for Chromium, 1964 and 1974.

	Percent of Demand	
	1964	1974
Transportation (motor vehicles, railroads, ships)	15.7	16.5
Construction (bridges, structural residential, industrial)	22.7	22.4
Machinery (pumps, tanks, chemical and refinery equipment)	15.4	14.4
Fabricated Metal Products (household appliances)	5.5	6.4
Refractories	19.1	13.8
Plating of Metals	2.4	2.7
Chemicals	7.5	9.8
Other	11.7	14.0
Total	100.0	100.0

NOTE: Data from U.S. Bureau of Mines, 1975

TABLE 3 Chromium Ferroalloy Usage Data -- 1963 and 1974.

	1963		1974	
End Use Form	Gross Weight (thousand short tons)	Percent*	Gross Weight (thousand short tons)	Percent*
Stainless	269.0	71.3	438.4	75.5
Superalloys	8.0	2.0	17.4	3.0
Alloy Steels	86.5	22.9	93.7	16.1
Tool Steels	4.2	1.1	7.4	1.3
Cast Iron	6.4	1.7	10.5	1.8
Nonferrous	3.3	0.9	5.0	0.8
Weld Rod and Miscellaneous	**	--	8.3	1.4
Total	377.4		580.7	

NOTE: Data from U.S. Bureau of Mines, 1964 and 1974

* Percentage total is not 100.0 due to rounding of numbers.
** Included in nonferrous alloys.

alloy steel. Thus, chromium usage is increasing in applications where no satisfactory substitute exists and decreasing in applications where replacement is more feasible.

C. PROJECTED USE

Refractory applications probably never will require the percentage of chromium consumption that they did prior to the universal adoption of basic oxygen refining practice; however, while further decline in chromite refractory applications is possible, it is not expected to equal that which occurred during the past decade. Environmental control equipment for the treatment of waste water, boiler flue gases, industrial stack emissions, or automotive exhaust gas (catalytic converters) is expected to increase the demand for stainless steel -- and, thus, for chromium in the future. Plant construction to satisfy the increasing demand for electric power and other energy forms also will require substantial amounts of chromium and chromium alloys.

Table 4 shows a forecast of chromium demand for the year 2000. The low values represent a compounded annual growth rate of 2 percent and the high values, a compounded annual growth rate of 3.3 percent.

Utilization of coal resources as raw materials for the production of gaseous and liquid fuels is being pursued actively within the continental United States. Development programs include the production of liquid fuels, high-Btu

TABLE 4 U.S. Demand in 1974 and Forecast for 2000 for Chromium by End Use (in thousand short tons of contained chromium).

End Use	Demand 1974	Contingency Forecasts for Year 2000: Forecast Base	Forecast Range: Low	Forecast Range: High	Forecast Range: Probable
Metal					
Construction Products	140	210	210	310	280
Transportation	103	165	150	230	200
Machinery and Equipment	90	210	180	270	240
Fabricated Metal Products*	40	80	50	100	90
Plating of Metals	17	50	40	80	70
Nonmetal					
Refractory Products	86	30	20	60	30
Chemicals	61	132	110	160	120
Other	88	200	180	220	210
Total	625		940	1,430	1,240

NOTE: Data from Table 7, U.S. Bureau of Mines, 1975.

* Includes home appliances and chromium plated products.

pipeline-quality gas, and low-Btu gas for power generation. The design and construction of full-scale plants to produce the desired quantities of these fuels at an acceptable cost await the solution of engineering problems of great magnitude. Regardless of which competing technology is adopted, the requirements for heat-resisting alloy in these plants represent a potentially large increase in chromium demand.

To a great extent, these plants involve the selection or development of materials that are capable of giving satisfactory operating life under the very severe operating conditions (temperature, pressure, stress, corrosive, and abrasive environment) to which they will be exposed in service. The best available information indicates that those units which must operate under the most adverse conditions (high temperatures, corrosion, and erosion) may require frequent repair or replacement. Of the raw materials required, chromium is the most critical and probably will be used in high-temperature alloys or heat-resisting steels that contain at least 25 percent chromium.

A U.S. Geological Survey report (1976) presented an estimate of the amount of each basic non-fuel raw material needed by the energy industries in the 1975-1990 period if the United States is to attain energy independence. Preliminary estimates for chromium are shown in Table 5.

TABLE 5 Estimated Chromium Requirements for Energy Production, 1975-1990 (in thousand short tons of contained chromium).

Energy Production	Requirements	
Fossil Fuel		
Coal Transportation (rail and water)	2.25	
Underground Coal Mines (82)	4.80	
Surface Coal Mines (74)	1.50	
Gasoline Refineries (25 at 200,000 BBL/day each, 1977-1990)	13.95	
Oil Exploration and Development (1977-1988)	11.45	
Gas Exploration and Development (1977-1988)	10.15	
Oil Shale Mining	15.60	
Fossil-Fueled Electric Power Plants (406 at 900 MW each)	9.40	
Gas Turbine Generator Sets (at 59 MW each)	6.20	
Other Uses Not Specifically Identified	10.85	
Subtotal		86.15
Nuclear		
Uranium Mining	7.45	
Boiling Water Reactors (150 at 1000 MW each	18.20	
Pressurized Water Reactors (350 at 1000 MW each)	160.15	
Other Uses Not Specifically Identified	1.65	
Subtotal		187.45
Other		
Other Energy Sources and Balance of Fossil-Fuel Requirements for Years Not Included Above		17.30
Total		290.90

NOTE: Data from U.S. Geological Survey, 1976.

D. CURRENT STARTING MATERIALS (SUPPLY AND SUBSTITUTES)

1. Current and Future Supply

Chromite ore is the starting material for the production of all chromium-containing products (metallic, chemical, and refractory). As indicated in Table 6, over 95 percent of world chromite reserves are located in the Republic of South Africa (63 percent) and Rhodesia (33 percent). Depending upon their content of chromium and impurities, chromite ores are categorized into three grades or end use classifications as shown in Table 7.

TABLE 6 Identified World Chromite Ore Resources (in thousand short tons of gross ore).

	High Chromium		High Iron		High Aluminum	
Country	Reserves	Other	Reserves	Other	Reserves	Other
Western Hemisphere						
United States*	--	400	--	5,600	--	100
Brazil	2,800	3,400	3,900	2,200	100	150
Canada	--	100	--	2,800	--	--
Cuba	--	100	--	--	280	1,100
Greenland	--	--	--	11,000	--	--
Other	--	200	--	--	--	--
Subtotal	2,800	4,200	3,900	21,600	380	1,350
Eastern Hemisphere						
Finland	--	--	11,000	5,600	--	--
Greece	50	50	--	--	50	50
India	5,600	4,500	2,200	2,200	--	--
Iran	1,700	1,100	--	--	--	--
Malagasy Republic	4,500	3,400	1,100	2,200	--	--
Philippines	780	560	--	--	4,500	2,200
Republic of South Africa	56,000	56,000	1,100,000	2,200,000	--	--
Southern Rhodesia	560,000	560,000	56,000	56,000	--	--
Turkey	5,600	5,600	--	--	--	--
USSR	11,000	11,000	1,100	2,200	11,000	11,000
Other	1,100	1,100	1,100	1,100	--	--
Subtotal	646,330	643,310	1,172,500	2,269,300	15,550	13,250
Total (rounded)	650,000	650,000	1,200,000	2,300,000	16,000	15,000

NOTE: Data from Table 3, U.S. Bureau of Mines, 1975.

* Submarginal resources not included.

TABLE 7 Chromite Ore Grades.

Grade	Composition Limits	Major U.S. Sources	Approximate % of U.S. Consumption
High Chromium (metallurgical)	Cr_2O_3, 48% minimum Cr:Fe ratio, 3:1 Silicon, 8% maximum	Rhodesia, USSR, Turkey	60
High Iron (chemical)	Cr_2O_3, 44% minimum Silicon, 5% maximum	South Africa	20
High Aluminum (refractory)	Cr_2O_3, 31% minimum Iron, 12% maximum	Philippines	20

NOTE: Data from National Materials Advisory Board, 1970.

Because about two-thirds of the chromium supply is consumed in the production of stainless steel, the demand for chromium and chromium-bearing minerals has parallelled stainless steel production and the need for the high-chromium grade typically has been greater than for the other grades. The development of the argon-oxygen-decarburizing (AOD) steelmaking practice permits utilization of a greater percentage of ferrochromium made from high-iron chromite than was previously possible, and tends to alleviate the imbalance between supply and demand for the high-chromium grade.

From 1965 through 1970, about 8 percent of each year's chromium imports entered as ferrochromium; however, this proportion has increased sharply since 1970 and reached approximately 45 percent of chromium imports in 1975. Several factors contributed to this change: Imported ferrochromium historically has cost less than the domestically produced product, and exporting countries could increase their income greatly by shipping ferrochromium, that is much more valuable than lower-priced chromite ore. Expansion of ferrochromium production facilities in South Africa and Rhodesia enabled them to increase exports of that product.

2. Possibility of Substitution

Metallurgical applications account for the greatest usage of chromium; however, significant amounts also are consumed in the production of refractories, pigments and chemicals. In metallic form, chromium is used principally as an alloying element in steel, cast iron and nonferrous alloys and for electrodeposited coatings for functional and decorative applications.

Chromium generally is used in applications where material selection is governed by technical and economic factors rather than by aesthetic considerations. Consequently, for some applications, no satisfactory substitutes for chromium exist, and for many other uses, substitution may be made only at a significant penalty in cost and/or function.

A search for suitable acceptable alternatives for chromium logically begins with the properties or functions served by chromium in different types of applications as set forth below:

a. Corrosion Resistance

The greatest consumption of chromium is in the production of iron-chromium and iron-nickel-chromium alloys that contain from 12 to 25 percent chromium. These alloys derive their corrosion resistance (stainless characteristics) from their chromium content that is sufficient to form a tenaciously adherent, stable, inert oxide film that protects the underlying metal from attack by hostile environments.

Because this class of material includes alloys that are corrosion-resisting, inert, nontoxic and compatible with many chemicals and body fluids, it is used widely in equipment producing chemicals, foods, and biological and medicinal materials as well as for prosthetic devices, implants, and surgical instruments. Likewise, its excellent appearance, durability, and low maintenance cost makes it the preferred material for many architectural, industrial, and transportation applications.

Selection of alternate materials for applications requiring corrosion resistance involves substantial risk of unsatisfactory performance because the choice of stainless steel for many end uses is based upon extensive experience that is not available for the potential substitutes.

b. High-Temperature Oxidation and Corrosion Resistance

The tenacious, inert, and stable oxide film that forms on materials with high chromium content protects the underlying metal from oxidation or corrosion at elevated temperatures just as it protects chromium alloys from corrosion at room temperature.

Aluminum, silicon, and titanium also form stable oxides and often are added to chromium alloys to enhance oxidation resistance further. Because each of these elements also may have undesirable side effects, a complete substitution of any one, or a combination of them, for chromium is not a practical alternative.

c. Elevated Temperature Strength

In applications such as electric power generating systems, steam and gas turbines, engine exhaust valves and heat treating furnaces, materials must have sufficient strength to carry operating stresses and to resist oxidation and corrosion or service life will be short. In addition to quenching and tempering, high-temperature strength can be achieved by mechanisms such as cold working or precipitation hardening but chromium is the overwhelming choice among elements that might be added to enhance the oxidation resistance of these materials.

d. Response to Heat Treatment

Chromium is used in many heat-treatable alloy steels, including tool steel compositions and engineering alloy steels used for machine parts such as shafts, springs, gears, bolts, and bearings. In most engineering applications, mechanical properties (such as strength or hardness) are paramount determinants of suitability, and selection of a material may involve only finding a steel whose hardenability permits heat treatment to the desired properties. Because several different alloying elements may be used to achieve a desired hardenability, it is possible to substitute manganese, nickel, molybdenum, and even boron or carbon for some or all of the chromium in a heat-treatable steel.

Chromium-bearing steels have been preferred for the manufacture of ball and roller bearings for many years, and the degree of freedom in replacing chromium for this use is more restricted. Usage of chromium-bearing grades in tool steels evolved on the basis of economic performance, particularly in air-hardening and high-speed types. Offsetting the limited ability to substitute in these applications is the fact that the total amount of chromium used for them is not large in relation to total demand for chromium.

e. Refractories

The high melting point and chemically neutral characteristics of Cr_2O_3 make it a desirable constituent in refractories for kilns and metallurgical furnaces, especially electric arc and basic open hearth steelmaking.

f. Electroplating

Electrodeposited chromium coatings are used widely in architectural and consumer applications for decorative and aesthetic considerations, but even these uses have functional aspects by virtue of the corrosion resistance and ease of cleaning or maintenance made possible by the chromium coating. In industrial chromium plating, such considerations also may be important but are usually subordinate to the advantages offered by the hardness and wear resistance of the chromium plate. Consequently, the chromium plating in applications such as cutting tools and dies, cylinder walls, piston rings, and crankshafts is based upon functional rather than aesthetic considerations. Finding a substitute for these applications is considerably more difficult than finding one for the primarily decorative applications.

g. Chemicals and Pigments

Chromium chemical compounds are used in applications, such as leather tanning, pigments and dyes, water-treating compounds, and aluminum anodizing, where they serve to control corrosion. Since the use of chromium chemicals in these applications is based upon economic and technical advantages, the substitution of any alternate may result in cost penalties and inferior performance.

Table 8 is very subjective and serves to illustrate the relative ease, or difficulty, of replacing chromium in various application categories by assigning relative weights to decision criteria that affect the selection of chromium-bearing materials for different end uses.

E. CONCLUSIONS AND RECOMMENDATIONS

Based on its study and assessment of the situation, the Committee has concluded that the assurance of an adequate supply of chromium minerals and alloys is a problem of the greatest magnitude because:

1. The major applications for chromium are in strategic uses (primarily for stainless steels) requiring resistance to heat and corrosion.

2. While world chromite reserves are considered adequate to meet cumulative domestic and world needs for several decades, the United States depends totally upon Eastern Hemisphere sources (principally Africa and Russia) for chromium minerals and alloys. No known reserves or deposits capable of supplying a significant portion of U.S. demand exist in the United States or Western Hemisphere.

3. No acceptable alternative materials exist for chromium in its major applications.

4. Potential net demand is considerable. The anticipated requirements for chromium in energy and fuel production technologies are not excessive; however, the probability of curtailment of imports is significant and these considerations warrant the concern of commercial and government inventory holders.

TABLE 8 Qualitative Determinants of Chromium Usage and Replaceability Decision Criteria.

Application or End Use Requirements	Technical Function	Aesthetics or Appearance	Feasibility of Replacement
Corrosion Resistance	2	6	3
Heat and Oxidation Resistance	2	8	2
High-Temperature Strength	2	9	1
Hardenability or Heat Treatment	3	9	6
Tool Steel or Cemented Carbide	3	9	3
Electroplating	4	4	5
Refractories or Ceramics	2	9	3
Chemicals	2	9	4

NOTE: Scale of Values from 1 to 10

1 -- Primary Factor -- No acceptable alternate material for chromium
3 -- Major Factor -- Extremely difficult to replace chromium
5 -- Significant Factor -- Considerable difficulty replacing chromium
7 -- Minor Factor -- Some difficulty replacing chromium
9 -- Not a Factor -- Satisfactory substitute for chromium available

In view of its conclusions, the Committee recommends that:

1. The technical and economic aspects of chromium supply must be evaluated continuously:

    a. The preparation of updated projections for new and growing uses, particularly as influenced by the development of alternate or expanded energy sources, should be a primary objective.

    b. A detailed analysis of potential substitutes for chromium in specific applications and plans for reallocation to "most critical" areas should be made.

    c. Alternatives, such as metal cladding and electroplating for corrosion-resisting and some high-temperature applications, need repeated evaluation.

2. Commercial and government inventories of chromium must be evaluated and updated continuously to minimize dislocations resulting from changes in short-term availability.

Chapter Four

GERMANIUM

A. CRITICAL AND STRATEGIC ASPECTS

Germanium is a potentially critical material because its electrical properties make it the optimum material for use in electronic devices and rectifiers and infra-red beam, nuclear detection, and thermoelectric devices. One small refinery near Miami, Oklahoma, produces all domestic germanium from zinc smelter residues; however, the consumption rate is low. Supplies, which depend on the recycling of new scrap to meet demand, seem adequate. High prices for germanium might make recovery from coal fly ash economic and would open up a large new source of supply. In semiconductor applications, high-purity silicon is a major substitute for germanium as are certain tellurium, selenium, indium, and gallium bimetallics.

B. PRESENT USE

During the past five years, U.S. germanium consumption averaged 42,200 pounds per year and increased 10 percent, an average of 2.4 percent per year, and was as follows:

	1971	1972	1973	1974	1975
Demand (lbs)	40,000	40,000	43,000	44,000	44,000

(U.S. Bureau of Mines, 1975). The major uses of germanium are 50 percent electrical and 48 percent in specialized optical glass (U.S. Bureau of Mines, 1974).

Germanium imports totalled 28 percent of domestic consumption during the 1970-75 period (Table 9). At present, U.S. production comes primarily from stockpiled zinc smelter residues although the refinery at Miami, Oklahoma, also processes new scrap. Production figures indicate that 65 to 88 percent of germanium output is recycled as scrap from the cutting of shapes used in manufacturing semiconductors, and imports often supply the new primary germanium.

Germanium was developed first to meet the demand of the semi-conductor market but a substitute, silicon, soon captured a major portion of the market. It now is recognized that germanium is more reliable than silicon in some

TABLE 9 Germanium Imports as Percentage of U.S. Germanium Consumption.

Producing Country	Percentage of U.S. Consumption*
Belgium, Luxembourg	7
Italy	11
Japan	7
USSR	39
West Germany	20
Other	16
Total	100

NOTE: Data from U.S. Bureau of Census, 1971, 1972, 1973, 1974, and 1975.

* Average of years 1971 to 1975 in which imports totalled 28 percent of domestic consumption.

high-frequency and high-power applications. In rectifying devices, germanium displays no aging effects but must have cooling systems. Other electronic applications include photodiodes, special semi-conductors for computer applications, strain gauges, and tunnel emission amplifiers.

Germanium is used in infra-red materials, electronic nuclear detection devices, and glasses. Like most semi-conductors, it is opague in the visible region but begins to transmit in the infra-red region. Devices have been developed to beam infra-red energy, and others are used, for example, to detect abnormal surface temperatures.

Germanium is used in catalysts and, for example, wide usage is reported in the production of polyester fibers in Europe and Japan (not in the United States). Germanium also has been used in organo-germanium compounds for catalysis in preparation of polyurethane foams. Other experimental areas for germanium include atomic batteries, alpha particle counters, germanium-magnesium phosphor in fluorescent lights, and as an additive to storage batteries to reduce internal resistance to current flow.

C. PROJECTED USE

No new major uses of germanium are expected that would change the consumption pattern significantly. U.S. demand is projected to increase at 2 percent per year through 1980; however, accelerated growth in the dissipative applications (e.g., infra-red radiation, nuclear detection devices, and glass fiber lightguides) could increase U.S. demand significantly.

D. CURRENT STARTING MATERIALS (SUPPLY AND SUBSTITUTES)

1. Current and Future Supply

At present, all primary germanium production comes from processing zinc residues stockpiled at U.S. smelters, that used horizontal retorts. U.S. reserves at 1973 prices were estimated at 900,000 pounds of germanium with about a 15-year life. Other than these residues, the only currently known U.S. germanium reserve is the Tri-state* region's lead-zinc ore, which has a limited life and in which germanium occurs as an impurity.

At higher prices, it may be possible to recover germanium from fly ash from power plants using coal from certain deposits. The fly ash from this coal, if burned and collected properly, has sufficient germanium to meet U.S. needs (Corcy et al., 1959). The coal fly ash typically contains 0.025 percent germanium (0.5 lb/ton) and at 300 tons per day or 109,500 tons per year, this fly ash would contain 54,750 pounds of germanium, more than the total present U.S. demand. This byproduct is available for the cost of recovery; however, the technology for obtaining germanium from the fly ash needs further development.

2. Substitutes

Silicon is a major substitute for germanium in semi-conductors. Tellurium, selenium, indium, and gallium also may be used as substitutes for germanium in selected applications.

E. CONCLUSIONS AND RECOMMENDATIONS

On the basis of its study, the Committee has concluded that:

1. The industry stockpile, potential for increased production, and the substitution possibility for germanium indicate that no national stockpiling is warranted at present.

2. A national resource of germanium exists in the zinc residues, stockpiled at U.S. smelters, that have an estimated life of 16 years. Other than these residues, the currently known germanium reserve is the Tri-state region's lead-zinc ore that has a limited life. An

---

* The Tri-state region is Missouri, Kansas, and Oklahoma.

> unexploited natural resource exists in the thousands of tons of coal fly ash generated daily in the United States from coal in certain deposits. Recovery of germanium from 200 to 300 tons of fly ash daily could supply current germanium needs. Because of the limited tonnage projected from the zinc residues and ores, the expected rise in the price of germanium should make fly ash a viable resource.

The Committee therefore recommends that, if major uses for germanium should emerge, the technology for economic extraction of germanium from coal fly ash should be developed.

Chapter Five

IRIDIUM

A. CRITICAL AND STRATEGIC ASPECTS

Iridium has been classed as a potentially critical and strategic material since it is obtained only as a byproduct of the platinum group metals coming essentially from the USSR and the Republic of South Africa and since there is the possibility of considerable growth in its usage as spacecraft propulsion thrusters and similar applications.

B. PRESENT USE

Table 10 presents data on total U.S. iridium consumption and the amounts sold to some consuming industries. As is indicated, iridium consumption has decreased annually since 1972.

TABLE 10 Domestic Iridium Consumption by Industry (in troy ounces).

Year	Chemical	Petroleum	Electrical	Jewelry and Decorative	Total U.S.*
1971	8,342	447	2,619	1,104	15,512
1972	12,429	16,725	4,042	1,565	37,754
1973	10,635	13,385	3,516	1,191	30,676
1974	7,334	9,970	2,840	884	22,778
1975	2,559	3,587	1,969	401	9,143

NOTE: Data from U.S. Bureau of Mines, 1972, 1973, 1974, 1975, and 1976.

* In addition to uses shown in table, includes glass, medical and dental, and others.

Imports of iridium in 1974 amounted to more than 39,000 troy ounces with about 50 percent coming from the United Kingdom (a refiner), 23 percent from the Republic of South Africa, and 8 percent from Japan (a refiner). A significant amount of iridium is recovered as secondary metal by refiners and, in 1974, 3,494 troy ounces of iridium were recovered from secondary sources by domestic refiners. The stock of domestic iridium held by refiners, importers, and dealers as of December 31, 1975 amounted to about 18,000 troy ounces. The present U.S. government stockpile of iridium is about 17,000 troy ounces. Of the iridium consumed in this country, almost half is used as a catalyst in petroleum refining. The second major user is the chemical industry, while electrical applications, the glass industry, dental and medical uses, and jewelry applications also consume large amounts. Its newer uses include encapsulating radioisotopes in spacecraft power supplies, in high-temperature thermocouples, and in high-temperature growth of quality oxide crystals.

The drop in demand in 1975 apparently was due to depressed economic conditions and the use of less expensive reforming catalysts by the petroleum industry. Normal usage for iridium seems to be from 12,000 to 15,000 troy ounces a year.

The use of iridium for the long period may increase if these last mentioned uses increase appreciably.

1. Properties

Iridium, a metallic element with atomic number 77 and atomic weight 192.22, is one of the six metals of the platinum group metals that occur naturally in close association and possess strong physical and chemical similarities. These metals offer chemical inertness, catalytic activity, excellent corrosion resistance and low vapor pressures at high temperatures, and high thermal and electrical conductivities.

Some of the important properties of the platinum metals are given in Table 11. In addition, it is interesting to note that iridium and osmium are the heaviest elements known (i.e., with specific gravities greater than 22.4); iridium is the most corrosion-resisting metal known; with the exception of osmium, iridium has the highest melting point and lowest vapor pressure of the platinum group metals; iridium's modulus of elasticity is one of the highest for an element (i.e., 75,000,000 psi); and iridium's excellent high-temperature strength properties place it in the category of the common refractory metals (i.e., tungsten, tantalum, molybdenum, and niobium).

C. PROJECTED USE

New uses are high-temperature thermocouples and the encapsulation of radioisotopes in spacecraft power devices. In 1975, the Energy Research and Development Administration borrowed 7,000 troy ounces of iridium from the

TABLE 11 Some Properties of the Platinum Group Metals.

Property	Pt	Ir	Os	Pd	Rh	Ru
Thermal Neutron Cross Section (barns)	9	425	15	6	150	3
Density at 20° C (g/cm^3)	21.45	22.65	22.61	12.0	12.4	12.4
Melting Point (°C)	1768	2443	3050	1552	1960	2310
Specific Heat at 0° C (J/kg K)	131	128	129	244	246	230
Coefficient of Linear Expansion at 20-100° C (cm x 10^{-6}/cm/°C)	9.1	6.8	6.1	11.1	8.3	9.1
Resistivity at 0° C ($\mu\Omega$m)	9.8	4.7	8.1	9.9	4.3	6.8
Tensile Strength, Annealed (kN/m^2 x 10^3)	124	1100	--	172	688	496
Modulus of Elasticity in Tension (kN/m^2 x 10^6)	172	516	556	117	316	417

NOTE: Data from Darling, 1973 (copyright American Society for Metals, 1973).

government stockpile for use as the encapsulant in thermoelectric generators in space flight.

No substitutes for iridium are presently known.

D. CURRENT STARTING MATERIALS (SUPPLY AND SUBSTITUTES)

Except for some output in Alaska, the United States produces very little of the platinum group metals. The United States mines only about one percent of the platinum metals that it uses and therefore is almost totally dependent upon foreign sources for its supply of primary metal. The origin and output of platinum group metals in 1970 and the relative proportions of the metals in their ores are given in Table 12.

The Republic of South Africa, the USSR, and Canada continue to account for 99 percent of the world output of the platinum metals. With the exception of osmium, the United States consumes less iridium than any of the other platinum family metals; however, this metal is the most expensive of the platinum group, with a price of $300 per troy ounce as of April 1, 1976.

Chapter Six

RHENIUM

A. CRITICAL AND STRATEGIC ASPECTS

Applications for rhenium are promising due to its use as a refractory dispersoid in special high-temperature alloys and to its increasing use in electronic materials and catalysts. Less than 15 percent of the potentially recoverable rhenium presently is recovered at molybdenite (MoS_2) roasting plants.

B. PRESENT USE

In 1973 and 1974, an estimated 75 to 80 percent of all rhenium consumed in the United States was in the form of bimetallic catalysts. Estimated domestic consumption of rhenium for the years 1970 to 1975 are presented in Table 13.

Rhenium is a refractory metal with a melting point of 3,180° C (5,755° F). In the pure state, it suffers from catastrophic oxidation beginning at about 600° C (1110° F), but it produces a series of specialty alloys offering properties especially useful in special high-temperature metals; high-temperature thermocouples; filaments; metallic coatings; heat-, wear-, and corrosion-resisting alloys; and special electronic applications. Its high price (between $625 and $800 per pound in 1974) and limited demand have retarded needed research to establish potential applications for rhenium.

C. PROJECTED USE

Although rhenium clearly will continue to be useful as a bimetallic reforming catalyst in the production of no-lead and low-lead high-octane gasoline and its unique high-temperature properties undoubtedly will lead to a variety of other

TABLE 13 Domestic Rhenium Consumption, 1970-1975 (pounds of contained rhenium).

Year	Consumption	Remarks
1970	5,100	
1971	7,600	
1972	4,800	Sharp decline due to limited development of new refineries.
1973	4,400	
1974	4,500	
1975	6,000	An estimated 51 percent of U.S. reforming capacity was accounted for by bimetallic catalysts in 1975 with platinum-rhenium catalysts representing 60 to 70 percent of that figure, or 30 to 35 percent of total U.S. reforming capacity.

NOTE: Data from U.S. Bureau of Mines, 1975.

uses in the future, its importance as a critical material is difficult to estimate. The properties of rhenium are well established but its potential uses require thorough examination, particularly in light of its promise in producing gasoline from alternate fuel sources and in special alloys.

D. CURRENT STARTING MATERIALS (SUPPLY AND SUBSTITUTES)

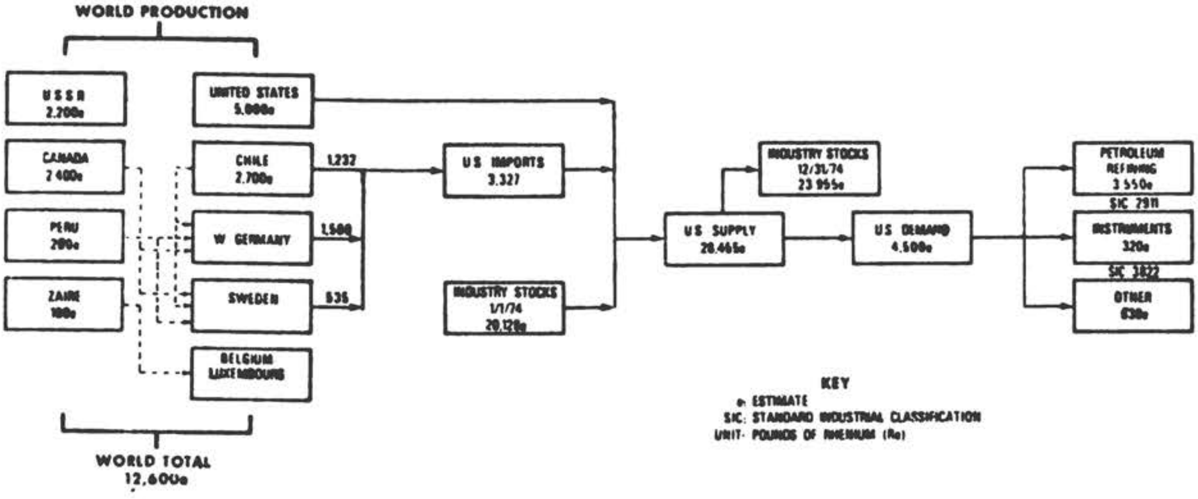
1. Current Supply

Rhenium is derived almost exclusively as a molybdenum byproduct that is recovered from the flue gas from molybdic oxide plants. Since it is not the principal product, it suffers in recovery. The major source of rhenium is the molybdenite concentrate recovered from porphyry copper ores. Deposits of such ores are present in a zone that extends from Chile through Peru, Mexico, the western part of the United States, British Columbia, and Alaska. Deposits also are found in the Soviet Union and western Europe. Porphyry molybdenum deposits also contain rhenium but in much lower concentrations.

Total U.S. rhenium reserves are estimated at 1,300 short tons, nearly 50 percent of the total world reserves; however, economics limit rhenium recovery almost exclusively to molybdenite concentrates produced from the porphyry copper-type ore deposits and rhenium reserves from deposits of this type are estimated at 1,200 short tons. In 1970, an estimated 22,200 pounds of rhenium and 34 million pounds of molybdenum were contained in molybdenite concentrate from porphyry copper ores. The amount of rhenium potentially recoverable in 1970 production was estimated to be between 13,000 and 18,000 pounds*; however only 5,900 pounds, or between 33 to 45 percent of this amount, were actually recovered. The 2,000 pounds of rhenium recovered in 1975 is believed to represent only 10 to 15 percent of the amount potentially recoverable.

In 1974, imports of metallic rhenium as unwrought rhenium, waste, and scrap decreased sharply to only 40 pounds, all from West Germany, while imports of rhenium as ammonium perrhenate, from Chile, West Germany, and Sweden, increased 8 percent and totaled 3,287 pounds of contained rhenium. Rhenium supply-demand relationships are illustrated in Figure 1 and Table 14.

FIGURE 1 Rhenium Supply-Demand Relationships, 1974 (U.S. Bureau of Mines, 1975).



2. Future Supply

For the period 1972 through 1980, estimated free world demand for rhenium can be met adequately by the 15,000 pounds that potentially can be produced annually by U.S. suppliers -- Kennecott Copper Corporation, S. W. Shattuck Chemical Company, M & R Refractory Metals, Inc., and Molybdenum Corporation of America.

---

* Based upon a 60 to 80 percent recovery and assuming all MoS_2 concentrates were processed for rhenium.

TABLE 14 Rhenium Supply and Demand Relationships, 1965-1974* (in pounds).

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
World Production										
United States	1,200	1,620	1,350	2,400	3,500	5,900	7,250	6,100	7,000	5,000
Rest of the World	1,100	1,300	1,400	1,700	2,100	2,100	4,150	5,000	7,400	7,600
Total World Production	2,300	2,920	2,750	4,100	5,600	8,000	11,400	11,100	14,400	12,600
Components of U.S. Supply										
Domestic Mines	1,200	1,620	1,350	2,400	3,500	5,900	7,250	6,100	7,000	5,000
Imports	469	84	96	657	2,700	1,035	3,812	2,013	4,477	3,327
Industry Stocks, January 1	560	620	900	900	2,961	5,022	6,200	9,700	13,051	20,128
Total U.S. Supply	2,229	2,324	2,346	3,957	9,161	11,957	17,262	17,813	24,528	28,455
Distribution of U.S. Supply										
Industry Stocks, December 31	620	900	900	2,961	5,022	6,200	9,700	13,051	20,128	23,955
Industrial Demand	1,210	1,200	1,350	825	3,250	5,100	7,600	4,800	4,400	4,500
Apparent Surplus (+) or Deficit (-) of Supply**	+ 399	+ 224	+ 96	+ 171	+ 889	+ 657	- 38	- 38	--	--
U.S. Demand Pattern										
Petroleum Refining	25	40	55	60	2,800	4,350	6,384	3,800	3,500	3,550
Instruments	200	200	300	200	100	200	380	400	300	320
Other	985	960	995	565	350	550	836	600	600	630
Total U.S. Demand	1,210	1,200	1,350	825	3,250	5,100	7,600	4,800	4,400	4,500

NOTE: Data from U.S. Bureau of Mines, 1974.

* All data estimated, except imports.

** U.S. supply less industry yearend stocks and industrial demand.

3. Substitutes

High production costs, limited current demand, and lack of knowledge regarding the full potential of rhenium make it impossible to assess the importance of rhenium as a critical material. Its properties, however, are sufficiently unique to dictate that serious thought be given to its high irrevocable loss by current processing plants. Since the potential to supply rhenium far exceeds present demand, little impetus exists to consider substitutes; however, the potential future uses of rhenium in various applications should receive careful consideration.

E. CONCLUSIONS AND RECOMMENDATIONS

On the basis of its study, the Committee has concluded that:

1. Less than 15 percent of potentially recoverable rhenium is being recovered at present and the current market for rhenium does not provide incentive for additional recovery or stockpiling by producers or primary consumers.

2. There is only one major source of rhenium (roasting of molybdenite concentrates from poryphyry copper operations). If it is not recovered at the time of processing the concentrate, it is dissipated forever.

3. Rhenium has unique properties that make it potentially useful as an alloying constituent in special high-temperature alloys and thermocouples, a catalyst in the production of no-lead and low-lead high-octane gasoline, and a corrosion-resisting metal useful in electronic applications.

Given this situation, the Committee recommends that:

1. The cost of conserving the present potential output of rhenium -- currently being dissipated, either by economic incentives or technical programs -- should be examined.

2. A survey of properties relative to potential applications of rhenium should be made to assess its general importance.

Chapter Seven

VANADIUM

A. CRITICAL AND STRATEGIC ASPECTS

Vanadium is a substitute for other critical and strategic commodities such as molybdenum, columbium, and platinum. Most U.S. production of vanadium has been as a byproduct or coproduct of uranium and, therefore, is not related directly to vanadium demand. However, the bulk of future uranium production is not expected to be from this type of ore. Domestic reserves of vanadium are limited. Accordingly, the United States has been a net importer of vanadium and probably will depend more on imports in the future.

Vanadium is a key element in the manufacture of alloy steels used in construction, industrial and construction equipment, transportation, and chemicals. It has new applications in vanadium-titanium alloys that may increase its importance in aerospace industries. Also, vanadium has potential new applications as a fuel element cladding in fast breeder reactors that may increase in importance.

B. PRESENT USE

U.S. industrial demand for primary vanadium over the past five years (1970-1974) has averaged 7,600 tons of contained vanadium. In 1974, major uses for vanadium followed the categorical patterns shown in Table 15.

Vanadium is noncorrosive and has high heat resistance and a high density. It is an important alloying element (and is added in small quantities) in the manufacture of carbon, stainless, and heat-resisting steels, and cast irons. Along with nickel, aluminum, boron, and manganese, it is an important alloy in nonferrous and superalloys. Ferrovanadium is used in welding electrodes as an oxidizer.

While recent consumption has been low because of depressed economic conditions, the long-term use of vanadium should increase as steel production

TABLE 15 Vanadium Use Patterns.

Vanadium Use	% Vanadium Consumption
Intermediate Products	
Carbon Steel	13
Alloy Steel (high strength, low alloy)	33
Tool Steel	14
Nonferrous Alloys	10
Catalysts	4
Cast Irons, Superalloys, Cutting and Wear-Resisting Materials, Welding and Alloy Hard Facing Rods and Materials, Other	26
	100
End Uses	
Construction Materials	30
Construction Machinery and Industrial Equipment	10
Metalworking Machinery and Tools	10
Transportation	30
Other	20
	100

NOTE: Data from U.S. Bureau of Mines, 1974 and 1975.

increases. Present vanadium use patterns illustrate its critical and strategic nature, and in the event of an interruption of foreign supply, domestic production would have to expand, or substitutes be found, if a serious curtailment of several basic U.S. industries were to be avoided.

C. PROJECTED USE

Vanadium use in high-strength low-alloy steels is expected to continue to grow as is its use in alloys, particulary as an alloying agent in titanium alloys for the aerospace field. U.S. Bureau of Mines projections are based on expected growth ranging between 3.2 percent and 6.8 percent per year from 1975 to 2000.

The major potential new use, not considered in past assessments, is the application of high-purity vanadium as a structural material in nuclear reactors. Vanadium alloy as an alternative to stainless steel for fuel cladding in liquid-metal-cooled fast-breeder atomic reactors has been studied extensively, and its promise is great. In 1973, Westinghouse Electric obtained a $90 million contract for the nuclear portion of a liquid-metal-cooled fast-breeder reactor demonstration power plant in Tennessee. If vanadium is used in this project, a sizeable new market will be opened for the metal; however, because of the large amount of vanadium consumed in steel production, new uses are likely to appear small in comparison. Stainless steels and molybdenum-and-cobalt-base alloys are potential substitutes for vanadium in reactor applications.

D. CURRENT STARTING MATERIALS (SUPPLY AND SUBSTITUTES)

1. Current Supply

Vanadium is a minor element but an abundant one. World resources are very large, amounting to hundreds of years of supply at current consumption. The principal sources of vanadium are listed in Table 16.

Uranium-vanadium sandstone has been the source of 90 percent of total U.S. vanadium production between 1910 and 1970. Since vanadium is a byproduct or coproduct of uranium production, this source may not continue to supply vanadium indefinitely since the bulk of future output of uranium probably will contain little or no vanadium.

TABLE 16 Vanadium Sources

Country	Geologic Type	Commodities Recovered	Vanadium Reserves (thousand short tons)	Years Supply at 1974 U.S. Consumption Rate
United States				
Colorado Plateau	Sandstone, undetermined phosphate	U, V	40	6
Arkansas	Sandstone, undetermined phosphate	V	30	5
Idaho	Sandstone, undetermined phosphate	P, V	45	7
Republic of South Africa	Titaniferous Magnetite	Fe, V	2,000	
Finland	Titaniferous Magnetite	Fe, Ti, V	55	
Norway	Titaniferous Magnetite	Fe, Ti, V	20	
USSR	Titaniferous Magnetite	Fe, V	8,000	
Chile	Nontitaniferous Magnetite	Fe, V	150	

NOTE: Data from U.S. Bureau of Mines, 1973 and 1975.

The only domestic non-byproduct or coproduct, non-uranium-associated production of vanadium is from a deposit near Wilson Springs, Arkansas. This ore averages about 1 percent V_2O_5 and occurs as poorly defined bodies in irregular masses of argillic altered rock of an igneous intrusion and bordering sediments. Similar deposits occur nearby at Magnet Cove, Arkansas.

Present U.S. reserves are sufficient to meet projected U.S. 1985 demand for 7.4 years based on reserves of 115,000 short tons of contained vanadium and a probable annual demand of 15,500 short tons. In an emergency, domestic resources could supply cumulative domestic demands through 2000 at increased prices. Much of the vanadium reserve is in deposits in which vanadium will be a coproduct or byproduct.

In 1973, U.S. production furnished 56 percent of total domestic consumption. Vanadium-bearing materials, such as ashes and slags, are the most important source of vanadium from imports and, in 1973, most of these materials originated in the Republic of South Africa and Chile. Imports of ferrovanadium in 1973 came from Australia, Austria, West Germany, Norway, and Canada.

2. Future Supply

Industrial and natural residues of petroleum are also commercial sources of vanadium and may become more significant in the future. Vanadium is recovered from ash and soot of oil-burning furnaces and from refinery residues.

Titaniferous magnetite deposits in the United States and Canada are known to contain large quantities of vanadium. This resource is unevaluated but may be a major future source of vanadium.

3. Substitutes

If a shortage of vanadium occurs, a potential exists for limited substitution of other metals. The amount of such substitution is unquantified but could involve the following:

a. Larger quantities of lower strength steel could be used as a substitute for high-strength low-alloy steel in construction and machinery applications.

b. Molybdenum and columbium could be substituted for vanadium in construction materials and it might be possible to substitute columbium for vanadium in high-speed steels.

c. Tungsten alloys and carbides could be substituted for vanadium in tool steels.

d. Oxidizing compounds of chromium and magnesium could be substituted for vanadium compounds in some chemicals.

e. Platinum could be substituted for vanadium compounds in catalysts.

In the event of shortages of other critical materials, vanadium may be an important substitute for chromium, nickel, and tungsten in some applications.

E. CONCLUSION AND RECOMMENDATION

Given its assessment of the situation, the Committee has concluded that industry stockpiles and domestic production of vanadium coupled with conservation, substitution, and shifting of import sources should meet short-term interruption in supply. It recommends that future needs in the nuclear and aerospace fields should be quantified more accurately and that more information should be developed on alternate sources for domestic vanadium supplies.

Chapter Eight

ZIRCONIUM AND HAFNIUM

A. CRITICAL AND STRATEGIC ASPECTS

Zirconium and its coproduct metal, hafnium, are essential major components of conventional nuclear power systems. If the substantial projected nuclear demands for power here and abroad are supplied by conventional reactors, such as those presently available commercially, considerable quantities of pure zirconium metal would be necessary. On the other hand, if the projected energy demands are met by the development of liquid-metal fast-breeder reactors or substitute fuels and technologies, demand for zirconium metal will falter and the commercial supply of hafnium with it. Thus, the critical and strategic aspects of the two metals jointly depend on the technical and economic conditions surrounding the choice of boiler and reactor systems for both special U.S. and overall energy requirements.

The two elements invariably occur together in currently mined mineral deposits, in ratios of about 50 zirconium to 1 hafnium. The metals are obtained principally through a process (similar to that for titanium) developed by the U.S. Bureau of Mines under the direction of W. J. Kroll. In a multistage extraction, zirconium sponge metal is produced that is suitable for nonnuclear applications. In a second stage, reactor-grade zirconium and hafnium are separated chemically, processed to chlorides, and further reduced by the Kroll process to metals. This second reduction is the only source of hafnium.

B. PRESENT USES

As indicated in Table 17, zirconium and hafnium have closely associated physical and chemical characteristics (Reno, 1956; Weast, 1965; and Klemic, 1975) and as pure metals, they share properties of high corrosion resistance, structural stability at elevated temperatures, and special alloying properties. They have distinctly different nuclear properties, however, with hafnium being especially effective in nuclear control rods in naval reactors and zirconium being employed as cladding in conventional reactor fuel containers.

TABLE 17 Physical Properties of Zirconium and Hafnium.

Physical Property	Zirconium	Hafnium
Neutron-Capture Cross Section (barns)	0.18	105.0
Atomic Weight	91.22	178.49
Atomic Number	40	72
Specific Gravity	6.53	13.29
Melting Point (°C)*	1,852	2,150
Specific Heat (cal/g/°C)	0.067 (20° C)	0.0351 (25° C)
Hardness (Vickers hardness number)	105	152

NOTE: Data from Klemic, 1975 and Weast, 1975.

* The boiling points of zirconium and hafnium are very difficult to determine because of the high temperatures involved and the reactivity of these elements with crucible materials, including graphite. Estimated boiling points are 3,580° C for zirconium and 3,100° C for hafnium.

Other uses as oxidation-resisting alloys are possible for hafnium. However, zirconium metal has many uses other than as a structural material for conventional nuclear reactors. In its commercial grades, it is useful in the chemical industry, especially as an alloy in heat exchangers, acid concentrators, tank shafts, valves, pump housings, fan wheels, high-speed agitators, electrode assemblies, steam jet exhausts, tubing, pipes and pipe fittings, spinnets and crucibles (Ampian, 1976). Up to one percent zirconium alloy increases the strength of magnesium alloys and adds corrosion resistance to columbium base alloys. The latter are used in super-conducting magnets.

At present, zirconium's major applications, primarily in casting ferrous metals, are in foundries as shell molding material and mold facings. Its nonmetallic uses constitute over 90 percent of the consumed zirconium, as shown in Table 18. In contrast, metal consumption has been small and variable, from 2,500 to 6,000 short tons, depending on fluctuations in inventory demands. U.S. government stocks of zirconium metal approximate 1,000 short tons.

C. PROJECTED USES

The metal use projections include all nuclear applications and consumption is forecast to increase 4 percent per year. Nonnuclear metal applications are projected to reach 7,000 tons maximum. Thus, the nuclear uses are estimated

TABLE 18 Contingency Forecasts for Zirconium by End Use (in short tons).

	Demand		2000 Forecasts	
End Use	1968	1973	Low	High
Foundries	40,000	46,500	60,000	125,000
Refractories	12,000	13,500	35,000	90,000
Ceramics	12,000	11,000	22,000	60,000
Chemical	2,000	1,000	6,000	15,000
Metal	6,000	2,500	8,000	23,000
Total	72,000	74,450	131,000	313,000

NOTE: Data from Stamper and Chin, 1970 and Ampian, 1976.

to reach 7,000 tons minimum to 27,000 tons maximum annually by 2000 (Ampian, 1976), a reduction from the earlier low-high predictions of 5,000 and 10,000 tons (Stamper and Chin, 1970). Presumably, greater emphasis on conventional nuclear power through 2000 because of delays in breeder reactor development could result in higher zirconium consumption.

No official estimates exist for the zirconium required in the construction of future atomic plants or for the number of conventional reactors likely to be in place through the year 2000. However, power estimates are made in terms of quadrillion Btu (Quad) and megawatt (MW) of total U.S. electricity demand through 1985 (Federal Power Survey, 1970). About half of the increase is expected to be from nuclear systems. These projections for nuclear needs are shown in Table 19. The number of nuclear reactors required to supply the nuclear portion of electric power indicated in Table 19 at 1,000 MW per reactor could reach 434 in 1985-1990 and 1,085 after 2000. Assuming 100 to 300 tons of zirconium per reactor, meeting nuclear needs with conventional reactors could require cumulative zirconium production up to 325,000 tons over the next 30 years. Price rises and imports may be required to meet overall U.S. demands. However, variations in the maximum levels of zirconium metal demand, due to variations in the number of sited conventional reactors, do not result in total zirconium forecasts materially different from those forecast because of the dominant weight given nonmetal expectations.

D. CURRENT STARTING MATERIALS (SUPPLY AND SUBSTITUTES)

1. Current Supply

Zirconium is not geologically rare and is a rather common element in the earth's crust (twentieth in order of abundance). The primary resources in

TABLE 19 Contingency Forecasts for Nuclear Power, 1985 and 2000.

	1968 (actual)	1985 (forecast)	2000 (forecast)
Total Electricity			
(quadrillion Btu)	18	59	100
(thousand megawatts)	390.6	1,280	2,170
Electricity in Nuclear Capacity (quadrillion Btu)	1	20	50
Demand for Nuclear Reactors* (cumulative number)	19	434	1,085

NOTE: Data from National Coal Association, 1974; Federal Power Survey, 1970; Newcomb et al., 1975.

* Demand for nuclear reactors is based on 1,000 megawatt stations and estimates for 1985 and 2000 of 0.8, 20.0 and 50.0 quadrillion Btu capacities, respectively. Average efficiencies yield 21.7 megawatts per quadrillion Btu.

veins and disseminated deposits of baddeleyite and eudialyte are few, occurring mainly in Brazil and South Africa; however, abundant secondary sources of zircon occur in unconsolidated sedimentary formations in placer deposits, primarily in beach sands and sand dunes. World resources are estimated at 44 million short tons (zircon equivalent), of which 27 million tons are in the United States and Australia (Klemic, 1973). Currently mined deposits are associated with dredging operations in sands mined primarily for titanium. Table 20 shows percentages of world and U.S. supplies.

Identified domestic zircon resources, estimated at 14 million tons, contain about 6.8 million tons of zirconium and 130,000 tons of hafnium, all in placers and mostly in the Atlantic coastal states of Florida, Georgia, South Carolina, and New Jersey. The three mines currently operating are in Georgia. Prices of $50 to $60 per ton of concentrate prevailed before the environmental requirements were enacted for such mining; the present price is $300, but most of the tonnage is expected to be recovered for under $200. Table 18 presents zirconium demand in 1968 and 1973 and forecasts for zirconium use in 2000.

2. Future Supply

The price of zirconium recently has risen to several times the historic level. A cursory examination indicates that this change does not reflect

TABLE 20 Zirconium Supply and Demand Relationships.

	Percent	Short Tons
World Production		
USSR	13	
United States	19	
Australia	63	
India, Republic of South Africa, Peoples Republic of China, Brazil, Thailand, Malaysia, and Other	5	
Total	100	314,175
U.S. Supply		
Ore Imports (Australia and others)	34	
Chemicals, Oxide, and Metals	1	
Stocks	23	
U.S. Production	42	
Total	100	143,881
U.S. Demand		
Exports	11	
Stocks	37	
Consumption	52	
Total	100	143,881

NOTE: Compiled from Ampian, 1976.

scarcities of long duration; however, other conditions may have changed to create higher prices permanently. If the titanium output from rutile or ilmenite changes and the average zirconium percentage in sands decreases, zirconium recovery must fall or bear a greater share of joint mining costs. On the other hand, the possibility of substitution in non-reactor uses of zirconium needs investigation before one could recommend a national subsidy program or resumption of stockpiling to stabilize prices.

3. Substitutes

In casting, chromite sand is a substitute for zircon*. Titanium oxide is a substitute in opacifiers and ceramics; stainless steel is used as structural material in reactors; and aluminum, columbium, and vanadium are used for fuel containers, depending on reactor design. Stainless steels, titanium, and tantalum are substitutes for zirconium in commercial applications. Manganese, vanadium, and other deoxidants serve as well as zirconium in ferrous metal applications. Aluminum and titanium can be used to inhibit grain growth, and vanadium and chromium can substitute for zirconium to improve low-temperature strength.

E. CONCLUSIONS

Based on its study, the Committee has concluded that:

1. Potential market imbalances in zirconium and hafnium could occur in the future, both domestically and abroad, if the upper range of forecast demands materializes, since these forecasts understate the potential upper bound of nuclear-grade metallic demands. On the other hand, substitution and higher prices on demands and supplies should offset most of the excess demands predictable, even in extreme cases.

2. The coproduct nature of current zirconium and hafnium supplies creates short-term adjustment lags that can lead to unexpected periods of high prices. In the long run, however, U.S. access to free world supplies of ores of either metal does not appear critical.

Accordingly, the Committee does not recommend any action.

---

* Zirconium silicate.

Appendix A

NATIONAL STOCKPILE OBJECTIVES

SUMMARY OF GOVERNMENT INVENTORIES, OBJECTIVES, EXCESSES AND BALANCE OF DISPOSAL AUTHORIZATIONS

Basic Stockpile Materials
June 30, 1975

(Market Value - $ Millions)

Commodity	Unit	Objective	Total Inventory[1]	Market Value[2]	Excess[3]	Market Value[2]	Balance of Disposal Authorization
1. Aluminum	ST	0	799	$ 0.6	799	$ 0.6	799[4]
2. Aluminum Oxide, Abrasive Grain	ST	17,200	50,905	15.8	33,705	10.4	0
3. Aluminum Oxide, Fused, Crude	ST	0	267,062	39.3	267,062	39.3	18,053
4. Antimony	ST	0	40,700	132.1	40,700	132.1	0
5. Asbestos, Amosite	ST	0	42,433	14.8	42,433	14.8	24,033
6. Asbestos, Chrysotile	ST	1,100	10,956	5.3	9,856	4.8	0
7. Bauxite, Metal Grade, Jamaica	LDT	4,638,000	8,858,881	178.5	4,220,881	85.0	1,370,077
8. Bauxite, Metal Grade, Surinam	LDT	0	5,300,000	111.4	5,300,000	111.4	0
9. Bauxite, Refractory	LCT	0	173,000	18.6	173,000	18.6	0
10. Beryl Ore	ST	0	17,986	5.9	17,986	5.9	0
11. Beryllium Copper Master Alloy	LB	0	14,773,731	44.0	14,773,731	44.0	0
12. Beryllium Metal	ST	88	229	34.3	141	21.1	0
13. Bismuth	LB	95,900	2,100,004	15.7	2,004,104	15.0	0
14. Cadmium	LB	4,446,500	6,449,746	19.3	2,003,246	6.0	449,746
15. Castor Oil							
a. Castor Oil	LB	0	0	0	0	0	0
b. Sebacic Acid	LB	0	5,009,697	6.8	5,009,697	6.8	0
16. Chromite, Chemical Grade	SDT	8,400	250,000	10.0	241,600	9.7	0
17. Chromite, Metallurgical	SDT	444,710	2,504,560	281.0	2,059,850	219.5	0
18. Chromium, Ferro, High Carbon	ST	11,476	402,694	319.5	391,218	310.4	0
19. Chromium, Ferro, Low Carbon	ST	0	318,893	466.5	318,893	466.5	0
20. Chromium, Ferro, Silicon	ST	0	58,356	42.5	58,356	42.5	0
21. Chromium, Metal	ST	0	3,763	18.4	3,763	18.4	0
22. Chromite, Refractory	SDT	54,000	399,960	20.5	345,960	17.8	0
23. Cobalt	LB	11,945,000	48,920,040	195.7	36,975,040	147.9	10,720,040
24. Columbium Concentrates	LB	0	1,930,483	4.3	1,930,483	4.3	178,930
25. Columbium Carbide Powder	LB	16,000	21,372	0.4	5,372	0.09	1,372
26. Columbium, Ferro	LB	748,000	930,911	3.7	182,911	0.7	0
27. Columbium, Metal	LB	36,000	44,851	0.9	8,851	0.2	0
28. Copper							
a. Copper Oxygen Free, High Conductivity	ST	0	489	0.6	489	0.6	489[4]
b. Other	ST	0	0	0	0	0	0

SUMMARY OF GOVERNMENT INVENTORIES, OBJECTIVES, EXCESSES AND BALANCE OF DISPOSAL AUTHORIZATIONS (Continued)

Basic Stockpile Materials
June 30, 1975

(Market Value - $ Millions)

Commodity	Unit	Objective	Total Inventory[1]	Market Value[2]	Excess[3]	Market Value[2]	Balance of Disposal Authorization
29. Cordage Fibers, Abaca	LB	0	0	$ 0	0	$ 0	0
30. Cordage Fibers, Sisal	LB	0	0	0	0	0	0
31. Diamond Dies, Small	PC	7,900	25,473	1.0	17,573	0.7	0
32. Diamond, Industrial, Crushing Bort	KT	0	34,635,595	73.8	34,635,595	73.8	10,935,595
33. Diamond, Industrial, Stones	KT	0	20,270,115	185.9	20,270,115	185.9	270,115
34. Feathers and Down	LB	1,938,000	1,675,065	7.4	0	0	1,675,065[5]
35. Fluorspar, Acid Grade	SDT	0	889,991	93.4	889,991	93.4	0
36. Fluorspar, Metallurgical Grade	SDT	159,000	411,788	34.2	252,788	21.0	0
37. Graphite, Natural, Ceylon	ST	3,100	5,499	2.4	2,399	1.1	0
38. Graphite, Natural, Malagasy	ST	8,200	17,939	9.0	9,739	4.9	0
39. Graphite, Natural, Other than C&M Crystalline	ST	0	2,802	0.5	2,802	0.5	0
40. Iodine	LB	0	8,011,751	20.7	8,011,751	20.7	0
41. Jewel Bearings	PC	62,740,000	62,986,683	20.7	0	0	0
42. Lead	ST	65,100	601,716	228.7	536,616	203.9	72,314[4]
43. Manganese, Battery Grade, Natural Ore	SDT	10,700	308,278	34.1	297,578	32.8	173,278
44. Manganese, Battery Grade, Synthetic Dioxide	SDT	0	3,436	1.5	3,436	1.5	1,536
45. Manganese Ore, Chemical Grade, Type A	SDT	12,800	146,586	10.9	133,786	10.0	111,586
46. Manganese Ore, Chemical Grade, Type B	SDT	12,800	96,238	7.2	83,438	6.2	61,238
47. Manganese Ore, Metallurgical	SDT	750,500	4,134,922	202.9	3,384,422	157.9	1,529,322
48. Manganese, Ferro, High Carbon	ST	200,000	600,000	235.7	400,000	157.1	0
49. Manganese, Ferro, Low Carbon	ST	0	0	0	0	0	0
50. Manganese, Ferro, Medium Carbon	ST	10,500	28,920	26.2	18,420	16.7	0
51. Manganese, Silicon	ST	15,900	23,574	11.3	7,674	3.7	0
52. Manganese Metal, Electrolytic	ST	4,750	14,166	15.3	9,416	10.2	0
53. Mercury	FL	42,700	200,061	33.5	157,361	26.4	0

SUMMARY OF GOVERNMENT INVENTORIES, OBJECTIVES, EXCESSES AND BALANCE OF DISPOSAL AUTHORIZATIONS (Continued)

Basic Stockpile Materials
June 30, 1975

(Market Value - $ Millions)

Commodity	Unit	Objective	Total Inventory[1]	Market Value[2]	Excess[3]	Market Value[2]	Balance of Disposal Authorization
54. Mica, Muscovite Block, Stained and Better	LB	1,600,000	6,390,017	$ 28.0	4,790,017	$ 17.6	1,281,884
55. Mica, Muscovite Film, First and Second Qualities	LB	413,000	1,365,622	16.2	952,622	11.3	97,843
56. Mica, Muscovite Splittings	LB	2,200,000	26,209,075	31.4	24,009,075	28.8	7,149,200
57. Mica, Phlogopite Block	LB	51,000	146,885	0.04	95,885	0.02	95,885
58. Mica, Phlogopite Splittings	LB	200,000	3,485,128	4.2	3,285,128	3.9	2,535,128
59. Molybdenum							
a. Molybdenum Disulphide	LB	0	35,325	0.09	35,325	0.09	35,325[4]
b. Molybdenum, Ferro	LB	0	0	0	0	0	0
c. Molybdic Oxide	LB	0	0	0	0	0	0
60. Nickel	ST	0	0	0	0	0	0
61. Opium							
a. Opium, Gum	LB	0	40,150	9.1	40,150	9.1	3,762[4]
b. Opium, Salt	LB	0	39,514	11.8	39,514	11.8	0
62. Platinum Group Metals, Iridium	TrOz	1,800	17,002	8.6	15,202	7.7	12
63. Platinum Group Metals, Palladium	TrOz	328,500	1,254,994	103.5	926,494	76.4	0
64. Platinum Group Metals, Platinum	TrOz	187,500	452,645	72.4	265,145	42.4	0
65. Pyrethrum	LB	0	0	0	0	0	0
66. Quartz Crystals	LB	209,000	3,106,845	35.9	2,897,845	33.4	2,786,845
67. Quinidine	OZ	1,059,000	1,800,356	14.7	741,356	6.0	0
68. Quinine	OZ	779,500	3,246,166	20.1	2,466,666	15.3	0
69. Rubber	LT	0	120,190	78.1	120,190	78.1	0
70. Rutile	SDT	0	39,186	27.8	39,186	27.8	0
71. Sapphire and Ruby	KT	0	16,305,502	0.2	16,305,502	0.2	0
72. Shellac	LB	0	0	0	0	0	0
73. Silicon Carbide	ST	0	110,753	32.5	110,753	32.5	110,753
74. Silver	(Fine)TrOz	21,663,000	139,500,000	622.2	117,837,000	525.6	0
75. Talc, Steatite Block and Lump	ST	0	1,149	0.4	1,149	0.4	949
76. Tantalum Carbide Powder	LB	2,900	28,688	0.8	25,788	0.7	0
77. Tantalum Metal	LB	45,000	201,133	8.1	156,133	6.3	0

SUMMARY OF GOVERNMENT INVENTORIES, OBJECTIVES, EXCESSES AND BALANCE OF DISPOSAL AUTHORIZATIONS (Continued)

Basic Stockpile Materials
June 30, 1975

(Market Value - $ Millions)

Commodity	Unit	Objective	Total Inventory[1]	Market Value[2]	Excess[3]	Market Value[2]	Balance of Disposal Authorization
78. Tantalum Minerals	LB	312,000	2,613,543	$ 45.6	2,301,543	$ 40.2	68,133
79. Thorium	ST	0	3,642	9.1	3,642	9.1	3,555
80. Tin	LT	40,500	207,118	1,521.7	166,618	1,224.2	6,492
81. Titanium Sponge	ST	0	30,922	152.9	30,922	152.9	11,197
82. Tungsten Carbide Powder	LB	0	2,032,833	21.9	2,032,833	21.9	2,032,833
83. Tungsten, Ferro	LB	0	2,025,463	15.7	2,025,463	15.7	2,025,463
84. Tungsten, Metal Powder, Carbon Reduced	LB	0	716,910	5.7	716,910	5.7	716,910
85. Tungsten, Metal Powder, Hydrogen Reduced	LB	0	1,048,456	10.6	1,048,456	10.6	1,048,456
86. Tungsten Ores and Concentrates	LB	4,234,000	112,081,482	612.0	107,847,482	588.8	86,913,520
87. Vanadium							
a. Vanadium, Ferro	ST	0	0	0	0	0	0
b. Vanadium Pentoxide	ST	0	540	5.3	540	5.3	0
88. Vegetable Tannin Extract, Chestnut	LT	4,400	21,886	8.5	17,486	6.8	12,386
89. Vegetable Tannin Extract, Quebracho	LT	0	170,578	81.7	170,578	81.7	119,978
90. Vegetable Tannin Extract, Wattle	LT	0	21,545	9.9	21,545	9.9	12,045
91. Zinc	ST	202,700	374,208	290.0	171,508	132.9	171,508[4]

NOTE: Table from Federal Preparedness Agency, 1975, pp. 5-9.

[1] Total inventory consists of stockpile and nonstockpile grades and reflects uncommitted balance.

[2] Market values are estimated from prices at which similar materials are being traded; or in the absence of trading data, at an estimate of the price which would prevail in the market. Prices used are unadjusted for normal premiums and discounts relating to contained qualities or normal freight allowances. *The market values do not necessarily reflect the amount that would be realized at time of sale.*

[3] Includes materials for which (1) Congressional disposal legislation was pending, and (2) proposed legislation pending GSA submission to the Congress, as of June 30, 1975. (See page 16.)

[4] Committed for sale but undelivered under long-term contracts.

[5] Balance available due to rotation in order to prevent deterioration.

Appendix A

ABBREVIATIONS

FL	Flask
KT	Carat
LB	Pound
LCT	Long Calcined Ton
LDT	Long Dry Ton
LT	Long Ton
OZ	Ounce
PC	Piece
SDT	Short Dry Ton
ST	Short Ton
TrOz	Troy Ounce

APPENDIX B

ORGANIC SOURCE MATERIALS -- PETROCHEMICALS

1. CRITICAL AND STRATEGIC ASPECTS

Chemicals derived from petroleum are required in almost every manufactured item of commerce that is organic in its primary composition. The few exceptions are those formed directly from wood or other cellulosic substances such as natural fibers and even in these cases, synthetics usually are required for surface treatments or as binders and assistants in fabrication. Petrochemicals, as classified here, are those nonmetallic compounds of which the raw materials derive directly or via antecedent reactions from crude oil.

There is an absolute dependence upon petrochemicals as primary raw materials in the following categories of manufactured commodities which represent necessities in the areas of health, clothing, housing, food, drugs, construction, transportation, corrosion/decay prevention, weed/pest control:

- Synthetic Rubber
- Agricultural Fertilizers (ammonia, nitrates, urea)
- Biocides (insect control, germicides, herbicides, mildew proofing)
- Pharmaceuticals
- Synthetic Fibers
- Film (photographic, packaging, protective)
- Coatings (paints for corrosion protection, decoration, safety coding)
- Molded Plastics
- Explosives
- Reinforced Plastics
- Lubricants (additives to motor oils, greases)
- Adhesives

- Foodstuffs (preservatives, texture regulators)
- Cosmetics (camouflage)
- Drugs ("medicine cabinet items")
- Dyes and Pigments

The strategic aspects are equated readily with the critical since chemicals derived from petroleum are necessary to support life, health, shelter, and comfort. With respect to specific strategic needs, the obvious chemicals are benzene, toluene, and pentaerythritol, which in nitrated form are explosives. Ammonia is a petrochemical as is its derivative nitric acid.

2. PRESENT USE

The production of petrochemicals consumes (as raw material feedstock) 5 percent of the total crude oil presently processed to produce motor fuel/lubricants, heavy oils for thermal energy to stationary boilers and power plants, plus all other uses.*

3. PROJECTED USE

The projected usages of petrochemicals are considered to be identical to present uses and the amount required can be equated to population growth. Requirements for strategic purposes may include the nitration products of certain aromatic hydrocarbons, jet fuel, and rocket propellants -- the identity of which are not public knowledge.

4. CURRENT STARTING MATERIALS (SUPPLY AND SUBSTITUTES)

a. Current Supply

No systematic stockpile of petrochemicals exists except for the national inventory, which is normally in transit between manufacture and bulk storage. The U.S. Department of Commerce is the source of information on specific products at any given time.

---

* For details concerning annual production of petrochemicals see Tariff Commission Reports -- Department of Commerce; also, interim survey analyses (Magnusson, 1974; U.S. Department of Commerce, 1975).

b. Future Supply

Because of the large numbers of organic petrochemicals and product formulations therefrom, any statement of future supply would require a detailed study of inventories and end use fluctuations. Obviously, future supply is related to the flow of crude oil to refineries and the plant capacity to convert petrochemical feed-stock hydrocarbons to the appropriate derivatives on demand. Since it is acknowledged generally that a certain substantial ratio of crude requirement is to be imported, there is a direct relevance to the constancy and interruption frequency of such imports.

c. Substitution

It is unreasonable and unrealistic to assume that within a 10-year period substitutes can be found for more than a small portion of the many petrochemicals now necessary in critical and/or strategic end use applications. It also is unrealistic to consider stockpiling the essential hydrocarbon gases (methane, ethane, propane, and butanes).*

The critical concern is the availability of large volumes of the four gases for petrochemical conversion in the event of crude oil curtailment from foreign sources. To counter this exigency it has been proposed to produce motor and thermal fuels from coal. This assumes that at least one of the alternative processes of coal-to-fuel conversion now in pilot scale-up will provide the requisite hydrocarbons.

In coal liquifaction, five basic methods currently are undergoing pilot scale tests: pyrolysis, catalytic cracking, hydroreforming, solvent extraction, and Fischer-Tropsch processing. The critical uncertainties under intensive study are the choice and optimization of catalysts, the materials of plant construction, and the problems of separating ash, as well as desulfurization plus numerous other confounding details that are set aside pending the determination of yields and quality of basic fuels.

Unfortunately, the yields of low carbon number hydrocarbons are considerably less than those from present petroleum (crude oil) processing, since coal is a highly aromatic, hydrogen-poor raw material from which aliphatic and naphthenic hydrocarbons are not directly derivable by pyrolytic and catalytic-pyrolytic processing. To supply the appropriate hydrocarbons at

---

* Three of these gases could be pressurized in abandoned mines; the fourth can be stored in tanks at low pressure. The enormous cubic capacity necessary to store even a two-month supply of low-density hydrocarbons is unavailable, and furthermore, the presence domestically of low-carbon-number hydrocarbons in the earth now constitutes an effective stockpile, free of storage cost and inconvenience.

current ratio of use and demand would require lengthy research which, if successful, would be followed by construction of the usual pilot and commercial coal-oil processing plants. The commercial production of commonplace petrochemicals derived from coal is not predictable.

It can be assumed that, by extension through research, the Fischer-Tropsch process can provide methane, ethane, and propane; however, important questions of yields and thermal efficiency must be resolved before considering the costs and capital needs in constructing new plants for this primary purpose.

5. CONCLUSION AND RECOMMENDATION

Based on its study and assessment of the situation, the Committee has concluded that traditional hydrocarbon feedstock derivatives cannot be produced from coal in the near term and are not predictable in the next 10-year period. In view of this, the Committee recommends that if petroleum products are allocated, consideration should be given to petrochemicals (that currently use 5 percent of crude oil production).

REFERENCES AND BIBLIOGRAPHY

Alverson, L.J. "Rhenium." In Minerals Yearbook. Washington, D.C.: U.S. Bureau of Mines, 1973.*

________. "Rhenium in 1974." Mineral Industry Surveys. Washington, D.C.: U.S. Bureau of Mines, December 1974.

________. "Rhenium." In Mineral Facts and Problems. Preprint from USBM Bulletin 667, pp 361-68. Washington, D.C.: U.S. Bureau of Mines, 1975.*

American Metal Market. Metal Statistics 1975. New York: Fairchild Publications, Inc., 1975.

Ampian, S.G. "Zirconium and Hafnium." In Mineral Facts and Problems. Preprint from USBM Bulletin 667. Washington, D.C.: U.S. Bureau of Mines, 1976.*

Butterman, W.C. (Division of Nonferrous Metals, U.S. Bureau of Mines). Personal Communication, January 12, 1976.

Corcy, R.C.; Myers, J.W.; Gibson, F.H.; and Calbassani, P.J. Occurrence and Determination of Germanium in Coal Ash from Power Plants. USBM Bulletin 575. Washington, D.C.: U.S. Bureau of Mines, 1959.

Darling, A.S. "Some Properties and Applications of the Platinum-Group Metals." International Metallurgical Reviews 18(1973): 91-122.

Federal Power Commission. Federal Power Survey, Vol. 1, pp. 1-18. Washington, D.C.: Federal Power Commission, 1970.

---

* Available from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

Federal Preparedness Agency. Stockpile Report to the Congress: January-June 1975. Washington, D.C.: General Services Administration, 1975.

Klemic, H. "Zirconium and Hafnium Minerals." In Industrial Minerals and Rocks, pp. 1275-83. New York: AIME Society of Mining Engineers, 1975.

Klemic, H.; Gottfried, D.; Cooper, M.; and Marsh, S. "Zirconium and Hafnium." In United States Mineral Resources. USGS Professional Paper 820, pp. 713-22. Washington, D.C.: U.S. Geological Survey, 1973.*

Klemic, H.; Marsh, S.; and Cooper, M. "Titanium." In United States Mineral Resources. USGS Professional Paper 820, pp. 653-65. Washington, D.C.: U.S. Geological Survey, 1973.*

King, R.U. "Rhenium." In United States Mineral Resources. USGS Professional Paper 820, pp. 557-9. Washington, D.C.: U.S. Geological Survey, 1973.*

Magnusson, F. "Raw Materials for Industrial Organic Chemicals." Washington, D.C.: U.S. Department of Commerce (Materials Division, Chemicals and Rubber Program), August 1974.

National Materials Advisory Board. Trends in Usage of Rhenium. Report No. MAB-251. Washington, D.C.: National Academy of Sciences, 1968.**

_______. Trends in Usage of Chromium. Report No. NMAB-256. Washington, D.C.: National Academy of Sciences, 1970.**

Newcomb, R.T.; Paik, S.; and Lariccia, V. "Forecasting Capital and Investment Formation in the U.S. Coal Industry." Proceedings of the Council of Economics, pp. 206-16. New York: American Institute of Mining, Metallurgical and Petroleum Engineers, 1975.

Reno, H.T. "Zirconium and Hafnium." In Mineral Facts and Problems, pp. 1005-9. Washington, D.C.: U.S. Bureau of Mines, 1956.*

Shimamoto, K. Availability of Rhenium in the United States. Information Circular 8573. Washington, D.C.: U.S. Bureau of Mines, 1973.

---

* Available from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

** Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

Stamper, J.W., and Chin, E. "Zirconium." In *Mineral Facts and Problems*, pp. 825-35. Washington, D.C.: U.S. Bureau of Mines, 1970.

Thomas, D.E., and Hayes, E.T. *Metallurgy of Hafnium*, p. 213. Washington, D.C.: U.S. Atomic Energy Commission, May 1960.

U.S. Bureau of Census. *Foreign Trade: U.S. Imports for Consumption and General Imports (by TSUSA, Commodity and Country)*. Annual Report No. FT 246. Washington, D.C.: U.S. Bureau of Census, 1971, 1972, 1973, 1974, 1975.

U.S. Bureau of Mines. *Mineral Facts and Problems*. USBM Bulletin 667. Washington, D. C.: U. S. Bureau of Mines, 1975 (preprint).*

________. *Mineral Industry Surveys*. Washington, D.C.: U.S. Bureau of Mines, 1975, 1976.

________. *Mineral Industry Surveys, Platinum-Group Metals, Quarterly*. Washington, D.C.: U.S. Bureau of Mines, June 1975, September 1975, and November 1975.

________. *Minerals in the U.S. Economy: Ten Year Supply-Demand Profiles for Mineral and Fuel Commodities (1965-1974)*. Washington, D.C.: U.S. Bureau of Mines, 1975.

________. *Minerals Yearbook*. Washington, D.C.: U.S. Bureau of Mines, 1972, 1973, 1974 (preprint).*

U.S. Department of Commerce. "Selected Petrochemicals Supply Situation as of June 30, 1975," Appendix B. Washington, D.C.: U.S. Department of Commerce (Chemicals and Rubber Program, Office of Business Research and Analysis), August 1975.

U.S. Geological Survey. *Demand and Supply of Nonfuel Materials for the United States Energy Industry, 1975-1990*, parts A and B, pp. A17 and B3. Washington, D.C.: U.S. Geological Survey, 1976.

Weast, R.C., ed. *CRC Handbook of Chemistry and Physics*, 55th edition, section B, pp. 15-6 and 58. Cleveland, Ohio: The Chemical Rubber Company, 1975.

---

* Available from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

BIBLIOGRAPHIC DATA SHEET

1. Report No. NMAB-329

2.

3. Recipient's Accession No.

4. Title and Subtitle
Potentially Critical Materials

5. Report Date
1977

6.

7. Author(s)
Committee on Technical Aspects of Critical and Strategic Materials

8. Performing Organization Rept. No. NMAB-329

9. Performing Organization Name and Address
National Materials Advisory Board
Commission on Sociotechnical Systems
2101 Constitution Avenue, N.W., Washington, D.C. 20418

10. Project/Task/Work Unit No.

11. Contract/Grant No.
GS-OO-DS-(P)-94008

12. Sponsoring Organization Name and Address
General Services Administration, Washington, D.C.
U.S. Department of Commerce, Washington, D.C.
U.S. Bureau of Mines, Washington, D.C.

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstracts

Inorganic and organic source materials were reviewed in an attempt to identify materials of greatest potential criticality. While primary criticality was based upon short-term stockpiling needs, other aspects such as the impact of new energy developments, alternate sources, alternate materials or design, and conservation were considered. Surprisingly few additional materials could be identified clearly as being critical on a worldwide basis; however, after screening a broad spectrum of source materials, chromium, germanium, iridium, rhenium, vanadium, and zirconium and hafnium were identified for a more detailed examination. Of these commodities, chromium stands out in importance on the basis of criticality. The study emphasizes the importance of continual updating of need in the light of rapidly changing technology and abrupt changes in sources of supply.

17. Key Words and Document Analysis. 17a. Descriptors

Chromium
Critical Materials
Germanium
Hafnium
Iridium
Metallurgy
Organic Source Materials
Petrochemicals
Rhenium
Strategic Materials
Vanadium
Zirconium

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement
This report has been approved for public release and sale; its distribution is unlimited.

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page)
UNCLASSIFIED

21. No. of Pages
69

22. Price

FORM NTIS-35 (REV. 3-72)

THIS FORM MAY BE REPRODUCED

USCOMM-DC 14952-P72