Review of the Minerals and Materials Research Programs of the Bureau of Mines: Report (1984)

Pages
95

Size
7 x 10

ISBN
0309325536

Committee on Mineral Resource Technology; National Materials Advisory Board; Commission on Engineering and Technical Systems; National Research Council

NATIONAL RESEARCH COUNCIL
COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS

NATIONAL MATERIALS ADVISORY BOARD

The purpose of the National Materials Advisory Board is the advancement of materials science and engineering in the national interest.

5/83

A REVIEW OF THE MINERALS AND MATERIALS RESEARCH PROGRAMS OF THE BUREAU OF MINES

Report of the

Committee on Mineral Resources Technology

National Materials Advisory Board
Commission on Engineering and Technical Systems
National Research Council

Publication NMAB 410-3
National Academy Press
Washington, D.C.
1984

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.

The 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.

The National Research Council was established by the National Academy of Sciences in 1916 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 under the authority of its congressional charter of 1863, which established the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

This study by the National Materials Advisory Board was conducted under Contract J-0100106 with the Bureau of Mines of the U.S. Department of the Interior.

The report is for sale by the National Technical Information Service, Springfield, Virginia 22161.

Printed in the United States of America.

ABSTRACT

In an ongoing review of the minerals and materials research programs of the Bureau of Mines, the NMAB Committee on Mineral Resources Technology has performed both an overall review of the Bureau's programs and in-depth evaluations of two program areas, minerals thermochemistry and materials substitutes. Separate reports of the latter two have already been issued and only summaries are presented here. Brief discussions are also included of the new programmatic decision-making process of the Bureau and the closely related but much smaller program of the NSF on minerals and processing materials.

In response to the question of how Bureau programs could more directly and adequately help to meet the continuing concerns of the U.S. minerals industry in the minerals and materials research area, several mechanisms have been proposed, including the establishment of permanent advisory committees, initiation of frequent workshops, broadening of Bureau contacts with the industry, annual assessments, periodic program presentations, expanded cooperative agreements, and a consideration of coordination of research support by the Bureau, NSF, and industry. These suggested mechanisms may require a broadening of the function of the Bureau, and a reexamination of the enabling legislation may be necessary.

PREFACE

In 1980, at the request of the Bureau of Mines of the U.S. Department of the Interior, the National Materials Advisory Board established the Committee on Mineral Resources Technology to assess the Bureau's mineral resources technology program. The committee's general objective has been to provide an ongoing overview and assessment of the materials aspects of the Bureau's program, identify gaps, and suggest opportunities for making the program as effective and responsive as possible to national needs.

The committee presented an initial report of its assessment in 1982 in "Assessment of Mineral Resources Technology Program of the U.S. Bureau of Mines" (NMAB-399). In a subsequent phase of its work, the committee has pursued in greater depth selected portions of the in-house and contracted research programs of the Bureau, particularly those of the minerals and materials research directorate in the areas of materials, with special attention to the efforts in minerals thermochemistry and materials substitutes. Separate reports have been published of these latter two evaluations of minerals thermochemistry (NMAB 410-1) and materials substitution (NMAB 410-2). This report, NMAB 410-3, represents the committee's overall views on the mineral resources technology effort. (As a result of a recent reorganization of the Bureau of Mines, the nonmining portion of the Mineral Resources Technology Program is now identified as the Minerals and Materials Research Program.)

This review speaks principally to the Bureau of Mines program in minerals and materials research, with a general awareness of related research being conducted elsewhere by industries and universities. However, beyond a special look at the newer, closely related but much smaller Minerals and Primary Materials Processing Program of the National Science Foundation, the committee has made no attempt to critically assess the sponsored programs of other agencies (such as the U.S. Department of Energy) in the minerals technology area.

During the course of the review by the Academy, concern was expressed over the precarious future of the U.S. minerals industry and the consequent implications for the technical program for the Bureau. The committee believes that there is need for stocktaking and possible changes in direction and emphasis, not only for the Bureau's programming but also for industrial and academic research.

The Bureau's Summary of 1982 Raw Nonfuel Mineral Production shows clearly the extent of the sharp decline in production that began in 1981 and continued more precipitously in 1982. The dollar value decline in 1982 of 21 percent compared to 1981 does not, however, show the even sharper volume declines in specific cases. For example, copper mine production was down nearly 30 percent for the year, with the mines operating at only 55 percent of capacity in late summer. The inflation-adjusted (real) price of copper was at its lowest levels since the 1930s.

Iron ore production in 1982, at 35 million tons, was 50 percent less than in 1981. Average use of steel plant capacity was less than 50 percent, compared with 78 percent in 1981, with imports making up over 19 percent of steel consumption in 1982 and nearly 18 percent in 1981.

Molybdenum production in 1982 declined 54 percent from that of the previous year, ilmenite production 49 percent, and tungsten 59 percent. Lead and zinc production, by contrast, did not follow the sharp downward trend in the other commodities, mostly because of the opening of two new zinc mines and fewer strikes in 1982 than 1981.

Among the major commodities in the nonmetallic field, clay output was down 18 percent, fluorspar 36 percent, phosphate rock 30 percent, potash 19 percent, sand and gravel 13 percent, and crushed stone 8 percent.

It may be argued that these figures are merely symptoms of the national and worldwide economic recession of 1981-1982, with current indications that this may have reached its low point and that a recovery is now in progress. However, there are longer term trends clearly indicating that for a number of major commodities there has been a leveling off and in some cases a decline in U.S. production. For example, domestic copper production, after reaching peaks in 1970 and 1974, appears to be declining. Domestic mine production of iron ore has been substantially flat since peaks in the 1950s near 70 million tons per year and with the average for the past 30 years in the range of 50 to 60 million tons per year. Domestic zinc production has been declining since the 1950s, and lead, after a large increase around 1970, has leveled off.

In the fertilizer field, while phosphate has shown a long-term continuing increase, potash production has declined slowly since 1966.

Underlying the downward trends have been the declining quality of domestic reserves, availability of higher quality foreign reserves, relatively higher U.S. labor costs, environmental regulations, and the growing need of many producing countries to obtain foreign exchange through commodity sales, regardless of market price or profit consideration.

This essentially profound change in the U.S. position with respect to a number of major mineral commodities raises a number of serious questions: (1) Should this country continue to deplete poorer reserves in competition with much higher grade reserves from abroad, such as copper from Chile, Zambia, and Zaire, and iron ore from Brazil and Australia? (2) Are there trade-offs involving lower grade, better technology, lower freight, and more readily available capital in the United States against the opposites for foreign producers? (3) Is there a need for U.S. government subsidy for strategic production reserves, and should a certain level of production of iron ore, copper, lead, zinc, and potash be considered strategic, regardless of economic consideration alone, as with commodities such as manganese, chromium, cobalt, nickel, and the like? (4) How, and to what extent, should the Bureau of Mines be involved in these considerations, either directly through its programs or indirectly by such things as the organization of and participation in conferences, surveys, and committee activities?

In response to these and similar _quo vadis_ type questions, the committee has proposed, in the final chapter, a number of possible mechanisms by which the Bureau of Mines might more directly and adequately help to ameliorate these continuing concerns of the U.S. minerals industry. These proposals apply to both the larger problem and the more specific concerns of minerals and materials research.

Finally, it is recognized that the effective control, utilization, and disposal of mineral process waste products is also a critical issue facing the nation. As such, it has significant impact on the economic viability and international competitiveness of many of the U.S. minerals and materials related industries. However, such serious environmental concerns, while of great importance, were deemed to be beyond the scope of the charge to the committee, and thus were not addressed in this review. Similar omissions will be noted in the area of recycling.

I would like to thank the members of the committee past and present; the members of the working groups for the two in-depth assessments; the staff; and the liaison representatives who have participated in this project. Our thanks are also extended to the directors and staffs of the several Bureau of Mines research center operations visited by representatives of the committee during the course of this study.

Nathaniel Arbiter
Chairman

COMMITTEE ON MINERAL RESOURCES TECHNOLOGY

Chairman

NATHANIEL ARBITER (Professor Emeritus, Columbia University), Consultant, Vail, Arizona

Members

DONALD D. DAHLSTROM, Envirotech Corporation, Salt Lake City, Utah

JOHN J. deBARBADILLO, INCO Alloy Products Research and Development, Suffern, New York

HAROLD E. GOELLER, Oak Ridge National Laboratory, Oak Ridge, Tennessee

JOHN C. HALL, Consultant, Freeport Mineral Company, New York, New York

HERBERT H. KELLOGG, Henry Krumb School of Mines, Columbia University, New York, New York

MILTON E. WADSWORTH, College of Mines and Mineral Industries, University of Utah, Salt Lake City, Utah

Technical Advisor

REINHARDT SCHUHMANN, JR., School of Materials Engineering, Purdue University, West Lafayette, Indiana

Liaison Representatives

WILLIAM L. MILLER, Bureau of Mines, U.S. Department of the Interior, Washington, D.C.

KENNETH W. MLYNARSKI, Bureau of Mines, U.S. Department of the Interior, Washington, D.C.

JAMES T. DUNHAM, Bureau of Mines, U.S. Department of the Interior, Washington, D.C.

RALPH C. KIRBY, Bureau of Mines, U.S. Department of the Interior, Washingon, D.C.

JEROME PERSH, Staff Specialist for Materials and Structures, Military Systems Technology, Office of the Under Secretary of Defense, Research and Engineering, Washington, D.C.

SAMUEL J. SCHNEIDER, JR., Center for Materials Sciences, National Bureau of Standards, U.S. Department of Commerce, Washington, D.C.

RICHARD SCHMIDT, Naval Air Systems Command, Washington, D.C.

ROBERT J. MROCZEK, Federal Emergency Management Agency, Washington, D.C.

LEONARD A. HARRIS, National Aeronautics and Space Administration, Washington, D.C.

TAPPAN MUKHERJEE, National Science Foundation, Washington, D.C.

ROBERT J. GOTTSCHALL, U.S. Department of Energy, Washington, D.C.

ROBERT REILEY, U.S. Department of Commerce, Washington, D.C.

Staff

RICHARD M. SPRIGGS, Staff Scientist

1

INTRODUCTION

The Committee on Mineral Resources Technology of the National Materials Advisory Board has been charged with providing an ongoing assessment of the mineral resources technology program of the Bureau of Mines, especially to identify gaps and to suggest opportunities to make the program as effective and responsive as possible to national needs.

In addition to providing an overall review of the program, the committee during 1982 was requested to assess selected portions of the program in depth. Assessments have thus been made of the Bureau's efforts in minerals thermochemistry and materials substitution. Separate reports have been issued for these, and only summaries are presented here. The present report also reiterates the original guidelines that were established by the committee to assist it in its review.

During the course of the present review, the Bureau of Mines underwent a reorganization that changed the scope of the projects under review, and that reorganization is outlined here. Project titles and brief descriptions of the currently active studies are included in Appendix A.

The committee also received presentations on programmatic decision-making in the Bureau and on a closely related but much smaller program of the National Science Foundation (NSF) on minerals and primary materials, and brief discussions of those are included. Some program overview comments are made on the various in-house and contracted projects of the Bureau in the minerals and materials research area.

It should be emphasized that it is not "business as usual" for the domestic mineral resources industry. Despite long-standing and close relationships between the Bureau and the various domestic minerals industries, domestic production of many mineral materials has been declining steadily. This decline has been accelerated by factors such as extensive depletion of domestic high-grade ores, high labor costs, strict environmental regulations, a slowing of industrial research, and more aggressive research and operations in foreign nations, many of whose governments extensively subsidize such efforts.

The Bureau's role in developing new processes, process equipment, and technical information is considered to be valid. In fact, the serious position in which the domestic minerals industry now finds itself virtually requires an active Bureau program designed both to develop new processes that utilize domestic resources and to provide a technological base for use in conjunction with national stockpile policies in the event of a long-term emergency.

2

GUIDELINES

The earlier report (NMAB-399, "Assessment of Minerals Resources Technology Program of the U.S. Bureau of Mines") presented a set of guidelines that were established by the committee to assist it in its review. Still relevant to the committee's task, these guidelines, in the form of a series of questions, are repeated here:

- Are long-range goals clearly identified?
- What criteria are used to establish these goals, and are the criteria suitable?
- What is the likelihood that the program will achieve the goals?
- Are the tasks identified in the program appropriate for federal study or support?
- Are there gaps or omissions in the program?
- What are the opportunities for R&D in the program areas?
- Does the program have the proper overall balance?

Additional questions addressed by the committee are:

- What problems face the mineral resources industry in terms of technology and research and development?
- What kind of R&D activities will most likely lead to solutions?
- What constituencies and facilities are best qualified and equipped to pursue solutions?
- In light of the present and projected state of the economy and the mineral resources industry, what should be the role of the government--especially through the Bureau of Mines--in sponsoring R&D in the area?

More generally, the committee hopes to be able to answer the question, "What should be the direction and scope of the Minerals and Materials Research Program of the Bureau of Mines to meet these goals and needs?"

The foregoing questions have been considered by the committee as it conducted its review and arrived at its conclusions and recommendations; however, explicit answers to each question have not been framed and reported for the various program areas.

3

BUREAU OF MINES REORGANIZATION

During the course of the present phase of this review and assessment, the Bureau of Mines underwent a reorganization (February 1, 1982). In addition to returning to line management from matrix management, the Minerals Resources Technology Program under study by the committee was reorganized into two separate directorates, each headed by an assistant director of the Bureau. These two units are Mining Research and Minerals and Materials Research. An organization chart, showing the reorganized structure (as of August 1983) is shown in Figure 3-1.

The thrust of the committee's review and assessment was changed at the time of the reorganization from minerals resources technology (which combined both mining and minerals and materials) to minerals and materials research. The minerals and materials research function of the Bureau involves "long-range, high-risk basic research as well as research aimed at more immediate application for strategic and critical mineral needs that together are concerned with the development and assessment of technological alternatives in mineral processing and related materials development to support the security and economic well being of the Nation with regard to mineral and mineral material processing, performance, utilization, and recycling" [Part 71, General Functions, Chapter 7, Minerals and Materials Research, Part 115, Bureau of Mines Organization, Department of the Interior Departmental Manual, #2385 dated February 3, 1982].

As shown in Figure 3-1, the Minerals and Materials Research directorate is supported by two staff divisions (Division of Extractive Metallurgy Technology and Division of Materials and Recycling Technology); the programs are carried out in the field at six principal research centers (Albany, Oregon; Avondale, Maryland; Rolla, Missouri; Salt Lake City, Utah; Tuscaloosa, Alabama; and Reno, Nevada), in one engineering laboratory (Boulder City, Nevada), and in the other research centers of the Bureau as may be required.

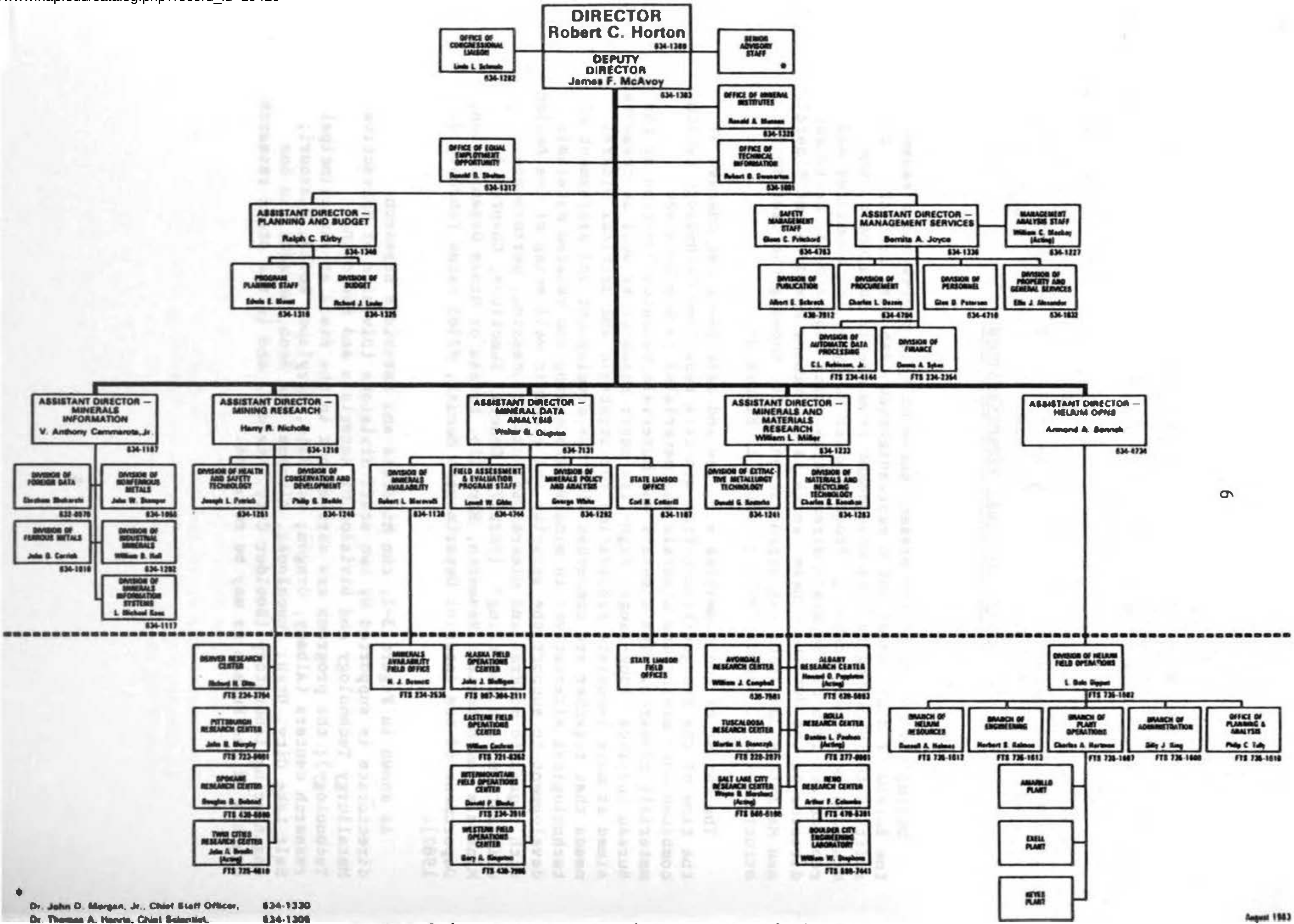

FIGURE 3-1: Organizational Structure of the Bureau of Mines, U.S. Department of the Interior

4

THE BUREAU'S MINERALS AND MATERIALS RESEARCH PROGRAM FOR FY 82 AND FY 83

As noted in the foregoing chapter, the minerals and materials research function of the Bureau of Mines involves long-range, high-risk research and development in the areas of the processing, use, and recycling and disposal of minerals and mineral products. It also includes concerns for critical and strategic material substitutes, reduction of adverse environmental effects, and improvement of material performance.

In the initial report of the committee, the 146 FY 81 research projects and subcontracts of the Bureau of Mines under the Mineral Resources Technology (MRT) Program of that time were listed and described (Appendix B of NMAB-399). In the intervening time, certain projects have been concluded, new ones have been added, and the Bureau has been reorganized, with the former MRT projects being divided into mining and nonmining (or minerals and materials research) sections. There are now 102 projects in the minerals and materials area currently under review, and these are listed and described in Appendix A, using project titles and/or descriptions for FY 82 and FY 83, along with the original listings for FY 81.

At the beginning of FY 81, the budget for the 146 projects amounted to $23.466 million, with other MRT funds raising the 1981 MRT total to $26.190 million. The budgets for those tasks now identified as Minerals and Materials Research are $29.660 million for FY 82 and $30.387 million for FY 83.

5

ASSESSMENTS AND OVERVIEWS

In the initial phase of the committee's effort (reported in NMAB-399), the committee assessed the program of the Minerals Resources Division (the predecessor of the Minerals and Materials Research Directorate) in basic research, electrometallurgy, hydrometallurgy, materials handling, pyrometallurgy, materials, and minerals processing. In its initial assessment, the committee also included visits to six of the Bureau of Mines research center operations involved in these programs.

In the present phase, the overall assessment has continued and is reported below. In addition, the remaining research centers were visited, and special in-depth assessments have been performed in the areas of minerals thermochemistry and materials substitutes. Separate reports have been published of these two evaluations (NMAB 410-1 and 410-2 for minerals thermochemistry and materials substitutes, respectively). A summary of the findings of these two special assessments follows.

SPECIAL IN-DEPTH ASSESSMENTS

Minerals Thermochemistry

Report NMAB 410-1 assessed the Bureau of Mines efforts in the area of minerals thermochemistry, based principally on findings from a visit to the Albany Research Center by a working group of the committee. After including comments on organization, budget, personnel, major experimental methods, data compilation and evaluation, equipment and facilities, and the utility of thermochemical data, the Bureau's program was evaluated through answers to a series of questions: Does a real need exist? Who are the users? Are the current approach and priorities responsive? Is the current level of effort appropriate? Could personnel be used to greater advantage elsewhere?

The committee concluded that the minerals thermochemistry program is an extremely valuable one that fills a special need and that the current approach and priorities are responsive to that need. A number of specific recommendations are made concerning the support of current research as well as expanding research beyond that being presently performed with pure substances.

More specifically, the committee was asked to evaluate the Bureau's thermochemical program with respect to four criteria, as follows:

1. The committee was asked whether a real need for the information generated by this research exists in the mineral community. Who are the users?

The users are industrial laboratories and process development teams, offices of design and construction, companies engaged in metallurgical projects, contract research organizations, and academic laboratories. Any researcher or laboratory called on to make the most basic evaluation of a metallurgical process--namely, a heat balance--must employ thermochemical data. In addition, more sophisticated metallurgical calculations that attempt to predict the chemical equilibria that determine the feasibility of an untried metallurgical process must use free-energy calculations.

The use of thermochemical calculations by all sectors of the metallurgical industry and academia is now so common as to be comparable to the use of computers. In fact, the use of computers and the use of thermochemical calculations have much in common. Both provide means to arrive at useful answers as quickly as possible. When combined--thermochemical calculations made with the aid of computer--they form a powerful team that has become a necessity for modern metallurgical and chemical process research and development.

The Bureau's work on thermochemistry fills the special need of providing data on important mineral and metallurgical materials. Other laboratories engaged in thermochemical research are mostly academic laboratories in departments of chemistry and metallurgy. Their choice of substances to study is dictated by goals of chemistry rather than practical metallurgical problems. As a result, they have little interest in mineral materials, and only a dedicated laboratory such as the Bureau's can be relied on to fill the gaps in knowledge of metallurgically important substances.

The Bureau is to be specially commended for recognizing the importance of thermochemistry as long ago as 1930. At that time, thermochemistry was in its infancy, and some legitimate doubts of its utility might have been raised. Today, all metallurgists recognize its importance, and its value will increase as the properties of more and more substances of metallurgical interest are determined.

2. The committee was asked, if such a need exists, whether the current approach and priorities are responsive to that need.

The Albany Research Center Laboratory, where this work is conducted, is probably the only one in the world that continuously produces such a wide spectrum of thermochemical measurements. No one of the experimental techniques used by the laboratory can be singled out as less important than the others. Each contributes vital data to the bank of thermochemical knowledge. The data evaluation and compilation work should perhaps be singled out as having special importance. That work deserves the effort of at least two full-time, experienced researchers; unfortunately, the department has recently lost one of its full-time staff by retirement. It should be brought back to a full complement as quickly as possible.

The Bureau's work is more valuable to some researchers than to others. For example, recent studies of the properties of $FeCl_3$ and $FeOCl_2$ should prove valuable for research on chlorination of ilmenite or ferric chloride leaching of copper concentrates, but other researchers may wish that the Bureau had studied the unknown properties of pentlandite [Ni(Fe)S] in order to better understand smelting of nickel concentrates. However, the Thermodynamics Group systematically maintains a list of "Compounds for Which Thermodynamic Data Are Needed" and sets priorities, taking into account potential applications of the data to problems in mineral extraction. The committee believes that, within the limitations of budget and personnel under which the thermochemistry program operates, the priorities assigned to the various projects properly reflect the needs of the metallurgical industry.

Another measure of the responsiveness of the program to need is the number of publications, which place new thermochemical data promptly into the hands of the users. Measured solely by number of publications per dollar funding, figures supplied to the committee indicated that the Thermodynamics Group generated at least 9 times as many publications per dollar as all the rest of the Bureau's field research activities.

3. The committee was asked whether the current level of effort is appropriate, in terms of both manpower and funding.

During the more than 50 years that the Bureau's thermochemical research program has operated, it has made landmark contributions that are cited and used throughout the world--in the chemical industry, the metallurgical industry, and academia. Probably no other Bureau research can rival that of thermochemistry in value generated per dollar spent, in the permanency of that value, and in the recognition it has brought to the Bureau's work.

Thermochemical research is no longer fashionable in academic departments of chemistry. It is viewed as routine and painstaking application of known methods of measurement and not attractive for most graduate research. A few academic metallurgy or chemistry departments engage in thermochemical studies, but their numbers are small and their budgets severely limited. As a result, the output of new thermochemical data from academia is quite limited. Industrial laboratories, with one or two exceptions like Dow Chemical Company and U.S. Steel Company, seldom engage in thermochemical research; the metallurgical industry has always looked to government and academic laboratories for basic thermochemical data.

The committee's familiarity with the thermochemical work of other laboratories in government (U.S. Geological Survey, National Bureau of Standards, other agencies), industry, or academia is general rather than specific in nature. There are indications, however, that a study should be made on an international scale and that such a study could conceivably reveal deficiencies that should be rectified by expansion of thermochemical research funding by the Bureau of Mines, other government agencies, or by government funding of academic research. In any event, such a study would provide a better basis for decisions on what changes in the level of effort are needed.

Bureau research should be expanded on a modest scale by providing several new personnel and the corresponding budget to conduct the types of measurement and data evaluation currently performed at Albany. The committee reiterates its belief that strengthening the effort on data evaluation should be given top priority. It is important for all the specialized areas of thermochemical research to hire and train new scientists so that the program will not suffer major disruption with the retirement or loss of a single key individual. Another manpower need to be considered is the strengthening of the metallurgical and mineral technology component of the staff to broaden the present strong chemical orientation.

A vigorous case can be made, in addition, for a significant increase in thermochemical funding to expand thermochemical research beyond the limitations of current Bureau studies. Most current Bureau research is limited to determinations of the properties of pure substances, usually stoichiometric compounds. Although this information is of vital importance, it goes only part way toward thermochemical description of the phases encountered in practical metallurgy--the slags, mattes, molten salts, alloys, and concentrated aqueous solutions. The thermochemical behavior of these complex solution phases requires special measurement techniques and painstaking data evaluation. With the exception of the recent Bureau work on measurement of activity in concentrated aqueous solutions, and the newly initiated studies of phase equilibria in the systems Al-C-Si and Al-O-C-Si, this vital area has been neglected by Bureau research. With its present budget limitation, the Bureau laboratory could engage in these new areas only at the expense of its current work; the committee doubts the wisdom of that course. With a significantly increased budget, however, the Bureau should expand into this new area.

4. The committee was asked <u>whether the personnel with the training and skills of those assigned to this research could be used to greater advantage in pursuit of other research objectives</u>.

As should be obvious from its response to the first three items in this evaluation, the committee believes that the personnel are properly assigned and that their capabilities are being effectively used.

Materials Substitutes

Report NMAB 410-2 presents assessments of efforts of the Bureau in two areas: alloy substitutes research, which deals with the substitution of plentiful domestic metals for imported strategic or critical metals, and minerals substitutes research, which deals with the development of strategic or critical mineral supplies from nontraditional domestic sources. These assessments are based principally on the findings from visits of committee members to the Albany, Rolla, and Salt Lake City research centers and on discussions between the working group and other committee members who had visited various research centers during the course of the committee study.*

Alloy Substitutes Research

The alloy substitutes work (see Table 5-1 for a listing by title and research center) represents a greatly augmented and expanded effort for the Bureau. Since much of this work had only recently been reprogrammed in response to the National Materials and Minerals Policy, Research, and Development Act of 1980, the committee felt a detailed project-by-project critique would be premature. Rather, general observations are presented concerning such things as a comprehensive strategy for substitution research; alloy development as a traditional industrial forte; long-run, high-risk project support; and cooperative agreements between the Bureau and nongovernmental organizations. Specific recommendations are made concerning the need for establishing clearly defined goals; identifying equipment and manpower needs; determining optimum levels of support; redirecting programs to more long-range activities; continuing contract research; expanding cooperative agreements; continuing joint sponsorship of symposia and workshops; increasing expertise in alloy development; and concentrating alloy substitution work at a single research center.

The following observations were made concerning alloy substitutes research, with the suggestion that they be addressed before the Bureau invests much more time and money in the program.

1. At the time of the assessment the Bureau had not yet developed a comprehensive strategy for alloy substitution research. The current program at that time was clearly a "grass roots" response to a fairly vague and broad directive, and the direction and probable results of some projects may not be consistent with the goal of reducing requirements for critical elements.

*As was noted in NMAB 410-2, several months elapsed between completion of the on-site assessment and publication of the report. In the intervening period, the Bureau implemented a number of changes anticipated by the recommendations of the report and the on-site discussions held between committee members and Bureau staff.

TABLE 5-1. Alloy Substitution Research Projects

BuMines Code	Title	Research Center
Phenomenological or Long-Range Alloy Development Projects		
S-82-MR-11	Wear of mining equipment	Spokane
Av-82-MR-11	Applied corrosion research	Avondale
RO-82-MR-15	Alloys to resist hydrogen embrittlement	Rolla
Alloy Substitution Projects		
AL-82-MR-19	Substitutes for critical materials in mining and processing equipment	Albany
AL-82-MR-16	Chromium-free and low-chromium alloys as substitutes for stainless steels	Albany
AL-82-MR-22	Dispersion-strengthened alloys to reduce critical materials needs	Albany
AL-82-MR-17	Substitutes for cobalt in cemented carbides and tool steels	Albany
RE-82-MR-15	Cobalt substitutes in permanent magnets	Reno
J0188167	Development of chromium-free constructional alloy steels	Contract
J0295073	Chromium substitution in stainless steels	Contract
J0295073	Potential for development of manganese-base alloys as substitutes for chromium-bearing alloys	Contract
J0113104	Development of chromium-free construction alloys steels	Contract
Unique Structures and Composites		
AL-82-MR-18	Wear-resistant materials for mining and mineral processing equipment	Albany
AL-82-MR-24	Surface alloying of iron-base castings	Albany
RO-82-MR-13	Chemical-vapor-deposited coatings for valve components	Rolla
RO-82-MR-12	Hard surfacing of steels	Rolla
AV-82-MR-12	Surface nitriding for corrosion protection of pump and valve components	Avondale
RO-82-MR-11	Improved soldering and brazing systems	Rolla
Miscellaneous Projects		
SL-82-MR-15	Vapor-phase productions of titanium alloy powder	Salt Lake
AL-82-MR-15	Improved titanium components through innovative processing technology	Albany

2. Alloy development has generally been the traditional forte of the industrial research community and, to a lesser extent, the national laboratories. Despite the current economic climate and widespread staff reductions at many industrial research facilities, an enormous amount of this type of work continues. Industrial firms most generally are better able to identify problems or opportunities for new alloys and are more capable of commercializing their work directly. The institutional isolation of the Bureau laboratories from the marketplace could prove to be a major disadvantage.

3. Since both industrial and national laboratories have been active in alloy development for many years, they possess a vast body of experience, equipment, and proprietary information. The cost of duplicating even a part of these technical and intellectual assets may be beyond the resources of the Bureau of Mines. Through appropriate contract funding (as exemplified by its contract with the International Harvester Company), the Bureau could gain direct access to some of these facilities and knowledge; if it does not do so, pertinent information on alloy development is likely to be incomplete and outdated when available at all.

4. Many believe that government involvement in any research should be restricted to supporting very long-range, high-risk projects (e.g., developing technology to extract minerals from domestic, low-grade, unconventional deposits) and to addressing national problems for which private-sector economic incentives are lacking (e.g., finding substitutes for chrominum in iron and steel). The Bureau's current alloy substitution program includes projects in areas already being addressed by industry. This is especially true in the coatings, claddings, and composites field, and continuation of the Bureau's applied research and development projects in this area should be reviewed very carefully for any duplication.

5. The Bureau has established an extensive series of cooperative agreements with industrial firms, trade associations, and other government agencies. For the most part, these agreements are in the traditional spheres of the Bureau's activities. However, it has moved to establish new agreements in the alloy development field. In particular, the Bureau has developed ties with the American Society for Metals, with which it cosponsored a symposium at Vanderbilt University in 1982. It is essential that these ties be extended and strengthened so that the Bureau's activities will have the visibility necessary to stimulate the needed technical input from industry. The effectiveness of such interaction would be further enhanced if it were directed by someone with considerable experience in industrial (or academic) alloy research and market development.

Thus, the committee makes the following recommendations in the area of alloy substitutes:

1. The Bureau's Washington staff should establish clearly defined goals for the alloy substitution research. Specific implementation strategies based on these goals can then be developed. The foregoing should take into consideration the major substitutions programs of other organizations and agencies.

2. Equipment and manpower requirements for the next 5 years should be determined. The resources likely to be available to the Bureau must be reconciled with what is needed to do the job.

3. The level of funding required to support successful research in specific selected areas should be determined. The needs of the industries most familiar to the Bureau should be emphasized. The resources (equipment, personnel, etc.) needed for specific projects will vary, but current funding levels for individual projects appear to be inadequate.

4. A permanent, independent oversight committee to advise the Bureau on the currency and pertinency of its alloy research, and composed of representatives from industry and academia who are experienced in the alloy development field, should be established.

5. Consistent with federal directives and guidelines for research, the alloy substitution program should be redirected to focus on long-range activities. Work should be aimed at identifying broad alloy responses to industrially important environmental conditions. The specification of optimum alloy should be left to industry.

6. Consistent with overall funding and staff levels within the Bureau, contract research at industrial facilities with extensive capabilities in specific alloy fields should be continued.

7. Cooperative agreements with appropriate societies and industrial groups should be strengthened and expanded to provide for program visibility and to generate private-sector input.

8. The various activities of the Bureau and its personnel in areas such as joint sponsorship of symposia and workshops, committee participation, and publication of reviews and data sheets, which have been effective in the past, should be continued.

9. The Bureau should increase its expertise in physical metallurgy and alloy development. This should include the hiring of personnel with industrial experience.

10. Alloy substitution work should be concentrated at one research center to facilitate project management, staff interaction, and efficient utilization of equipment. The research center at Albany appears to be the most logical choice.

Minerals Substitutes Research

Substitute raw materials research and development (see Table 5-2 for a listing by title and research center) is a traditional Bureau pursuit. Given the poor economic condition of the domestic mining, milling, and ore processing industries, it is noted that the Bureau must continue to expand its efforts in this area if the nation is to reduce imports of critical and strategic materials and remain competitive in world markets. There has been an overemphasis (already recognized by the Bureau) on the development of nonbauxitic processes for recovering aluminum from domestic nonconventional resources, and it is recommended that the scale of these efforts be reduced and that emphasis be placed on chromium, nickel, cobalt, manganese, and the platinum-group metals. Also recommended are increased Bureau efforts concerning improved recovery of nonferrous metal by-product elements (especially in _in situ_ leaching), potential recovery of additional elements from seafloor nodules, alternative potash resources, improved recovery of phosphorous pentoxide from phosphate rock, and recovery of additional materials from solar salt bitterns. It also is noted that many of the issues affecting increasing imports are institutional rather than technical and it therefore may be important for the Bureau to provide for deeper consideration of such issues.

More specifically, the committee makes the following general observations:

1. The current list of projects in the raw materials part of the Bureau's program for substitutes for critical and strategic minerals appears incomplete since many of the Bureau's other process development activities fall well within the definition of substitutes. The present list appears to overemphasize alumina, but this would not be so if these other projects were included. It is suggested that a further subdivision into processes for low-grade conventional ores and processes for alternative unconventional resources may be helpful, since work in the former area focuses largely on existing-process improvements and in the latter area, mainly on the development of new processes.

2. Using this expanded definition, the Bureau's projects appear to represent a reasonably balanced effort among the various critical and strategic minerals and between industry needs and governmental strategic concerns. The committee agrees with the Bureau's recent deemphasis of its efforts on alumina and suggests that the manpower and funds freed up by such deemphasis be redirected to increased efforts on the "ultramafic" metals (chromium, nickel, cobalt, and the platinum metals) and significantly increased activity on manganese, which is an indispensible ingredient in steelmaking. The bulk of resources and production of most of these elements is in southern Africa and the Soviet Union, both potentially unreliable import sources.

TABLE 5-2. Raw Materials Substitution Research

BuMines Code	Title	Research Center
Aluminum		
BC-82-MR-3	Extraction of alumina from clay using hydrochloric acid leaching	Boulder City
RE-82-MR-12	Bleedstream treatment and aluminum chloride hexahydrate dissolver design	Reno
RE-82-MR-13	Extraction of alumina from clay by new, improved leaching techniques	Reno
RE-82-MR-14	Extraction of alumina from anorthosite using hydrochlorite acid leaching	Reno
BC-82-MR-5	Recovery of alumina from coal ash and coal shale	Boulder City
J0215022-RE	Extraction of alumina from anthracite culm with energy recovery	Reno/Energy
AL-82-MR-14	Carbochlorination of domestic clay	Albany
J0199151-AL	Mass spectrometric study of vapor-transport reactions in carbochlorination of clay	Albany/Colorado School of Mines
Nickel, Cobalt, and Platinum-Group Metals		
TC-82-MR-23	Recovery of platinum-group metals, cobalt, and nickel from Duluth Gabbro	Twin Cities
SL-82-MR-14	Separation and recovery of cobalt from hydrometallurgy solutions by ion exchange	Salt Lake

3. Since the plight of the domestic minerals industry has considerably worsened since the committee's overall review in 1981 (NMAB-399), it heartily re-endorses its suggestion that the Bureau's efforts on new process development be significantly expanded. In particular, since many of the minerals companies have reduced their research staffs, this would be an excellent time for the Bureau to augment its professional staff with well-trained scientists and engineers if manpower ceilings could be lifted.

4. It will be very difficult to improve existing processes or to develop new ones that can compete economically with imports of many materials because foreign resources now are generally better and richer, foreign technology and facilities are often superior, labor costs are lower, and environmental regulations are less severe. Thus, process developments would have to be supplemented with economic incentives for industry, such as easier tax write-offs. In addition, improved self-sufficiency should depend on greater attention to strategic considerations by government, since economic forces alone will result only in increasing imports. Despite these problems, an active research program by the Bureau is imperative to keep such problems from becoming even worse.

5. Some increase in basic research efforts appears warranted under the long-range, high-risk process selection criteria because this is probably the best way for the United States to make quantum leaps in technology a decade or more away and to stay in competition with other nations. This type of effort (e.g., thermochemistry at Albany) can be done in-house where personnel and facilities are available and adequate, but much of it should be subcontracted to universities, where many of the latest scientific discoveries and innovations are being made.

6. At the other end of the process development spectrum, the Bureau, in cooperation with the national laboratories, could consider becoming involved to a greater extent in the pilot-plant testing of new processes. Given the current economic condition of the mineral industries, it is becoming increasingly less likely that industry will undertake such work. Thus, if it is to be done at all, the Bureau must take the lead. It is hard to sell new processes without a pilot-plant demonstration.

7. The committee was briefed by the Washington staff of the Bureau on a new programmatic decision-making process that includes a new method of selecting projects for study. This method appears quite superior to older ones, but only time and experience will really prove its worth. It has many commonalities with Delphi processes that have been quite successful in addressing and evaluating other types of activities.

The final section of the report on materials substitutes listed several specific examples of areas in which the Bureau might change the direction of existing programs and/or undertake new initiatives in the development of processes for domestic raw materials, in order to increase self-sufficiency in nonrenewable materials by reducing imports. The committee recommended the following actions in this area:

1. As noted earlier, the Bureau is now phasing out much of its work on nonbauxitic raw materials as domestic sources of aluminum. Consideration should be given to initiating a limited effort on the basic chemistry of the Al-Si-Fe-(O) system that later would be applicable to any of the alternative resources.

2. Seafloor manganese nodules represent a large potential source of several elements; their exploitation awaits the development of economical mining methods. The industry's chief concern with these nodules is as a resource of copper, nickel, and cobalt. Since this resource also contains very large amounts of manganese, significant quantities of iron, lead, and zinc, and lesser amounts of other elements, the Bureau should consider any necessary research and development techniques for recovering these additional metals as a means of lowering the cost of recovery of all products and coproducts. (It is also significant that the bulk of world manganese resources are in the Soviet Union and South Africa.)

3. Efforts on the "ultramafic" elements (Cr, Ni, Co, Pt) are devoted to the use of West Coast lateritic deposits, the Stillwater complex in Montana, the Duluth gabbros, and several Alaskan resources. Such efforts should be given high priority, culminating in appropriate exploratory research on the most promising of the common ultramafic rocks that are abundant in both the western coastal ranges and the Appalachians. This is a long-range, high-risk opportunity with an enormous payoff if successful.

4. The nation's potash resources, which are essential to agriculture, are only moderate. A future resource is in solar salt bitterns, but this resource falls far short of meeting domestic demands. There are large potassium resources in leucite and enormous ones in potassium feldspars that the Bureau might evaluate. The latter is also a potential source of aluminum.

5. As much as one-third of the P_2O_5 content of phosphate rock is lost during the production of phosphatic fertilizers. In view of the fact that phosphate is an absolutely necessary, nonsubstitutable material for agriculture, and although the United States currently exports phosphate, the Bureau should examine means of significantly increasing yields. Florida phosphate rock also contains significant quantities of heavy minerals (ilmenite, rutile, zircon, monazite, sillimanite, etc.) that are now discarded, and their recovery is also an area that the Bureau might examine.

6. By-product elements, mainly of the nonferrous metals, will seldom be recovered in their own right. The Bureau should intensify its efforts leading to maximizing their recovery, especially by *in situ* leaching, which is becoming a major mining method. Very large future demands for

these elements are likely to develop. Examples include large future requirements for selenium as a trace metal additive in agriculture, and gallium arsenide as photoelectric devices in solar power satellites and as semiconductors in very-high-speed computers. The Bureau, in conjunction with other agencies such as the Federal Emergency Management Agency (FEMA), should also evaluate the possibility and cost of establishing an economic stockpile of such elements; estimates indicate that, excluding the precious metals, the cost would be no more than a few percent of the value of the base metals.

7. Solar salt bitterns also appear to be a potential resource for boron, lithium, strontium, rubidium, and iodine. The Bureau should evaluate the recovery of multiple products from this source, especially since imports account for 100 percent of strontium demand and 90 percent of iodine needs.

PROGRAMMATIC DECISION-MAKING IN THE MINERALS AND MATERIALS RESEARCH DIRECTORATE

As part of a consideration of the issues of project selection, rejection, review, and determination, the committee received a Bureau presentation on "Programmatic Decision-Making--Minerals Research." Details were provided for the new planning and budgeting process for FY 84 within the Minerals and Materials Research Directorate, as an illustration of the Bureau's programmatic activities. Figure 5-1 shows, for example, how current research projects planned for continuation and new research proposals were integrated to form the preliminary FY 84 program.

The initial step is an assessment of current FY 82 projects to determine which would continue as part of the FY 84 base program. This determination was based on two factors: (1) how effectively the project is being performed, and (2) the relationship of the project to policies, goals, and objectives of the Bureau.

The second step is an evaluation for selection of new research proposals that have been developed by the research centers in response to problem areas identified as part of the Bureau's long-range program planning process. Those deemed acceptable for inclusion formed an idea pool that is to be used by the Washington staff in developing subprogram element objectives and for allocating resources available after development of the base program.

Figure 5-2 shows in additional detail the evaluation-for-selection procedure. In this process, proposals that have been prepared as proposed solutions to specific problems are catalogued and placed into a word-processing system upon receipt. A screening committee comprised of senior headquarters staff and managers meets monthly to evaluate these proposals for their relevance to, and impact on, Bureau and programmatic goals and objectives. Proposals failing this screening are returned promptly to the research centers with an explanation.

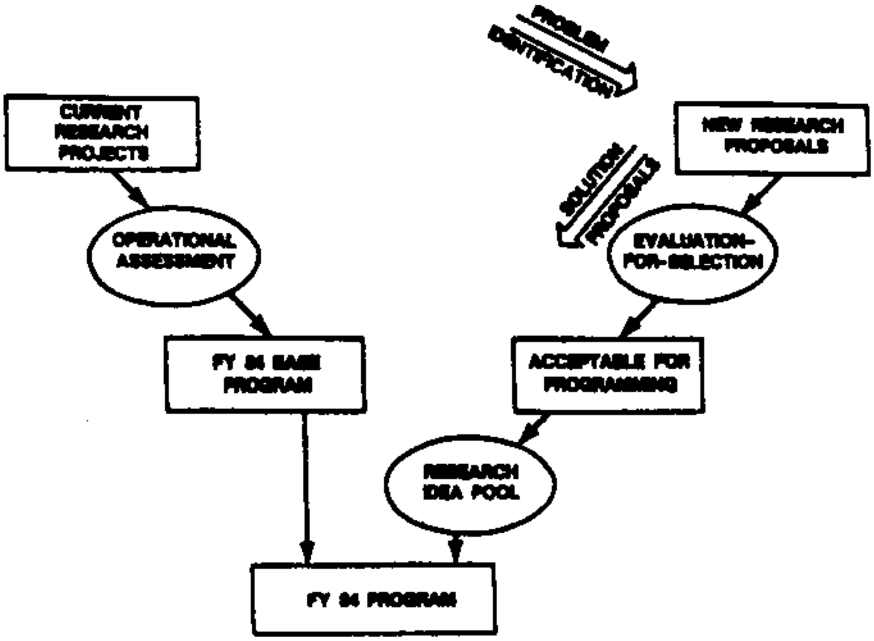

FIGURE 5-1: Programmatic Decision-Making: Program Development

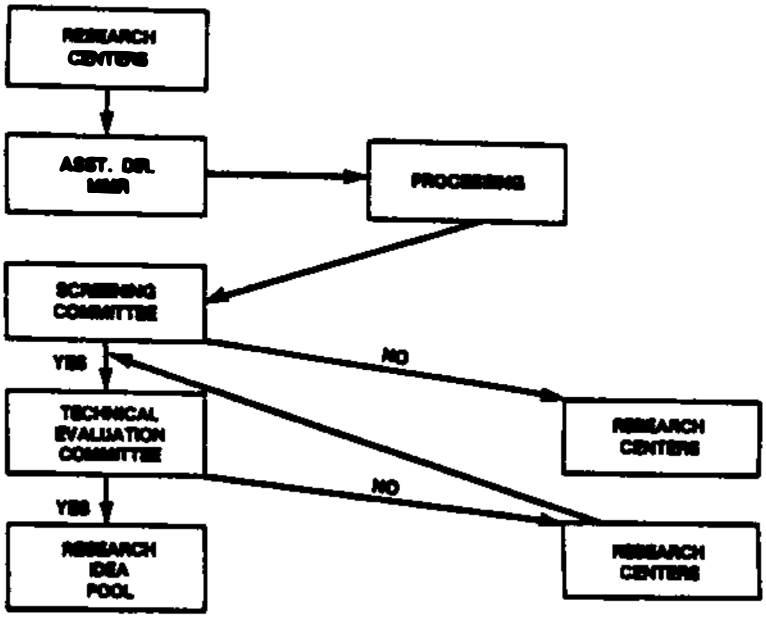

FIGURE 5-2: Programmatic Decision-Making: Research Proposals

Those passing the screening are subsequently evaluated by a technical evaluation committee that meets quarterly. Projects ranking in the top 20 percent by this evaluation are placed in a research idea pool as candidates for future programming. Those ranking below 20 percent are returned to the research centers. The centers have the option, at this stage, to rethink, rewrite, and resubmit their proposals for subsequent evaluation by the technical evaluation committee.

We applaud the Bureau's programmatic decision-making efforts and its initiative in establishing these program evaluation and development procedures. Because they are new, the procedures and processes need continual evaluation, and the terms and criteria used, both in assessing the current program and in determining program priorities, need to be refined and defined.

A set of ranked and weighted problem criteria used in the technical evaluation process is shown in Table 5-3. Such factor analysis criteria, while most useful, need close evaluation by a broader group than the Bureau's Washington staff. The actual rankings and weights assigned are also subject to discussion and concensus.

TABLE 5-3. Ranked and Weighted Problem Categories

1.	New Technology	(0.27)
2.	Basic Research	(0.21)
3.	Materials Conservation	(0.20)
4.	Macro-Improvements to Technology	(0.10)
5.	Efficient Energy Use	(0.10)
6.	Environmental Safeguards	(0.05)
7.	Process-Limiting Materials	(0.05)
8.	New Process-Control Concepts	(0.02)

In a similar vein, the decisions of the technical evaluation committee could be made more responsive to national needs by broadening the participation and inputs to the committee to include representatives of industry and academia. Part of the overall programmatic decision-making process could also well include broader issues, such as the role of the Bureau in basic research, and this theme could be the subject of a workshop.

BASIC RESEARCH IN MINERALS AND PRIMARY MATERIALS

As pointed out in NMAB-399, the new program funded by the National Science Foundation on minerals and primary materials processing appears to bear directly on the Bureau of Mines program under review, and to be deserving of evaluation. Thus, as part of its deliberations, the committee received a presentation on "The National Science Foundation's Program on Minerals and Primary Materials Processing." A brief description of this program is given in Appendix B.

The NSF program is much smaller in terms of budget ($1.734 million for FY 82 awards vs. $29.660 million for the Bureau of Mines), and the emphasis is more on fundamental academic research. (It should be pointed out that a direct comparison of the funds expended by the two agencies could be misleading since NSF does not do in-house research, whereas nearly all the Bureau's work is performed in-house, thus involving additional overhead costs to the Bureau.) In addition, the primary objective of the NSF work is to advance knowledge of fundamental principles and processes necessary for developing new and improved technologies, while the Bureau's objectives are to develop new and improved technologies to better the competitive position of domestic mining companies (through technology transfer to industry) and to be responsive to national needs.

The FY 82 awards totaled 39 and were distributed as follows: mineral beneficiation (9), hydrometallurgy (7), pyrometallurgy (11), electrometallurgy (5), and other areas (7).

In its earlier report (NMAB-399) the committee urged that the "appropriate agencies consider some form of collaboration in allocating program areas and funding between the two agencies." NSF's coordination with the Bureau was described in some detail to the committee; it includes, among other things, keeping the Bureau informed of NSF awards and requesting technical reviews of proposals by the Bureau. The committee is pleased to recognize this collaboration and urges that it be continued and expanded. However, the committee is disturbed by indications that research support by agencies such as NSF might not be continued in areas embraced by the generic centers (i.e., centers of technological research focus located at universities) presently supported by the Bureau of Mines, and the reported formation of an industry-sponsored nonprofit organization to support research—all of which would tend to diffuse (and confuse) appropriate efforts.

Overlooked Areas

In addition to the foregoing general and special considerations examined by the committee, a number of areas were cited as deserving consideration for possible inclusion in future programs:

- Microbial leaching--a long-range, high-risk area; more work should be done here.
- Improved recovery of P_2O_5 from phosphates--another long-range, high-risk area.
- Potash recovery via solution mining.
- By-products from in situ leaching of nonferrous metal ores.
- Mixed sulfides separation. (N.B. The Avondale Research Center is performing work in this area now.)
- In situ mining.
- Non-commodity specific fine particle technology.
- Smelter dusts research.
- Automation, computerization, sensors, and real-time analysis.
- Mechanisms for long-range oversight of Bureau projects, including 5-year rolling planning.

6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

As previously mentioned, separate reports have already been issued which deal with the Bureau of Mines programs on minerals thermochemistry and materials substitutes. These reports have been summarized in the preceding chapter. In addition, the committee proposes a series of mechanisms to assist the Bureau's programs--including those in the areas of minerals and materials research--in more directly and adequately meeting the needs of the U.S. minerals industry. These mechanisms include:

1. Continuing participation of the industrial and academic communities in Bureau programs and programming, including the establishment of permanent, independent committees to advise the Bureau on the currency and pertinency of its research in various materials research areas (such as alloys) and composed of representatives from industry and academia who are experienced in the various subject matter fields.

2. The initiation of frequent workshops to identify and define critical areas for Bureau activity in support of the industry.

3. Broadening of Bureau contacts with the mineral industry; assessment of the nature, scope, and effectiveness of minerals and materials research type interactions with the Bureau's minerals information and data analysis functions; and annual presentation of the assessments at Bureau-sponsored workshops with industry and academic participation.

4. Expanded cooperative agreements with appropriate technical societies and industrial groups, as well as continued joint sponsorship of symposia, workshops, etc. in the area of minerals and materials research.

5. Establishment of other mechanisms such as contract research or specific intra-Bureau assessment of areas needing Bureau program activities. Examples in the thermochemistry area are: (a) assessing on an international level the thermochemical research efforts of industry, academia, and government agencies and (b) assuming a greater role in basic research.

6. Periodic (e.g., annual) presentations by Bureau personnel to industrial and academic audiences of reviews of the Bureau's programs.

7. In activities outside the Bureau of Mines, consideration of overall coordination of research support by the Bureau, NSF, and industry for (a) generic centers, (b) university research outside of generic centers, and (c) nonprofit research organizations.

The foregoing may require a broadening of the functions of the Bureau, and a reexamination of the enabling legislation (1912 Organic Act) may be necessary.

Appendix A

MINERALS AND MATERIALS RESEARCH PROGRAM OF THE BUREAU OF MINES FOR FY 81, 82, AND 83

The national security and economic well-being of the United States depend on adequate supplies of certain critical and strategic mineral resources upon which the nation's industrial economy is built. To help maintain or improve its current posture in the world market, in the face of greater international competition for the same resources, the nation must develop the means to facilitate access to the minerals on which its economy depends.

The Bureau's research and development program is aimed at anticipating and helping to provide solutions to the technological aspects of this important national problem. Through both in-house and contract research, the program improves the technology base by which minerals and mineral raw materials are mined, processed, refined, and developed into materials. A strong technological base provides options to solve unanticipated problems likely to occur in a rapidly changing world with increasing competition for limited resources.

In addition, to help promote a sound economy, the program develops and transfers to industry specific mining and minerals processing technology to maximize the use of domestic resources, to improve productivity, to promote wider use of abundant materials as substitutes for scarce minerals, to promote conservation of nonrenewable mineral resources by reducing waste in the minerals and related-products industries, and by promoting increased recycling of materials.

The Bureau's research divisions work closely with other Bureau divisions, other federal agencies, industry, and academia to ensure that the resulting research will be as effective as possible in addressing national needs.

In the initial report of the committee (NMAB 399), the various Bureau of Mines FY 81 research projects under the Mineral Resources Technology Program of that time were listed and described. This appendix brings this information up to date with the addition of FY 82 and FY 83 project titles and descriptions; many of these are carry-on programs from FY 81 but some are entirely new. Reorganization of this material has been made somewhat difficult because of organizational changes within the Bureau. Initially, the approximately 145 FY 81 projects and subcontracts were under the Minerals Resource Technology Program, but they have now been divided between the Mining Research and the Minerals and Materials Research Directorates. The latter comprises the Division of Extractive Metallurgy Technology, currently with 52 projects, and the Division of Materials and Recycling Technology, with 50 projects. The Mining Research Directorate administers the remaining projects.

The Bureau's programs encompass research, development, demonstration, and technology transfer activities over a wide area, including mining, ore beneficiation, ore processing, and product refining of many mineral commodities. They also include work on by-products recovery, recycling of materials, and development of substitutes for strategic and critical materials. Most of this research is carried on at the Bureau's 11 research centers and laboratories; subcontract efforts are also administered by the centers. The centers are listed below under their respective administering divisions:

Mining Research Directorate

Denver, Colorado (D)
Pittsburgh, Pennsylvania (P)
Spokane, Washington (S)
Twin Cities, Minnesota (TC)

Minerals and Materials Research Directorate

Albany, Oregon (AL)
Avondale, Maryland (AV)
Boulder City, Nevada (BC)
Reno, Nevada (RE)
Rolla, Missouri (RO)
Salt Lake City, Utah (SL)
Tuscaloosa, Alabama (TU)

The Bureau also carries on limited research at the Alaska Field Operations Center, which is organizationally in the Mineral Data Analysis Directorate. Some of the projects at the Twin Cities Research Center are administered by the Mineral and Materials Research Directorate as well as the Mining Research Directorate.

All of the Bureau's nonmining programs of the last 3 fiscal years in the minerals technology area are listed and described in the following pages of this appendix. Nonmining generic programs are listed first, followed by specific commodity programs, which are given under the general headings of ferrous metals, refractory metals, nonferrous metals, nonmetals, and ceramics. The specific order of the listings is as follows:

Generic Research

Beneficiation
Comminution
Corrosion
Coupled-Transport Membrane Separation
Environmental Research
Energy Conservation
Engineering Assessments
Electrolysis
Flocculation
Flotation
Filtration, High-Temperature
Geothermal Brines as Resources
Leaching, *in situ*
Leaching, Other
Microwave Heating
Pickling of Metals
Recycle, General
Solubilities, Chlorides
Thermodynamics and Kinetics

Ferrous Metals

Iron
Manganese
Chromium, Nickel, Cobalt, Platinum Metals
Chromium
Nickel and Cobalt
Cobalt
Nickel, Cobalt, Platinum
Platinum
Tungsten and Molybdenum
Vanadium, Tantalum, Columbium (Niobium)
Alloy Steels and Superalloys

Refractory Metals

Titanium
Zirconium and Hafnium
Rare Earths and Barium

Nonferrous Metals

Aluminum
Copper
Uranium
Zinc
Lead
Tin
Gold, Silver, Mercury

Nonmetals

Fluorine and Lithium
Phosphorus and Potassium
Sulfur

Ceramics

Alumina Refractories
Strontia, Zircon, Chromite, Alumina
General

GENERIC RESEARCH

Beneficiation

Continuous Dielectric Separation of Minerals (FY 82 and 83)

Bureau of Mines research to provide basic background in fundamental principles of mineral processing has shown that differences in dielectric properties can be used to separate mixtures of minerals such as chromite, rutile, zircon, quartz, and feldspar. Separation is accomplished by passing a mixture of two minerals through a divergent, alternating electric field created in a fluid. Particles having dielectric constants lower than that of the fluid will move in the direction of the lowest field gradient, while particles with dielectric constants higher than the fluid will move in the direction of the highest field gradient. A prototype laboratory scale continuous separator operating on this principle was built and tested (U.S. Patent 4,164,460). Present research is directed toward establishing limiting parameters for electric field gradient, electrode geometry, liquid properties, and mineral properties. Because the dielectric constant is a bulk property, separation efficiency depends on the bulk of the mineral particle rather than a surface coating. Therefore, dielectrophoretic separation may be effective for separating badly oxidized ores and composite or coated particles. (TU-83-ET-3)

Mineral and Metal Recovery in Fine Particulate Systems (FY 83 only)

New or greatly improved technology will be required to process the increasingly lower-grade domestic ores that are accessible to U.S. producers. In addition, to process these ores requires that they be ground very finely, which complicates metal recovery further. This project will explore the potential for treating such finely divided ores by two different electrochemical techniques. One will consist of extending small-scale experimental results on electrochemically controlling the flotation response of minerals. The other will assess the prospect of simultaneously reducing sulfide mineral concentrates in the cathode compartment of an electrowinning cell and oxidizing them in the anode compartment. This would be followed by continuously recovering the electrochemically generated metal and sulfur values. (AV-83-ET-1)

Comminution

Comminution Principles (FY 81, 82 and 83)

Comminution, or size reduction, is the single most energy-intensive step in minerals beneficiation, and, because it determines particle size distribution, has a direct bearing on the efficiency of downstream processes. The increased tonnage of a lower grade ore that must be ground to maintain the same amount of concentrate has sparked a continuing industry research effort to make improvements in grinding mill circuits. However, revolutionary improvements in grinding technology are unlikely until a better understanding of breakage and transport of particle assemblies is available. To supplement the extensive fundamental research efforts by the academic community, this project is directed toward obtaining basic size reduction data on selected mineral systems in order to pave the way for reducing energy consumption and improving the size liberation characteristics of the ground material. (AL-83-ET-8)

Research on Comminution Processes and Simulation (FY 81, 82, and 83)

Initial contract studies showed that breakage processes in a grinding mill can be analyzed in terms of a breakage rate function (which is the fractional rate at which particles are selected for breakage in grinding) and a breakage distribution function (which gives the size distribution of the daughter fragments resulting from the fracture of the particles being broken). This served as the basis for models subsequently applied to continuous grinding in a ball mill, and to the considerably more complex grinding kinetics and material transport phenomena encountered in rod mills. Building on this foundation, present research is directed toward developing fundamental data on the grinding of mixtures of minerals and on transport phenomena in wet mill systems. (University of California, Berkeley/J0123049-AL)

Corrosion

Corrosion Fundamentals (FY 81 and 82)

Corrosion is a widespread and costly problem that results in an enormous economic loss, estimated to be $70 billion, or 4.2 percent of the gross national product in 1975. Research under this project is designed to discover the causes of metal and alloy corrosion resulting from exposure to reactive chemical species in corrosive environments. (AV-82-MR-2)

Applied Corrosion Research (FY 81, 82, and 83)

Corrosion is a widespread and costly problem that results in an enormous economic loss, as well as increasing the demand for imported chromium, cobalt, nickel, manganese, and platinum-group metals. This research is directed toward providing technology to permit use of domestic mineral resources as substitutes for imported critical minerals through the use of protective coatings, substitute alloying elements, and determination of factors leading to corrosive degradation of materials resulting from exposure to reactive chemical species especially in mining and metallurgical processing environments. (AV-83-MR-2)

Corrosion of Grinding Media (FY 82 and 83)

Metal wear in mineral grinding systems represents a significant loss to the mineral industry due to the cost of the grinding media, worn mill linings, and downtime for maintenance. Annually, well over 250,000 tons of metal grinding balls, rods, and mill liners are consumed by the domestic minerals industry through a combination of abrasion and corrosion. This work is directed toward determining the chemical and electrochemical factors that promote corrosion losses of grinding media and at suggesting techniques for reducing these losses. (SL-83-MR-1)

Coupled Transport Membrane Separation

Coupled Transport Membrane Separations (FY 81 and 82)

The objective of this research is to investigate a membrane process for the separation and concentration of metal values from ore leach liquors. This process uses a liquid-filled membrane containing an extractant of the desired species, which serves as a shuttle to transport the metal ion across the membrane in the form of a complex chemical. Work is conducted using hollow fiber and spherical bead materials, prepared by the contractor. Current research is directed toward the separation of vanadium and uranium. (Bend Research, Inc./J0205061-SL)

Environmental Research

Particulate Mineralogy Unit (FY 82 and 83)

Almost half of the mines operating in the United States are located in regions where fibrous minerals may be present. The potential health hazards of these minerals could have serious effects on the domestic minerals industry through loss of product sales, forced closure, overregulation, and worker lawsuits. Not all fibrous minerals are the same, yet medical research conducted with a single mineral is often extrapolated to apply to an entire class of minerals, potentially leading to extensive overregulation. The Particulate Mineralogy Unit conducts research to establish precise, workable definitions of, and analytical procedures for, mineral particulates originating in mining and mineral processing operations. The unit cooperates closely with health and regulatory agencies to fully characterize minerals used in their research and to help establish sampling and evaluation criteria for fibrous mineral particulates. (AV-83-ET-2)

Mineral Process Water Reclamation Chemistry (FY 82 and 83)

Water reclamation for recycle is a major problem for many metallurgical operations, particularly those which require treatment of difficult-to-wash, voluminous, gelatinous hydrous metal oxide precipitates. Hence, techniques are being investigated to increase water reclamation for recycling in hydrometallurgical processes by transforming light hydrous oxide precipitates of Fe, Al, Cr, and Zr to denser and more readily filterable and washable compounds by removing the waters of hydration. Also, the kinetics of formation and solubilities of basic iron sulfates or related compounds are being studied to determine the feasibility of preferably precipitating these denser compounds instead of iron hydroxide. (RE-83-ET-11)

Treatment of Mineral Processing Wastewater (FY 83 only)

The objective is to demonstrate at commercial facilities the increased capacity realized when magnesium oxide is used in place of conventional media to filter mineral processing wastewater. In additon, methods will be developed for treating wastes that contain cyanide in a variety of chemical forms so that total cyanide will be reduced below 0.02 ppm. (TC-83-MR-1)

Citrate Process Technology for Sulfur Dioxide Control (FY 82 only)

The objective of this project is to monitor the performance testing and demonstration operation of a prototype plant to remove sulfur dioxide and recover sulfur from the stack gas of a coal-fired power plant. The prototype plant, based on a citric acid scrubbing process developed by the Bureau, can treat 150,000 cfm of stack and was designed to capture 90 percent of the sulfur dioxide. The plant is located at St. Joe Mineral Corporation's George F. Weaton Power Station at Monaca, Pennsylvania. Radian Corporation is on contract with the Bureau for the performance test. (SL-82-MR-17)

Surface Restoration of Mineral Processing Wastes (FY 83 only)

The objective of this work is to provide methods for surface restoration of mineral processing wastes through the establishment of viable plantings. The effect of genetic variations within plant species on plant viability as a function of location on tailings piles will be studied. Capillary barriers (gravel, sand, and organic mulches) will be investigated as a means of preventing upward migration of salts that are harmful to plant growth. Establishment of viable plantings on tailings piles will significantly reduce or eliminate wind blown dust from these sources. (SL-83-MR-4)

Breeding of Improved Grasses for Mined-Land Reclamation (FY 83 only)

Studies are being conducted to identify genetic variations of plant species with improved survivability and coverage on minerals tailings. To these ends, genetic variations of a number of plant species have been placed on lead-zinc tailings at Bauer, Utah, coal spoils at Decker, Montana, and at a desert location to test resistance to salt and drought conditions. Plants that appear promising will be propagated and placed in other environments, e.g., copper tailings. (USDA/SEA/JO205024-SL)

Electrolysis

Experimental Electrolysis (FY 81, 82, and 83)

Research is being conducted to determine the possibility of: (1) reducing electrical energy requirements in electrowinning processes by adding chemical electron donors to the anode compartment, and (2) conserving critical metals such as chromium and cobalt by electrolytically depositing multicomponent alloys from a slurry of metal powders and aqueous electrolyte. (AV-83-ET-3)

Energy Conservation

Energy Management in Minerals Processing Plants (FY 82 only)

Rising costs for energy production are directly reflected in the cost of refining minerals. To evaluate the potential for reducing minerals processing costs by more efficiently managing energy use, the Bureau is investigating an operating plant to develop an accurate model for energy consumption. Recommendations for energy management techniques that emerge from this investigation will be tested in-plant to measure their effectiveness. (Michigan Technological University/JO113078-P)

Engineering Assessment

Engineering Assessment of Research Projects (FY 82 and 83)

Bench-scale research could result in promising technology for which the economic feasibility and/or the potential for larger scale, technical-feasibility studies must be determined. Engineering assessment of potentially promising, bench-scale research will help to point out that technology which may benefit from such studies and will determine the availability of the essential data necessary to conduct the studies. Advice will be provided on additional data needed for the design of large-scale test facilities, the relative importance of such data, and means of obtaining it. (BC-83-ET-3)

Flocculation

Fundamentals of Flocculation (FY 81 and 82)

Very fine mineral particles resist processing by conventional techniques such as flotation, thickening, and filtration. This Bureau project focuses on determining the properties of fine particles and of flocculating agents with the objective of developing a base for new flocculation technology. (TU-82-MR-1)

Dewatering of Mineral Processing Slimes by Flocculation (FY 83 only)

This research is concerned with developing techniques for dewatering slurries from mineral processing operations to improve water reclamation and for producing dewatered solids suitable for disposal. A 2,000 to 4,000 gallon per minute prototype unit will be constructed and operated to test the Bureau's polyethylene oxide flocculation technology. This effort will be supported by basic research on the bonds formed between clay particles and polymer flocculants. In addition, Bayer Process red muds will be characterized and potential dewatering methods will be investigated. Successful development and implementation of this technology can potentially eliminate serious environmental problems associated with slimes disposal. (TU-83-MR-4)

Flotation

Flotation Fundamentals (FY 81, 82, and 83)

Froth flotation is used to upgrade nearly a half billion tons of domestic ores annually to produce over 80 million tons of concentrates. However, in the face of lower grade and more complex ores, higher energy costs, and strict environmental controls, significant new technology must be forthcoming to maintain the same economic posture. The Bureau of Mines is developing a basic background in fundamental froth flotation principles for application by private sector engineers to (1) make incremental improvements in existing operations and (2) develop new technology for separating minerals not presently separable by froth flotation. Based on combined electrochemical and optical spectroscopic studies on packed beds of sulfide minerals, Bureau research has shown the possibility of using electrochemical potential as a means of controlling the flotation response of these minerals. The degree of selectivity exhibited by this method may permit froth flotation to be used to separate pentlandite, cobaltite, or molybdenite from other sulfides such as chalcocite, chalcopyrite, or pyrite. (AV-83-ET-5)

Selective Flotation Recovery of Very Fine Minerals (FY 81 only)

Large quantities of very fine minerals are presently wasted because fine minerals do not respond to existing beneficiation techniques. This research is directed at discovering the mechanisms of mineral-reagent interaction during beneficiation, and conditions that favor the recovery of fine particles not presently recoverable. (AVRC/South Dakota School of Mines)

Modeling and Control of a Flotation Cell (FY 82 only)

A half billion tons of ore are processed annually in the United States by the froth flotation process. Thus, any improvement in process efficiency can have a significant beneficial impact upon the minerals industry. This research will result in a mathematical model that should greatly facilitate regulation of flotation efficiency by use of modern computer controls. (University of Utah/J0215035-SL)

Filtration, High Temperature

Powder Metallurgy Prepared Filters for High-Temperature Process Streams (FY 83 only)

There are a variety of current and developing mineral-related processes where improved media are needed for filtering heated and/or corrosive solutions to remove precipitates or other particulate solids. Examples are filtration of contaminants from fused salt electrolytes, drosses from molten lead and zinc, and removal of precipitates from hot acidic or caustic leach solutions. Such filter media often determine whether a process is technologically and economically feasible. Alloy filters currently available are specialty items, very costly and difficult to fabricate and characteristically having high critical metals content. Research is being conducted to develop technology for fabricating alloy filters which have the optimum properties for temperature, corrosion, and time stability with the minimal content of critical metals. (RO-83-MR-2)

Geothermal Brines as Resources

Geobrine Minerals Recovery (FY 81, 82, and 83)

Geothermal fluids contain valuable metals and minerals such as manganese, lithium, zinc, lead, and silver. Successful recovery of these brine constitutuents could add to the reserve base and aid in the disposal of spent geothermal fluids in an environmentally acceptable manner. A number of recovery methods and associated corrosion problems are being investigated. (RE-83-ET-9)

Recovery of Heavy Metals from High-Salinity Geobrines (FY 81 only)

The objective is to perform laboratory and computer modeling experiments on precipitation and recovery of heavy metals and other insoluble minerals from high-salinity geothermal brines from Miland, California, Test Facility. Sulfide precipitation of metals and base additions to increase brine pH is being investigated. (RERC/SRI International)

Control of Scale and Heavy Metal Recovery in Geobrine Systems (FY 81 only)

One of the problems in recovering minerals from geobrines is the rapid formation of mineral scale on the inside of pipes through which the geobrines flow. The research is to better understand the behavior of the scaling and determine methods for its control as well as methods to enhance minerals recovery. (RERC/Pennsylvania State University)

In situ Leaching

Technology Assessment for Leaching (FY 81 only)

Objective of this project is to stay abreast of the state of the art in *in situ* leach mining, to identify technological gaps, to evaluate applicability of leach mining methods to various commodities, and to determine future trends. In order to keep industry and government informed on current research, the project will continue literature surveys and field visits, as necessary, to compile first-hand accurate information. Using the above information future areas of research will be proposed. (TCRC)

Feasibility of in situ Leaching Metallic Ores Other Than Uranium and Copper (FY 81 only)

This contract is designed to determine which commodities and which geologic situations offer the best chances for developing viable *in situ* leaching operations. The objective is to determine the feasibility of *in situ* leaching of metallic commodities other than copper and uranium and to assess potential locations in virgin deposits and previously mined ore bodies where *in situ* leaching appears most promising. (TCRC/Mountain States Research and Development)

Well Construction Techniques for in situ Leaching (FY 81 and 82)

The objective is to develop improved procedures for drilling and completing injection and production wells so as to minimize clogging, decrease the frequency of well failures, and reduce costs. Research includes laboratory testing of casing and drilling fluids, field examination of failed wells with a down-hole camera, and preparation of a manual covering all important aspects of drilling, casing, and completing *in situ* leaching wells. (TC-82-MR-18)

Improved Drilling and Recovery Systems for in situ Mining (FY 82 only)

The objective is to study and evaluate the present solution application, distribution, containment, and recovery systems used in *in situ* leach mining in order to determine the most efficient and cost-effective methods for solution handling and maximum resource recovery. The results of this project will provide information on leach solution application and recovery systems and the feasibility of heating leach solutions for improved mineral recovery. (TC-82-MR-19)

Use of Clay Stabilizers to Prevent Permeability Losses (FY 81 and 82)

The objective is to evaluate the effectiveness of clay stabilization polymers for preventing clay swelling and fines migration which can cause permeability losses in leaching wells. Laboratory and field tests will be conducted to evaluate the effectiveness of the polymers. (TC-82-MR-20)

Small-Diameter Corrosion-Resistant Pumps for in situ Leaching (FY 81 only)

Smaller and more corrosion resistant pumps than those presently used for *in situ* leaching would enable significant cost savings and also help increase percentage recovery of mineral. The purpose of this procurement is to design, construct, and test a submersible pump system suitable for two-inch-diameter monitor wells and three-inch-diameter production wells (about one half the diameters commonly used at present). (TCRC/Jacuzzi Brothers, Inc.)

Leaching, Other

Improved Leaching (FY 83 only)

New leaching technology will be developed and applied to bench-scale systems for evaluating innovative hydrometallurgical extraction processes, with emphasis on aggressive leaching conditions of high temperature and pressure. Dependable mechanical equipment will be integrated with reliable data acquisition systems in order to assure obtaining meaningful process engineering information. (BC-83-ET-4)

Microwave Heating

Application of Microwaves to Minerals Processing (FY 82 only)

Microwave heating is a new technology that has recently become available. This research will assess the applicability of microwaves to minerals processing. Among the potential applications being investigated are drying of filter cakes and sludges, calcining, and transformations of mineral structure. (TC-82-MR-12)

Pickling of Metals

Fundamentals of Pickling Process (FY 83 only)

Acid pickling is widely used in the metals industry for cleaning annealed and hot worked stainless steels. Compositions of pickling solutions are generally chosen for their ability to remove mill scale, to minimize alloy depleted surfaces, and to provide an acceptable surface appearance. The most frequently used solution, HNO_3/HF, operates by undermining the scale and thus causing it to fall off. The simultaneous dissolution of the stainless steels removes any alloy-depleted surface layers but also results in annual losses amounting to several thousand tons of iron, chromium, and nickel, as well as creating a sizable disposal problem. Research is being conducted to determine the effect of pickling bath variable on the pickling of commercial stainless steels. The result will provide information needed to develop a model of the pickling process in order to optimize it and extend the useful life of the bath so that the need for waste disposal or additional treatment will be reduced. (AV-83-MR-1)

Recycling, General

Recycling Unconventional Wastes (FY 81 only)

There is currently a wide variety of waste materials being generated which contain metal and mineral values but are not amenable to conventional recovery techniques. Examples of these wastes are sludges from commercial detinners and dusts and sludges from secondary copper and brass smelters. This research will devise procedures for recovering these values from the wastes. (AVRC)

Rapid Identification, Sorting, and Characterization of Secondary Resources (FY 81, 82, and 83)

Efforts to recycle individual alloys from mixed scrap materials are currently hampered because of processors' inability to easily recognize and separate each of the alloys. Techniques will be devised using a combination of currently available, low-cost instruments for rapidly identifying/separating various alloys. Emphasis will be concentrated on superalloys, precious metals, copper-base alloys, and aluminum scrap. (AV-83-MR-5)

Recovering and Recycling Materials from Automobile Scrap (FY 81, 82, and 83)

Currently, as many as eight million junk automobiles are shredded annually in the country, and at most of the shredding centers only the magnetic metals are recovered for recycling. The goal of current research is to devise improved methods and equipment for the recovery and separation of metals, plastics, glass, and other materials contained in the nonmagnetic residues from automobile-shredding operations. The composition of newer foreign and domestic compact cars will be determined and current recovery technology will be evaluated regarding its ability to recycle the new materials being used in these cars. Water elutriation and barite separation will receive final evaluation at industrial sites on full-scale equipment.

In addition, a determination will be made as to whether any improvements are needed in the technology for recovering platinum group metals from spent auto catalytic converters. (SL-83-MR-5)

Solubilities, Chlorides

Solubility of Metal Salts in Acidic Chloride Systems (FY 82 and 83)

For many years the chemistry of systems with high chloride concentrations has been important in the processing of metals such as magnesium, lithium, potassium, and others. Proposed hydrometallurgical processes for other metals, notably aluminum, also involve the chloride system. To provide a basis for developing new process technology, and for evaluating candidate processes, this research will develop new data on the form and solubility of metal chlorides as a function of temperature, acidity, and chloride concentration. (RE-83-ET-10)

Thermodynamics and Kinetics

Thermochemical Data Compilation (FY 81 only)

Thermochemical calculations, which are useful in evaluating proposed processes and predicting reaction products, require accurate data to complement data acquired under the Minerals Thermochemistry project. Published data from all available sources are critically evaluated, compiled, and published in the Bureau publications series for use by the minerals science community. (ALRC)

Minerals Thermochemistry (FY 81, 82, and 83)

Precise knowledge of thermodynamic quantities is important in research to devise new and innovative metallurgical process technology. Thermodynamic data are being determined with high accuracy to aid in the understanding of specific metallurgical reactions, and to determine the fundamental role of accessory minerals and elements in minerals processing streams. To complement new data acquired under this project, published data from all available sources are critically evaluated, compiled, and published in the Bureau publications series for use by the minerals science community. (AL-83-ET-7)

Thermodynamic Data of Metal Carbonates (FY 81 and 82)

Calcination, which is one of the more important operations in process metallurgy, often involves treatment of metal carbonates. This research is planned to increase the reliability of thermochemical data available for evaluating new calcination processes by critically reviewing existing data and determining value where needed for selected metal carbonates. (ALRC/University of Wisconsin)

High-Temperature Thermodynamics and Kinetics (FY 82 and 83)

To develop and evaluate alternative mineral processing techniques requires a sound knowledge of the plausibility of proposed reactions and the rates of these reactions in the temperature range of interest. This project will emphasize the kinetics and thermochemistry of mineral systems at temperatures greater than 1000°C and at pressures exceeding one atmosphere. Initial emphasis is on the Al-Si-C-O system, of great importance in direct reduction of aluminous raw materials. (AL-83-ET-6)

Metallurgical Reaction Kinetics (FY 81, 82, and 83)

To make improvements in a metallurgical process reaction requires a thorough understanding of the details of the reaction. This research project is concerned with measuring the rates of and proposing mechanistic explanations for important metallurgical reactions, such as the reduction of chromite, and the leaching of manganese. A secondary objective is to determine the nature of chemical additives that may accelerate such reactions. (TC-83-ET-3)

Solvent Extraction Kinetics (FY 83 only)

One way to improve the effectiveness of solvent extraction separations would be to exploit differences in the rates at which different metals transfer between phases in the system. This project will develop techniques for measuring the rates of forward and back extraction of metallic solutes with the objective of contributing to the understanding of exchange mechanisms and providing information that may lead to significant improvements in separation capabilities. This project complements work at the Albany Research Center (see below).

Prediction of Metal Extraction With Solvent Extraction Reagents (FY 83 only)

Solvent extraction has emerged as a powerful technique for separating mixtures of metals in solution; however, the selection of reagents and operating conditions has remained largely a trial-and-error process. This project will concentrate on developing accurate, detailed data on the performance of commercially available solvent extraction reagents. This, in turn, will permit the development of models for extraction mechanisms, which will facilitate the rational selection of process conditions. This project will be closely coordinated with a complementary project on Solvent Extraction Kinetics at the Reno Research Center. (AL-83-ET-9)

FERROUS METALS

Iron

Wet High-Intensity Magnetic Separation (FY 81, 82, and 83)

The oxidized nonmagnetic taconites of upper Michigan and Minnesota are a major domestic source of iron ore. Present commercial beneficiation practice for these ores involves selective flocculation, desliming, and froth flotation. Wet high-intensity magnetic separation (WHIMS) is an alternative that is potentially less energy intensive and could effect substantial savings in reagent costs. Potential energy savings stem from the fact that initial separation can be performed at coarser particle sizes, reducing the amount of material that must be finely ground. Results indicate reagent costs for WHIMS to be about one third that of the selective flocculation method. Current research efforts are directed toward obtaining processing data from WHIMS for comparison with data previously obtained for both selective flocculation and another alternative, reduction roasting. Concepts and economics are being evaluated on a scale sufficiently large to produce results of maximum usefulness to the private sector. (TC-83-ET-4)

The Effects of Flotation Machine and Froth Characteristics on Cationic Flotation of Finely Ground Iron Ores and Concentrates (FY 82 and 83)

The separation of silica (as quartz or other silicate minerals) from iron oxides by cationic flotation exhibits relatively poor selectivity, resulting in sizable iron losses or the need for multiple cleaning stages. The principal objective of the research being conducted under this contract is to determine the reasons for the poor flotation selectivity and, if possible, to develop procedures which will improve the separation. (Michigan Technological University/J0113076-TC)

Reduction of Iron Ore by Sulfur Bearing Low or Medium Btu Gases (FY 81, 82, and 83)

The objective is to generate experimental iron ore reduction data for a selected variety of lump ores and commercial pellets over a range of temperatures and pressures, for processes that use as the reducing agent low- or medium-Btu gases that contain sulfur. (Carnegie-Mellon University/J0215041-P)

Alternate Fuels for Mineral and Metallurgical Processing (FY 81, 82, and 83)

Fire hardening of iron oxide pellets relies heavily on premium fuels, such as natural gas. Future availability of natural gas is very uncertain. Accordingly, this program is devising pellet firming systems that use coals of various ranks and are compatible with standard pellet induration processes. For example, a pilot plant demonstration is being conducted in cooperation with the Department of Energy to determine the technical feasibility of using raw, hot low-Btu gas generated from the gasification of low-rank coals and fuels to indurate iron oxide pellets in a grate-kiln system. As part of this demonstration project, the Bureau is cooperating with 20 companies with interests in iron and steel, coal, gas, and industrial engineering. (TC-82-MR-9)

Direct Reduction of Iron Ore Pellets (FY 82 only)

The growth of electric arc furnace steelmaking in the United States in the near future may fail to reach projected levels due to shortages of iron units, primarily scrap. Therefore, an economic, energy-efficient process is needed for production of direct reduced iron. Existing technology is being evaluated to determine where research is needed to make direct reduction an economically viable process. (TC-82-MR-10)

Substitutes for Fluorspar in Steelmaking (FY 81 only)

Steel production from basic oxygen processes employing fluorspar fluidizer now exceeds 50 percent of all domestically produced steel. This has resulted in doubling the requirement of fluorspar consumption per ton of steel. Research is being conducted on substitutes or partial substitutes for fluorspar as a basic oxygen furnace or cupola slag fluidizer. Substitute materials, such as potlining material removed from an alumina reduction cell, will be studied for performance, availability, economics, pollution, and furnace refractory compatibility. (TCTC)

Potential Effect of Ferrous Scrap Composition Changes on the Quality of Iron and Steel Castings (FY 82 only)

The increased use of ferrous scrap in ironmaking and steelmaking could result at some future date in a buildup of tramp elements in the iron and steel products. A significant increase in deleterious tramp elements in the scrap charge would decrease the quality of iron and steel castings. The objective of this contract research is to determine whether or not the quality of scrap is deteriorating, and, if so, to determine what steps would be required to alleviate the problem. In cooperation with the foundry industry and the American Foundrymen's Society, the contractor is to collect samples and data on the quality of scrap iron and steel products, and foundry practice. This data would be analyzed to determine the effect of tramp elements in the scrap. (Battelle-Columbus/J0205002-AL)

Foundry Charge Materials Chemistry (FY 82 and 83)

This work is a continuation of the chemical analysis of ferrous scrap and castings which was initiated in support of Contract No. J0205002 (Battelle-Columbus), now completed, and is being conducted under a memorandum of agreement with the American Foundrymen's Society (AFS).

AFS periodically submits samples of gray and ductile iron from domestic cast iron foundries which are then analyzed by the Bureau for 28 elements. AFS correlates the analysis data with foundry practice data to identify and evaluate the effects of tramp elements in charge scrap on the quality of iron castings. (AL-83-MR-4)

Manganese

Recovery of Manganese from Low-Grade Domestic Sources (FY 82 and 83)

For its manganese requirements, the United States is heavily dependent on foreign sources because low-grade (less than 35 percent Mn) ores are the only domestic sources available and these cannot be processed economically. However, because of technological developments of the past few decades and the recent emphasis by the government on strategic minerals, the Bureau of Mines considers it essential now to review and update the processing technology for recovering manganese from domestic low-grade sources. Thus, a detailed evaluation is being made to identify the three most promising processes for recovering Mn from low-grade domestic sources in case of curtailment of foreign Mn ores. (Arthur D. Little, Inc./H0222005-SL)

Feasibility of in situ Leaching to Recover Manganese (FY 81 and 82)

About 74 million tons of manganese are present in low- and medium-grade ores in five areas of the United States. There is insufficient technology available for economic recovery of manganese from low-grade domestic ores and for economically mining less accessible manganese deposits. In situ leaching is a possible method that needs to be evaluated. A comprehensive evaluation of the feasibility of using in situ, SO_2 leaching as a practical method for recovery of manganese from domestic resources will be conducted. Technologic gaps that need to be overcome to make in situ leaching of manganese feasible will be identified and conceptual scenarios will be devised for situations where feasibility can be demonstrated. (TC-82-MR-21)

Development of Manganese-Base Alloys as Substitutes for Chromium-Bearing Alloy (FY 81 and 82)

Iron-aluminum-manganese alloys are being studied for intermediate temperature applications. The research focuses on the development of stainless steel substitutes, but the technical and economic ramifications of potentially abundant supplies of ocean floor manganese also are being considered. (Massachusetts Institute of Technology/J0295073-AL)

Chromium, Nickel, Cobalt, and Platinum Metals

Appraisal of Critical Minerals from Northwestern and Alaskan Resources (FY 81, 82, and 83)

Several critical mineral resources have been identified in Alaska and the northwestern states. To assess the potential of these resources, work is under way to define data needed on their chemical, mineralogical, and concentration characteristics. Of particular interest are the chromite and chromite-olivine massive rock deposits in Alaska. (ALRC)

In cooperation with the Alaska and Western Field Operations Centers, bulk samples of potential critical mineral resources will be obtained for characterization and chemical analysis. Beneficiation studies will then determine if concentrates that contain economically recoverable amounts of Cr, Pt, Co, W, Sn, Ta, and Cb can be prepared. (AL-82-MR-8)

Sampling Potential Alaskan Critical Minerals Deposits (FY 83 only)

This work is part of a joint effort with the Albany Research Center on an appraisal of critical minerals from Alaskan and northwestern resources. Field reconnaissance studies will be conducted and bulk samples obtained for chemical analysis and metallurgical testing. (Alaska Field Operation Center)

Chromium

Fundamentals of Chromite Flotation (FY 83 only)

The objective is to study the electrokinetic adsorption and flotation properties of chromite and other minerals found in chromite ores for the purposes of ultimately developing a superior flotation procedure. Hallimond tube flotation tests are being performed on Mouat chromite to study the effects of collector type, collector concentration, hydrofluoric acid depression, and pH on chromite recovery. (SLRC/University of Nevada)

Chemical Processing of Domestic Chromites (FY 81, 82, and 83)

The United States has only low-grade chromium resources that presently are not economically treatable. For example, Oregon/California nickel laterite deposits contain two to three percent chromium. Research is being conducted to devise technology for economically recovering chromium from concentrates produced from the hydrometallurgical process residues remaining after removal of the nickel and cobalt from the low-grade laterites. (AL-83-ET-1)

Extraction of Chromium From the Domestic Lateritic Ore Tailings and Chromite Ore (FY 81 and 82)

Research is underway to explore and develop the data base for low-temperature hydrometallurgical chromium extraction. The method utilizes soda roasting and subsequent water leaching to obtain the pregnant liquor and has the potential to extract chromium from low-grade domestic chromite ores as well as from the leached tailings of lateritic ores obtained from the nickel extraction process. (Denver Research Institute/G0284009-AL)

Carbonyl Recovery of Critical Metals and Minerals (FY 82 and 83)

Technology is needed which would allow economic extraction of critical and strategic metals from domestically available minerals. One potentially useful method involves the formation of metal carbonyls, compounds with very high vapor pressures. The conditions employing carbonyl methods for upgrading high iron chromites and for the recovery of metals such as cobalt and nickel from domestic ores and concentrates will be determined. (RO-83-MR-14)

Chromium From Ferrous Alloy Slags and Particulate Wastes (FY 81 and 82)

This research will investigate techniques for effective in-plant recycling of chromium and other critical metals contained in furnace slags and particulate wastes generated in the production of specialty steels and alloys. Physical beneficiation methods will be optimized to recover the values for reuse. (RO-82-MR-6)

Chromium Recovery From Spent Etching Solutions (FY 82 only)

Bureau-derived electrolytic diaphragm cell technology will be evaluated at industrial sites on production equipment. Chromic acid etching solutions, which are currently disposed of following each day's operation, will be regenerated on line in each plant to allow for 30-day or more use of these etchants. The quality of the regenerated solutions will be evaluated throughout the tests. (RO-82-MR-5)

Chromium Recovery From Tanning Wastes by Pyrolysis and Sulfuric Acid Leaching (FY 82 only)

The tanning industry uses large quantities of trivalent chromium in the form of water soluble chromium sulfate for tanning hides and skins. Over one half of the chromium used is contained in the sludges from the tanning solutions and in the leather trimmings and shavings--all of which are currently discarded. The contract research is to examine methods for pyrolyzing these wastes and recovering the chromium values. (Tanners' Council of America/J0113110-RO)

Chromium-Free and Low-Chromium Alloys as Substitutes for Stainless Steels (FY 81, 82, and 83)

This work is directed toward devising substitutes for important alloys without degrading their chemical or physical properties in order to reduce national requirements for chromium. Iron-base alloys strengthened by intermetallic compounds such as NiAl and iron-aluminum alloys strengthened by carbide precipitation are being investigated as substitutes for stainless steels. The techniques of internal oxidation and mechanical alloying to form stable dispersoids such as Al_2O_3 or Y_2O_3 as alternatives to superalloys for use up to 1000°C will be investigated. (AL-83-MR-5)

Chromium Substitution in Stainless Steels (FY 81 and 82)

A high percentage of stainless steel is used for ambient temperature, corrosion-resistant applications. An austenitic stainless steel with reduced chromium levels, but with good corrosion resistance, would conserve chromium supplies. A number of austenitic alloys are being evaluated with reduced chromium contents (5 to 14 percent) and with small additions of alloying elements such as molybdenum, silicon, and copper. (International Nickel Co./J0295073-AL)

Surface Nitriding for Corrosion-Resistant Ferrous Alloys (FY 81 and 82)

Research has shown that surface nitriding not only strengthens mild steel, but enhances oxidation resistance by encouraging the adherence of surface oxide films. The effects of surface nitriding are now being studied in chromium-free alloys that could substitute for stainless steels at ambient and intermediate temperatures. (Army Materials and Mechanics Research Center/J0188167-AL)

Development of Chromium-Free Construction Alloy Steels (FY 82 and 83)

This contract is directed toward the development of a new chromium-free construction alloy steel capable of replacing the 4100 and 8600 grades of constructional alloy steels currently being used in carburizing applications. These two steel grades account for almost 10 percent of the total U.S. demand for chromium. The objective of this work is to substitute for chromium other alloying elements in which the United States is self-sufficient, or for which a more secure and stable source of supply exists. The contractor is using a computerized metallurgical/alloy design system to develop an alloy composition that will have microstructures, heat treat response, and mechanical properties equivalent to the 4100 and 8600 steels. (International Harvester/J0113104-AL)

Nickel and Cobalt

Cobalt and Nickel Recovery From Western Laterites (FY 81, 82, and 83)

Cobalt and nickel are critical minerals for which the United States must rely almost entirely on foreign sources. Extraction of these metals from low-grade domestic laterite resources would help to reduce the nation's reliance on imports. Technology is being devised for the recovery of cobalt and nickel from nickel-bearing laterites found in northern California and southern Oregon by selective reduction, leaching, solvent extracton, and electrowinning. (AL-82-MR-4)

Nickel Laterite Pilot Plant Testing (FY 81 only)

As an extension of the Bureau's project "Nickel Recovery from Western Laterites," this cost-sharing contract was awarded to better define engineering and cost factors and to encourage transfer of Bureau-developed technology for the recovery of nickel, cobalt, and chromium from low-grade domestic laterites by conducting specified short-term tests on a five-tpd pilot plant scale. These short-term tests will be used to evalute recovery tecnnology based on laterite leach residue. (ALRC/Universal Oil Products, Inc.)

Cobalt and Nickel From Missouri Lead Ores (FY 81, 82, and 83)

Lead ore reserves in Missouri contain significant quantities of low-grade cobalt and nickel, both of which are lost as tailings and slag during processing to recover the primary lead, zinc, and copper minerals. The cobalt and nickel grades are sufficiently subeconomic to preclude research by the private sector to recover them. Therefore, the Bureau of Mines is conducting research to develop the basis for cobalt and nickel recovery by flotation and hydrometallurgical methods that are compatible with the current lead-zinc-copper operations. (RO-83-ET-1)

Cobalt and Nickel From Missouri Lead Smelter Wastes (FY 81 and 82)

Missouri lead smelters generate about 6,000 tons per year (tpy) mattes, 12,000 tpy dross, and 0.5 million tpy slags, containing about 700,000 lbs cobalt, 900,00 lbs nickel, and 7,000 tons copper. The objective of this research is to enhance the supply of cobalt and nickel by devising procedures for recovering these metals. Bench-scale operations are being optimized for selective recovery of cobalt, nickel and copper by oxidative leaching of smelter mattes and drosses with subsequent purification and sulfide precipitation. (RO-82-MR-4)

Recovery of Byproduct Cobalt and Nickel from Zinc Processing Liquors (FY 83 only)

An alternative purification process that does not use arsenic or antimony for precipitating cobalt and nickel from zinc electrolytes is needed. As co-precipitates with nickel and cobalt, arsenic and antimony create problems in the marketing, disposing, and processing of the critical metals-bearing precipitate. One promising approach is removal of cobalt and nickel by cementation using $CuSO_4$, As_2O_3, and An dust in combination or individually with a hydrogen source other than Zn. (RO-83-ET-2)

Cobalt

Processing Complex Domestic Cobalt Ores (FY 81, 82, and 83)

Cobalt is an industrially important and militarily strategic metal. There is no current domestic production, but the United States has some 24 known identified deposits of cobalt resources. The largest of these is in the Blackbird mining district of Idaho, where complex arsenical ores containing about 0.7 percent cobalt and 1.5 percent copper are found. Sustained production of cobalt from this deposit has been attempted but not achieved due to economic, technological, and environmental problems. Private sector research has addressed the technological and environmental problems, but only with marginal success. Therefore, to help provide technology to recover cobalt from this important domestic resource, the Bureau of Mines is conducting research to solve problems associated with several of the most practical alternative extraction methods. Methods under investigation include combinations of 2-stage roasting, acid and ammoniacal pressure leaching, solvent extraction, and electrowinning. Release of arsenic to the environment is avoided in all methods and an effort is made to recover it as a byproduct. (SL-83-ET-1)

Thermodynamics and Kinetics of Cobalt Reactions (FY 82 only)

Cobalt is a critical metal because of its role in jet engine parts and other vital uses where substitution would be difficult. Currently, domestic industry depends on imported cobalt, of which 80 percent comes from Africa, an easily interrupted source. Although domestic reserves are small, significant production can be achieved from the Blackbird, Idaho deposit. Exploratory research being conducted by the Bureau of Mines to enable profitable utilization of this ore can be substantially assisted by using kinetic and thermochemical data that will be developed for the roasting and leaching reactions of cobalt minerals found in the Blackbird deposit. (SL-82-MR-2)

Evaluation of Arsenic-Bearing Gases From Arsenopyrite (FY 81 only)

A study is being conducted of the kinetics of evolution of arsenic-bearing gases from arsenopyrite. The experiments will be carried out in both sulfidizing and oxidizing atmospheres. The results will be useful in controlling emission of pollutants during ore roasting operations. (ALRC/University of Washington)

Separation and Recovery of Byproduct Cobalt From Copper Processing Solutions (FY 81, 82, and 83)

The objective of this work is to improve the technology for recovering cobalt from waste solutions, in particular, copper processing solutions using ion-exchange technology. Copper processing solutions contain significant amounts of cobalt and other valuable metals which are not presently recovered. At one copper mine and mill alone, the potentially recoverable cobalt exceeds 650 tons annually. The initial emphasis is on recovery of cobalt and nickel and associated values from copper cementation plant effluents. (SL-83-MR-6)

Cobalt Substitutes in Permanent Magnets (FY 81 and 82)

Permanent magnets, a major electrical component, account for approximately 15 percent of the U.S. consumption of cobalt. In terms of materials use, Alnico alloys are a substantial portion of these permanent magnets. Rare-earth/cobalt magnets are also becoming an important factor. This research is directed toward decreasing the demand for cobalt by devising alloys and fabrication processes for Alnico magnets and rare-earth/cobalt magnets that will require smaller amounts of cobalt. (RB-82-MR-15)

Substitutes for Cobalt in Cemented Carbides and Tool Steels (FY 82 only)

The use of carbides for cutting and drilling tools was limited by extreme brittleness until 1923 when cobalt was introduced as the metal matrix to contain and bind the hard carbide particles. The toughness of the cobalt in the matrix and the hardness of the carbides provide an excellent material for wear application, but the United States now depends on foreign sources for 100 percent of its primary cobalt supply, most of which comes from the country of Zaire. This research is aimed at reducing this country's dependence on cobalt from foreign sources by providing alternatives to cobalt for cemented carbide cutting tools. (AL-82-MR-17)

Nickel, Cobalt, and Platinum

Recovery of Platinum-Group Metals, Cobalt, and Nickel From Duluth Gabbro (FY 81, 82, and 83)

The copper-nickel ore of the Duluth Gabbro complex in northeastern Minnesota is a large potential domestic resource of cobalt and platinum-group metals. However, the low grade of the primary metal values (0.5 percent Cu, 0.5 percent Ni) has forced the private sector to assign a relatively low priority to the development of technology for processing this resource, anticipating that mining would probably not begin until the mid 1990's. Furthermore, the preliminary processing flowsheets considered by the mining companies centered on the primary metal values. As part of an effort to help provide the basis for technology to recover the critical and strategic minerals from this important domestic resource, the Bureau of Mines is investigating methods to recover all of the mineral values, paying particular attention to the byproduct critical minerals. Present research is addressing particular aspects of unit operations within the process flowsheet that are causing significant cobalt and platinum-group metal losses. (TC-83-ET-1)

Mineral Beneficiation Studies and an Economic Evaluation of the Copper-Nickel Bearing Duluth Gabbro in Minnesota--Phase IV (FY 81 only)

Research will optimize the use of ozone in the differential flotation of Duluth Gabbro ores to impart selectivity in flotation. In addition, investigation continues for the determination of the parameters that govern the mineralogical and textural charactristics of slow-cooled, high-ion mattes and their magnetic separation and flotation characteristics. (TCRC/University of Minnesota)

Platinum

Platinum from Northwestern and Alaskan Resources (FY 81 only)

Research is being conducted on methods for recovering platinum, as well as other valuable minerals such as copper sulfides, chromite, and magnetite, from a number of low-grade platinum resources in the northwestern United States and Alaska. (ALRC)

Platinum and Associated Metals from Stillwater Complex Deposits (FY 81, 82, and 83)

The United States is almost completely dependent on imports for platinum-group metals (PGM). Research is being conducted on methods for recovering PGM, along with associated copper and nickel, from a large resource in the Stillwater Complex, Montana. Large-scale beneficiation techniques to prepare a concentrate are being carried out, as well as research on leaching and smelting-leaching methods to recover metals from the concentrate. (RE-83-ET-3)

Substitution for Platinum Metal Crucibles Used in the Glass Industry (FY 82 and 83)

Platinum, which is widely used in glassworking and electronics, is a critical metal because of its import dependency. The use of ceramic furnace liners as replacements for platinum in glass furnaces will be evaluated. (Glass and Ceramics International/J0113098-TU)

Tungsten and Molybdenum

Tungsten Recovery from Low-Grade Deposits (FY 81 and 82)

A number of hydrothermal and tactite deposits containing minor amounts of tungsten occur in the western states. As 60 percent of the nation's tungsten requirements are met through imports, all domestic resources are being considered. Leaching and beneficiation techniques are being investigated. (RE-82-MR-11)

Tungsten Recovery from Searles Lake Brines (FY 81, 82, and 83)

The brines of Searles Lake, California, contain an estimated 135 million lbs of tungsten. While these brines are too dilute to process solely for tungsten, with appropriate technology it might be economically recovered as a byproduct during existing commercial processing that produces bromine, potassium salts, soda ash, salt cake, and boron chemicals. Key to recovery was the development of an ion exchange resin by the Bureau of Mines for sorption of tungsten (U.S. Patent 4,180,628). This enables tungsten recovery with negligible disruption to the existing plant. Through subsequent cooperative efforts with the commercial processor, feasibility of tungsten recovery on a commercial scale was shown. Present research is directed toward developing basic technology for tungsten product recovery from the ion exchange stripping solutions. Further development of the process to improve economics will be left to the private sector. (SL-83-ET-8)

Byproduct Recovery from Leaching of Low-Grade Copper Ores (FY 81, 82, and 83)

Many valuable byproduct metals such as molybdenum, tungsten, manganese, aluminum, gold, silver, and titanium are not fully recovered during the leaching of low-grade copper ores and slags. The Bureau is conducting research to improve the basic knowledge of leaching chemistry, so that technology can be devised for significantly improving byproduct metal recoveries. (TC-83-ET-2)

Vanadium, Tantalum, and Niobium (Columbium)

Vanadium Recovery from Western Resources (FY 81, 82, and 83)

In order to augment the U.S. reserve base for vanadium and uranium, improved methods are being devised for recovering vanadium and uranium from very low-grade western shales. (SL-83-ET-7)

Tantalum and Columbium from Domestic Resources (FY 81, 82, and 83)

The United States is entirely dependent on imports for its columbium and tantalum needs. Large, low-grade domestic deposits exist, but current technology is not adequate for economical recovery. Research is being conducted to obtain a concentrate from domestic resources that will be amenable to state-of-the-art recovery technology or to new or modified recovery techniques. (RE-83-ET-5)

Alloy Steels and Superalloys

Wear of Mining Equipment (FY 82 and 83)

Wear and corrosion are major factors in mining equipment failures that result in lower productivity and greater work hazards. The Bureau's high level of expertise in wear and corrosion will be combined with its expertise in mine operations and safety, and directed toward identifying research opportunities to improve performance of mine equipment while reducing the use of critical and strategic metals. (S-83-MR-1)

Hardfacing Alloys Containing Minimal Critical Metals (FY 82 and 83)

Mining and mineral processing equipment utilizes hardfacing techniques to retard excessive wear. Conventional hardfacing alloys are high in critical metals such as cobalt, nickel, manganese, and chromium, which are to a large extent lost in this essentially dissipative use. This research is directed toward finding new iron-base hardfacing alloys which conserve critical metals, improve processing efficiency, and lower costs. (RO-83-MR-1)

Surface Alloying of Iron-Base Castings (FY 82 only)

Abrasion-resistant materials are required in high-impact applications. This research will evaluate the concept of transferring an abrasion-resistant coating to a low-alloy casting during pouring, thereby conserving the use of critical alloying elements while the substrate can be designed for strength and toughness. Unlike coatings applied to solid casting surfaces, the bond between the coating and casting in this method shows a diffusion gradient with a resultant increase in bond strength. Thermal stresses encountered during conventional coating processes are also avoided. (AL-82-MR-24)

Wear-Resistant Materials for Mining and Mineral Processing Equipment (FY 81, 82, and 83)

Impact wear and abrasion in mining and milling operations result in such a high rate of materials loss that equipment operational life expectancies are sometimes measured in days and weeks. Present trends in material selection for the fabrication of such equipment requires greater use of the critical materials chromium, nickel, cobalt, and manganese. To help reduce this demand, new steels containing complex carbides and intermetallic compounds, designed specifically to resist high-impact wear for use in crushing and grinding operations are being investigated. Additionally, studies are being conducted on low-stress abrasion and the mechanism of erosion of pipes and fittings used for the pneumatic transport of ores, coal, and ash. To accomplish this research in a meaningful and practical manner, a facilitiy for simulating wear under a variety of conditions has been assembled for laboratory evaluation of wear-resistant materials. (AL-83-MR-3)

Substitutes for Critical Materials in Mining and Mineral Processing Equipment (FY 81, 82, and 83)

Improved materials of construction are needed in the harsh environments of wear and erosion that are encountered in the areas of mining and metallurgical processes. Presently these needs are satisfied mainly through the use of superalloys and cobalt-bonded carbides. Without exception, these materials contain significant amounts of expensive and critical metals such as chromium, cobalt, tantalum, and manganese. This research is directed toward the preparation of substitute materials of construction for use in hostile environments through the use of cast-on surface coatings, implants, or infused hard particles for improved wear- and erosion-resistance. Unlike coatings applied to solid casting surfaces, the bond between the coatings and castings using this method shows a diffusion gradient with a resultant increase in bond strength. Substitute binders for cemented carbide cutting tools and carbide substitutes for tantalum carbide and tungsten carbide in C-5 grade cermets will be evaluated. (AL-83-MR-7)

Surface Nitriding for Corrosion Protection of Pump and Valve Components (FY 82 only)

Alloys of nickel, chromium, cobalt, manganese, and other critical metals are frequently used to withstand the hot, corrosive environments typical of those known or anticipated to exist in processes associated with alternate fuels technologies. In addition, initial literature evaluations indicate that other recently devised nitrided materials are very resistant to abrasion and wear. This research will determine the feasibility of using nitrided materials for pump and valve components to replace currently used components that contain large amounts of critical metals. Because of the similarities in the environments, the results of this research will be directly transferrable to the solution of materials problems in the minerals processing industries. (AV-82-MR-12)

Reinforced Composites for High-Temperature Service (FY 81 and 82)

Investigations are under way to substitute metal-matrix composite materials for the chromium-and cobalt-laden superalloys used in gas turbine engines. These composite materials are ferritic and austenitic iron-aluminum matrices that are reinforced with either silicon carbide filaments or alumina dispersoids. Silicon carbide fiber-reinforced composites would be used in turbine blades that require longitudinal strength. The oxide (alumina) dispersion-strengthened materials, prepared from mechanically attrited prealloyed metal powders, would be used in turbine disks. (Army Materials and Mechanics Research Center/H0188162-AL)

Dispersion Strengthened Alloys to Reduce Critical Materials Needs (FY 82 only)

This research is directed at reducing the amount of chromium, cobalt, and manganese in alloys by taking advantage of the unique properties that can be achieved by dispersion of intermetallic phases in iron alloys. This technology is known to impart unique high-temperature strength and oxidation resistance. Specific alloy systems being studied contain dispersions of NiAl compounds in iron-base alloys. These alloys have been shown to resist oxidation and sulfidation at 850°C. (AL-82-MR-22)

Alloys to Resist Hydrogen Embrittlement (FY 82 only)

Containment vessels used in metallurgical processes are susceptible to hydrogen embrittlement that can lead to catastrophic brittle failure. Current state of the art addresses this problem by using steels and alloys rich in critical metals. This research will identify alloys which will resist hydrogen embrittlement with minimum amounts of critical metals. (RO-82-MR-15)

Chemical Vapor Deposited Coatings for Valve Components (FY 82 only)

Chemical Vapor Deposited (CVD) coatings and technology have the potential to provide substitutes for alloys containing critical minerals in metallurgical, mining, and energy conversion systems. Cermet or ceramic CVD coatings can be utilized to provide erosion-, abrasion-, and corrosion-resistant coatings on low-alloy materials. The objective of this research is to devise substitutes and alternatives for critical and strategic mineral-containing components by application of CVD coatings and technology for increasing the erosion-, abrasion-, and corrosion-resistance of low-alloy materials. (RO-82-MR-13)

Critical Metals Recovery from Superalloy Scrap (FY 81 and 82)

Superalloy scrap will be cast into anodes to test the applicability of electrodeposition techniques for producing cobalt and nickel master alloys. In addition, potential methods for recovery of metals such as chromium, tungsten, and molybdenum from electrolytic sludges will be investigated. Electrolytic studies will also be conducted on samples of intermetallic compounds produced from superalloy scrap at the Reno Research Center. (RO-82-MR-7)

Recovery of Nickel, Cobalt, and Chromium from Stainless Steel and Superalloy Wastes (FY 83 only)

Research is under way to develop technologies for recovering nickel, cobalt, and chromium from ferrous alloy slags, spent specialty alloy acid pickling solutions, and mixed and contaminated superalloy scrap. Techniques being investigated for processing the slag include flotation, electrostatic separation, and smelting. Electrolytic methods will be devised for regenerating the spent pickle liquors while recovering nickel and chromium, and for recovering cobalt, nickel, and chromium from superalloy scrap. Application of these technologies will lessen dependence on foreign sources for cobalt, nickel, and chromium. (RO-83-MR-5)

Recovery of Critical Metals from Superalloy Scrap by Formation of Intermetallic Compound (FY 82 and 83)

A Bureau-patented process will be tested for converting unreactive superalloy scrap into intermetallic compounds with zinc or aluminum, a form that greatly reduces the dissolution time of cobalt, nickel, chromium, and other metal values in various solvents. Removal and recovery of zinc from zinc-superalloy intermetallics by distillation also will be investigated. Following dissolution of the alloy in acid solutions, recovery of the metal values by precipitation, cementation, ion exchange, and solvent extraction methods will be investigated. (RE-83-MR-1)

Assessment of Critical Metals in Waste Catalysts (FY 82 and 83)

The catalyst industry will be analyzed to determine the quantities of metals such as cobalt, chromium, nickel, copper, zinc, and molybdenum contained in spent catalysts. While it is known that certain waste catalysts (e.g., those containing precious metals) are being processed by various recovery plants, it is not known to what extent all spent catalysts are being treated. The scope of the contract is to determine the extent of mineral recovery being currently applied to these wastes and to delineate research needs in this area. (AL-82-MR-11 and Inco Research and Development Center/J0215042)

Recovery of Critical Metals from Waste Catalysts (FY 83 only; see above)

A recent contract report has delineated the quantities of metals, such as cobalt, chromium, nickel, copper, zinc, and molybdenum, contained in spent catalysts, and the extent of metal recovery currently obtained from these wastes. Based on these results, investigations will now focus on technology for recovering Ni, Mo, Co, and W from spent hydrodesulfurization catalysts; Cr from high-temperature shift catalysts; Cu, Ni, and Cr from certain hydrogenation spent catalysts; and Ni from activated Ni ("Raney Ni") waste catalysts. (AL-83-MR-8)

Critical Metals Recovery from Grinding Wastes (FY 82 and 83)

The objective of this work is to devise and test economically feasible techniques for recovering cobalt, nickel, chromium, and other values from grinding sludges. Efforts will concentrate on separating alumina particles from critical metal values and reducing the iron contamination in the sludges resulting from the grinding of hardfaced valves used in internal combustion engines. (SL-83-MR-3)

REFRACTORY METALS

Titanium

Utilization of Catalysts to Decrease Energy Requirements for the Preparation of Titanium from Domestic Titaniferous Materials (FY 81, 82, and 83)

Declining domestic reserves of high-grade iron ores and the importation of most of our titanium needs as rutile have stimulated the evaluation of more plentiful domestic reserves such as ilmenites and titaniferous magnetites as sources of iron and titanium. Prereduction using low-grade reductants and catalysts and the effect of promoters on selectrive sulfation to remove troublesome impurities are being evaluated in a large-scale continuous-circuit process research unit. Process characteristics, energy use, and metal product quality are being determined. (AL-82-MR-7)

Titanium Recovery from Domestic Perovskite Ores (FY 82 and 83)

Titanium has many applications where high-temperature strength and/or corrosion resistance is required. Titanium dioxide is used as a pigment. About 60 percent of the U.S. requirements for titanium are met from foreign sources. Therefore, beneficiation, hydrometallurgical, and pyrometallurgical techniques will be investigated for extracting TiO_2 from domestic perovskite in a form suitable for use as a pigment and/or production of titanium metal. (SL-83-ET-5)

Byproduct Titanium and Tungsten Recovery from Tar Sand Residues (FY 82 only)

There are seven major tar sands deposits in the United States totalling over 8×10^{10} tons of tar sands which contain titanium, tungsten, and aluminum in addition to recoverable bitumen. Currently the U.S. Department of Energy, the University of Utah, and others are working on technologies that recover bitumen from these tar sands leaving a waste residual of relatively clean sands. Processes will be devised to recover the metal values from the clean sands so that byproduct recovery systems can be added to commercial bitumen recovery facilities. (SL-82-MR-21)

Recovery of Critical and Strategic Minerals from Western Copper Ore (FY 82 and 83)

Some porphyry copper ores currently being mined contain trace amounts of materials such as cobalt, titanium, and tungsten that are lost in processing. In view of the large tonnage of copper ores processed each year, the trace amounts add up to a significant quantity of critical materials lost. On the other hand, the quantities are not economically significant enough to justify research by the private sector to recover them. The Bureau of Mines is, therefore, conducting research to identify and characterize the critical minerals present in the porphyry copper ores and to develop the scientific basis for recovery that can be incorporated into current copper processing operations. (TU-83-ET-2)

Recovery and Reuse of Chlorine from Ferric Chloride (FY 82 and 83)

Substitution of domestic ilmenite for rutile used in commercial Ti extraction processes results in the production of $FeCl_3$ as well as $TiCl_4$. To foster the use of ilmenite, this research is directed toward developing technology that will enable commercial $TiCl_4$ plants to dechlorinate the $FeCl_3$ wastes. Oxidizing $FeCl_3$ at 400 to 500° produces $FeCl_2$ and chlorine, which can be recycled to the chlorinator. The ability to dechlorinate $FeCl_3$ will conserve chlorine while eliminating the environmental problems associated with $FeCl_3$ disposal. Solving the disposal problem should encourage the increased use of ilmenite as a domestic source of titanium. (AL-83-MR-10)

High-Purity Titanium Powder for Making Powder Metallurgy Components (FY 81 only)

High-purity titanium powder could be used to make substitute materials for many high-performance applications of nickel and cobalt superalloys. Research is being conducted to prepare the titanium powder from molten metal contained in a novel induction furnace patented by the Bureau. An important objective is to prevent contamination of the powder with chlorine and tungsten, both of which can be introduced into the metal by conventional processing methods. Powder metallurgy offers an additional advantage of producing near-net-shape parts that minimize forging and machining. (ALRC)

Vapor Phase Preparation of Titanium Alloy Powder (FY 82 and 83)

Powder metallurgy techniques for producing titanium alloy components will conserve materials and improve productivity as well as offer a substitute material for chromium alloys currently used to provide corrosion resistance. This research is directed toward an innovative, economical method for producing titanium alloy powder from the vapor phase by coreduction of titanium, aluminum, and other metal chlorides. (SL-83-MR-2)

Improved Titanium Casting Technology (FY 82 and 83)

Limitations inherent in current titanium fabrication and processing technology impede additional uses for the metal. Investment castings of titanium strengthened by hot isostatic pressing are presently being evaluated commercially. However, investment castings are too expensive for chemical processing components and the less expensive castings produced in rammed graphite molds contain embrittling carbon contamination. The Bureau has developed zircon sand molds for titanium casting that eliminate many of the problems associated with rammed graphite, including carbon contamination, and they are less expensive than investment castings. Hot isostatic pressing of titanium components fabricated in zircon sand molds to provide near net-shape castings with improved physical properties will be investigated. (AL-83-MR-6)

Zirconium and Hafnium

Miniplant Evaluation of Zr/Hf Separation Technology (FY 81 only)

The Bureau-developed method for recovering nuclear-grade zirconium oxide from zircon sand will be tested at a scale of 100 lb ZrO_2/day in order to obtain engineering data to facilitate technology transfer. (BCEL)

Improved Zirconium/Hafnium Separation Technology (FY 81 and 82)

In anticipation of increasing U.S. demand for nuclear-grade zirconium for nuclear power reactors, the Bureau has devised an improved, more environmentally acceptable method for recovering hafnium-free zirconium oxide from zircon sand. The process involves caustic fusion, leaching, solvent extraction, using reagents only recently available, and hydrothermal precipitation. To conclude the research, the recovery of hafnium oxide from solvent extraction system raffinates will be demonstrated. (RE-82-MR-7)

Fractionation of Metal Chloride Mixtures (FY 82 and 83)

Carbochlorination is an attractive technique for opening ores such as zircon and clay. In order to get a nuclear-grade zirconium tetrachloride product it is necessary to separate hafnium chloride having nearly the same sublimation point, and in order to get a cell-grade aluminum chloride, it is necessary to separate silicon tetrachloride, ferric chloride, and titanium tetrachloride from the reaction mixture. Research will include fundamental and laboratory studies on a variety of methods whereby such separations might be carried out efficiently and economically. (BC-82-MR-1)

Calcia-Stabilized Zirconia Refractory Castables (FY 81 only)

The objective is to investigate and characterize calcium aluminate-bonded, high-ZrO_2 castables produced from commercially available raw materials. (TURC/Georgia Institute of Technology)

Rare Earths and Barium

Rare-Earth Technology (FY 81 only)

With demand for the rare-earths increasing, especially for catalysts, in iron and steel making, and in permanent magnets, the Bureau is investigating improved flotation techniques to increase recovery from bastinasite ore, as well as methods for recovering a barite product. (RERC)

NONFERROUS METALS

Aluminum

Extraction of Alumina from Clay Using Hydrochloric Acid Leaching (FY 81, 82, and 83)

The United States imports 93 percent of the aluminum raw material required to feed the existing domestic aluminum smelters. In an effort to provide technology options for reducing this nation's dependence on imported raw materials, the Bureau of Mines began an alumina research program to investigate the nonproprietary technology options available for recovering alumina from domestic resources. One technology involves the hydrochloric acid leaching, gas sparging crystallization technology in which the alumina is leached from kaolinitic clay as aluminum chloride. This aluminum chloride is crystallized from solution by sparging with hydrogen chloride and is then decomposed to alumina and hydrogen chloride. Selected primary and secondary unit operations in the cyclic flowsheet are under investigation and research will involve the treatment of ferric chloride waste liquor with calcined kaolinitic clay and alternate leaching techniques, such as quiescent dissolving of alumina from the calcined material. (BC-82-MR-3)

Research related to the alumina miniplant project is being coordinated and transfer of technical information resulting from miniplant operations is being effected by preparation of manuscripts reporting on R&D connected with the miniplant. (BC-83-ET-1)

Bleedstream Treatment and Aluminum Chloride Hexahydrate Dissolver Design (FY 81 and 82)

In the research on a hydrochloric acid leaching technology, a mother liquor is produced during crystallization of aluminum chloride hexahydrate, which is recycled to recover the aluminum and acid content.

This mother liquor also contains impurity chlorides, which, if recycled, will build up and eventually contaminate the alumina product. To reduce the impurity from recycling, a bleedstream is drawn off. Research is investigating the recovery of hydrochloric acid and aluminum chloride from the bleedstream prior to disposal. (RE-82-MR-12)

Leaching Clay with Aluminum Chloride Solution to Extract Alumina (FY 81 and 82)

A technique is being studied to use aluminum chloride solution to leach alumina from clay as an aluminum hydroxyl chloride, which is subsequently converted to alumina. (RERC)

Hydrothermal Precipitation of Boehmite from Aluminum Chloride Solutions (FY 81 only)

Precipitation of boehmite (alumina monohydrate) from aluminum chloride solutions resulting from hydrochloric acid leaching of clay is being studied. (RERC/SRI International)

Alumina from Domestic Clay Resources and Bauxite (FY 83 only)

Investigations on clay-HCl process bleedstream treatment, aluminum chlor-hexahydrate dissolve design, and leaching clay with aluminum salt solutions will be completed and research will be begun on methods for removing or deactivating organic impurities in Bayer process liquors. (RE-83-ET-1)

Extraction of Alumina from Anorthosite Using Hydrochloric Acid Leaching (FY 82 only)

The hydrochloric acid leaching of anorthosite is being studied as a means to utilize the anorthosite as a resource for alumina, for which major solution purification techniques may not be needed. (RE-82-MR-14)

Recovering Alumina from Coal Ash and Coal Shale (FY 82 and 83)

Research is being conducted to evaluate the technical and economic feasibility of extracting alumina from coal wastes. Following an evaluation of the suitability of alumina extraction processes for specific coal wastes, beneficiation and extraction procedures will be tested to determine the relative extractability of alumina. Identification of commercially feasible technology would allow the extraction of alumina from at least some of the 150 million tons of coal wastes generated annually. (BC-83-MR-2)

Extraction of Alumina from Anthracite Culm with Energy Recovery (FY 81 and 82)

Culm wastes from mining of anthracite contain about 15 percent alumina. Roasting of the anthracite culm is being studied for production of an ash that would contain the alumina in a form recoverable by acid leaching and for utilization of the culm as a source of energy for alumina processing. (Energy, Inc./J0215022-RE)

Extraction of Alumina from Clay Using Nitric Acid Leaching (FY 81 only)

Technology for leaching alumina from clay with nitric acid was investigated in the recent past. To complete the study, engineering data missing for the evaporative crystallization of aluminum nitrate nonahydrate from solution is being obtained. (BCEL)

Evaluation of Environmental Factors in the Utilization of Domestic Resources for Alumina Recovery (FY 81 only)

Studies are being made to determine environmental and health factors that could result if a 25 ton/day alumina pilot plant (previously designed by Kaiser Engineers) were operated using a clay/hydrochloric acid leaching technology. (RERC/REDCo Environmental, Inc./Colorado School of Mines Research Institute)

Soda Ash and Alumina from Dawsonite-Bearing Oil Shale (FY 81, 82, and 83)

The focus of this research is the design of a practical flowsheet for the extraction of alumina and soda from retorted oil shale. Laboratory investigations are concerned with the unit operations which may require substantial improvement to make the process feasible. These include retorting, leaching, pregnant liquor purification, and precipitation of alumina tri-hydrate. Availability of this technology should enhance the overall economics of utilizing oil shale, as well as make available a domestic source of alumina. (AL-83-MR-11)

Carbochlorination of Domestic Clay for Recovery of Alumina (FY 81, 82, and 83)

Fundamental research is being conducted on the carbochlorination of domestic kaolinitic clay to establish the chemical and physical requirements for improving selectivity of aluminum chlorination and separation of pure aluminum chloride from other metal chlorides, for use in manufacturing aluminum. (AL-83-ET-5)

Formation of Vapor Complexes Between Aluminum Chloride and Impurity Elements Associated With Aluminous Raw Materials (FY 81 and 82)

During carbochlorination of aluminous raw materials, vapor complexes may be formed between aluminum chloride and impurity elements found in the raw material. A mass spectrographic approach is being used to investigate reactions between clay and chlorine as well as the function of catalysts in the system. (Colorado School of Mines/J0199151-AL)

Development of a Salt-Free Aluminum Remelting Process (FY 82 and 83)

Bureau-patented technology for fluxless remelting of aluminum scrap and dross will be tested in an industrial-type furnace with industry cooperation under memoranda of agreement with the Aluminum Recycling Association and the National Association of Recycling Industries. A production furnace will then be modified, trial heats conducted, and the economic/technical feasibility evaluated. (AV-83-MR-6)

Recovery of Aluminum from Dross by Ultrasonic Coalescence (FY 83 only)

The feasibility of utilizing ultrasonics for separating molten aluminum metal from dross will be determined. Laboratory procedures will be established for measuring the ability of ultrasonic vibrations to promote metal coalescence in a metal oxide mixture. (AV-83-MR-7)

Copper

Chemical Treatment of Complex Sulfides (FY 81, 82, and 83)

Hydrometallurigical methods are being investigated for recovering zinc, lead, copper, silver, cobalt, arsenic, and associated metals from complex sulfide ores and concentrates as a means of adding to the U.S. reserve base for those metals. (RE-83-ET-7)

Copper Leaching Practices in the Western United States (FY 81 only)

The objective is to up-date Bureau of Mines Information Circular 8314 (published in 1968) by expanding several sections and adding new sections on solvent extraction-electrowinning and in situ leaching. (SLRC/New Mexico Institute of Mining and Technology)

Copper Dump Leaching Techniques (FY 81 only)

Copper dump leaching now represents about 10 percent of domestic copper production. Research is being conducted to improve dump leaching recovery by developing techniques to minimize plugging, channeling, and iron salt buildup while maximizing the amount of materials exposed to leach solution. (TCRC)

Chlorine-Oxygen Leaching of Complex Sulfides (FY 82 only)

Additional applications are being investigated for the Bureau-developed chlorine-oxygen or acid-oxygen pressure leaching techniques for recovering metal values from complex sulfides without evolution of sulfur oxides. Examples include nickel/cobalt from Duluth Gabbro concentrates, precious and base metals from arsenic-bearing sulfide resources, and treating domestic copper concentrate so that it can be legally used in U.S. smelters. (RE-82-MR-4)

Leaching of Bormite with Oxygen and Ferric Chloride as Oxidants (FY 81 and 82)

Little is known about the leaching behavior of bormite under heap leaching conditions. Research is being conducted to better understand the induction period observed with oxygen leaching and to compare ferric chloride with the more usual ferric sulfate leaching agent. The information will be useful in mathematical modeling of copper dump leaching. (University of Utah/G0284001-SL)

Leaching Systems for Depleted Underground Uranium and Copper Mines (FY 81 only)

The fringes of many depleted underground copper and uranium mines contain mineral values that could be extracted by in situ leaching. Pillars left behind after conventional mining operations represent a source of otherwise irretrievable mineral commodity. Possible leaching systems for these mines will be evaluated and potentially favorable locations will be assessed for implementing these systems. (TCRC/Mountain States Research and Development)

Concentration of Impurity Elements from Copper Reverberatory Slags (FY 81 only)

Impurities are important in the production of copper because of their influence on the electrolytic refining of anode copper and the necessity of many copper smelters to meet stringent environmental standards. The investigation is divided into two parts. One part is the identification of the forms and amounts in which impurities are present in the slag; the other involves the evaluation of high-temperature techniques for the recovery of impurity values from the slags. (ALRC/University of Nevada)

Metals Recovery from Copper, Brass, and Bronze Flue Dusts (FY 81, 82, and 83)

Current estimates place the production of copper and brass smelter flue dusts at 24 to 44 lbs of dust per ton of metal produced. These dusts, most of which are disposed of in landfills at some cost, contain as much as 60 percent zinc, 3 percent tin, and 6 percent copper, amounting to millions of dollars of metals lost annually. Research is being conducted to devise and test environmentally acceptable, nonacidic leaching technology to convert these dusts into marketable metals and/or compounds. (AV-83-MR-3)

Protective Coatings of Electrodeposited Copper-Nickel Alloys (FY 83 only)

A number of copper-nickel alloys, especially the Monel alloys (60 to 70 percent Ni), are widely used. These alloys, which are noted for their excellent corrosion resistance and strength, have many diversified uses in chemical and metallurgical processing. They are also the preferred alloy for use in marine-type environments. Previous Bureau research revealed that copper-nickel alloys can be uniquely electroplated in alloy form on metallic substrates from acetate electrolytes (U.S. Patent 4,167,459). Preliminary tests indicated that such copper-nickel deposits are dense, nonporous, homogeneous, adherent, and exhibit the excellent corrosion resistance characteristic of Monel alloys. Research is being conducted to extend the development of this basic discovery by devising methodology for electroplating the copper-nickel alloys onto common structural alloys including plain-carbon steel, aluminum, zinc, copper, and magnesium alloys. Deposits will also be made on Monel alloys to simulate repair build-up requirements. Major parameters such as electrolyte composition and pH, temperature, current density, additives, and anode materials will be assessed. (RO-83-MR-3)

Uranium, Leaching

Geochemical Model Development for Uranium in situ Leaching (FY 81 only)

Computer models that simulate in situ leaching processes are very useful for evaluating and optimizing lixiviant compositions, well-field designs, pumping rates, and other site-specific factors that are important to the success of leaching operations. The previously developed kinetic chemical model and the hydrology model are being updated, validated, and coupled to increase modeling capabilities. An equilibrium chemistry model capable of simulating site restoration is also being updated. (TCRC)

Kinetic Modeling of Uranium Solution Mining (FY 81 only)

A series of laboratory leaching experiments will be used to (1) develop quantitative models to describe the solubility of uranium peroxide and the oxidation, by hydrogen peroxide, of uraninite and pyrite under conditions found in the solution mining of uranium with an acidic lixiviant, and (2) develop and validate a model of the in situ leaching process which combines the quantitative geochemical model with a one-dimensional fluid flow simulation. (TCRC/Pennsylvania State University)

Cost and Sensitivity Analysis for Uranium in situ Leach Mining (FY 81 only)

Articles on in situ leaching costs have been written, but these are summary cost articles which do not detail costs of items such as pumps, casing, regional differences due to weather, and different reclamation and restoration rules. This contract objective is to determine detailed costs for several types of uranium in situ leaching operations, both pilot scale and commercial. (TCRC/NUS Corporation)

Zinc

Defluorinating Zinc Concentrates (FY 81 and 82)

Byproduct sphalerite concentrates from fluorite mining and milling operations now are considered undesirable by zinc producers because of their residual fluorite content. Methods will be investigated for either removing or controlling the fluorite in order to make the concentrates usable, thereby increasing the U.S. reserve base. (RO-82-MR-1)

Zinc Sulfide Retorting Without Pollution (FY 81 only)

Research is being conducted to study the retorting of zinc sulfide concentrate with the addition of sufficient lime and carbon to fix the sulfur as calcium sulfide, and to recover the zinc by condensing the vapor formed during this reaction. The residue is to be oxidized to stable calcium sulfate, and the energy from this step is recovered. (RORC/University of Utah)

Utilizing Zinc Wastes for Electrogalvanizing (FY 82 and 83)

The feasibility of using oxidized zinc wastes from a variety of sources as a replacement for primary zinc in electrogalvanizing will be determined. Using electrolytes prepared from zinc wastes, cyclic voltametry and electrogalvanizing tests will be conducted to determine the effects of pH, current density, temperature, impurities, and additives. The galvanized products will be subjected to corrosion tests and assessments of the coatings will be made. (RO-83-MR-6 and University of Missouri/H0222002-RO)

Improved Electrolytic Metal Processing by Means of Voltametry Techniques (FY 81 only)

Cyclic voltametry techniques will be used to characterize the zinc sulfate electrolytes used in zinc electrowinning. Ultimately, a portable electrochemical system will be developed that can be used in zinc electrowinning cell rooms to evaluate electrolyte quality. (RORC/University of Missouri)

Lead

Recovery of Lead from Lead Sulfide Concentrates (FY 81 and 82)

Research is being conducted on a nonpolluting process that recovers the lead as metal and the sulfur as hydrogen sulfide from lead sulfide concentrates. The reaction involved is the direct reduction of galena by carbon and calcium carbonate to yield lead metal and calcium sulfide. The latter product then is converted to calcium carbonate and hydrogen sulfide by reaction with carbon dioxide and water vapor. The hydrogen sulfide could be converted to elemental sulfur by the well-known Claus process. (University of Washington/J0205011-RE)

Ferric Chloride Leaching of Galena Concentrates/Fused-Salt Electrolysis of Lead Chloride (FY 81, 82, and 83)

A hydrometallurgical/fused-salt electrolysis process has been demonstrated in a process research unit that can produce at a rate of 500 lb/day of lead to obtain engineering data for technology transfer. Four lead producers are cooperating with the Bureau of Mines in this project: AMAX Lead and Zinc, Inc.; ASARCO; COMINCO, Ltd.; and St. Joe Minerals Corporation. Lead metal 99.999 percent pure has been produced in five-day campaigns, while maintaining lead concentrations in the workplace below OSHA standards. Research continues to complete the evaluation of the process for production of lead from galena concentrates and to test the process on a galena concentrate other than St. Joe's Missouri concentrate. (RE-83-ET-4)

Kinetics of Ferric-Chloride Leaching of Galena (FY 82 and 83)

In recent years the dissolution of galena with ferric chloride as an alternate to smelting for producing lead from sulfide concentrates has received particular attention because the processes would eliminate the generation of sulfur dioxide and lead-bearing particulates. Information on the reaction kinetics of galena in this system is very limited, and much is needed upon which the scale-up, optimization, or control of this promising technique can be based. Therefore, a study is in progress to identify the conditions under which this mineral can be leached effectively and to obtain rate data for the subsequent commercialization of this hydrometallurgical process. (South Dakota School of Mines and Technology/J0215026-RE)

Pollution-Free Technology for Battery Scrap (FY 81 only)

The Bureau developed environmentally acceptable pyrometallurgical technology for recycling lead alloys from scrap lead-acid batteries. This technology will be demonstrated in a newly developed process research unit (PRU), and the feasibility of smelting lead-acid batteries by this process will be studied. The leach and evaporator portions of this PRU will be used to treat salt slag produced in the scrap smelting furnace. (AVRC)

Electrolytic Recycling of Scrap Batteries (FY 81, 82, and 83)

Because of stringent environmental lead standards, new technology is required to insure the continued viability of the secondary lead industry. An electrochemical method is being developed for recycling lead from scrap batteries that is more energy-efficient and less polluting than conventional smelting. Sludge from scrapped lead-antimony batteries is carbonated with ammonium carbonate and leached with fluorosilicic acid in 120-liter plastic reactors. Lead is electrowon from the leach liquor. Adaptation of this technology on a bench scale to the processing of scrap from maintenance-free batteries is under way. (RO-83-MR-4)

Tin

Developing New Methods for Economical Recovery of Tin from Cans Recovered from Municipal Waste (FY 81 and 82)

Ferrous materials magnetically separated from municipal refuse at large resource recovery facilities are neither clean enough nor generated in sufficient quantities at individual facilities to be effectively utilized by current commercial detinning plants. The contractor will evaluate a number of metallurgical processes which have potential application for detinning cans in order to determine which process has the highest potential for this use. In-house research will provide data on the use of electrorefining tin scrap in acid fluoroborate electrolyte as well as on the solid state reaction of tin scrap with alkali salts at low to moderately elevated temperture. (AV-82-MR-10 and Arthur D. Little, Inc./J0113039)

Improved Soldering and Brazing Systems (FY 81 and 82)

There are numerous conventional, as well as promising, use areas where tin-lead solders have neither the strength nor the temperature stability required. Higher-temperature silver brazing alloys are normally used, although their strength and higher melting temperature (this can degrade substrate) are not needed. This practice is wasteful of silver for which the nation has a high foreign reliance. Zinc-base solders under investigation may substitute for silver-bearing fillers because of higher strength and temperature stability. Also, copper-base or other brazing alloys may substitute for silver-bearing brazing alloys. Investigation of fluxing practice to minimize pollution or corrosion problems is another part of this research. (RO-82-MR-11)

Gold, Silver, and Mercury

Gold and Silver Recovery from Low-Grade Resources and Heap Leach Solutions (FY 81, 82, and 83)

Although U.S. silver and gold resources are large, many deposits are too low-grade or too small for economical processing by conventional technology. New and improved methods for efficiently recovering silver and gold from such low-grade or refractory ores are being devised. Of particular interest is a particle agglomeration technique for treating clayey ores and mill tailings, and solutions generated by heap leaching low-grade resources are being devised. Research is being conducted on new cell designs, direct electrowinning of cyanide solutions, recovery from acid thiourea solutions, chemical fate of cyanide in tailings, and improved particle agglomeration technology. (RE-83-ET-2)

Improved Precious Metal Recovery Systems (FY 82 and 83)

Research is being conducted to develop less energy-intensive and more economical methods for recovering gold, silver, and byproduct mercury from low-grade resources. Alternate adsorbents, ion exchange resins, electrolytic stripping, and a variety of novel leaching techniques are being investigated. (SL-83-ET-3)

Recovery of Byproduct Mercury from Gold and Silver Ores (FY 82 only)

Present technology recovers less than 10 percent of the mercury values in precious metal ores. This project will investigate recovery of byproduct mercury by enhancing its solubility in leach solutions, and improving selective recovery of mercury by ion exchange or electrowinning. (SL-82-MR-19)

Cyanide Longevity in Heap Leaches (FY 82 only)

The increase in mining of low-grade precious metal ores utilizing the Bureau-developed technique of cyanide heap leaching has resulted in the potential for large amounts of cyanide to be tied up in leached pile in Nevada, Utah, Arizona, and New Mexico. The Bureau will determine how long cyanide exists in the nonoxidizing interior of heap dumps, and devise oxidizing techniques to destroy residual cyanide as part of the original recovery system. (RE-82-MR-20)

Precious Metals Recovery from Electronic Scrap (FY 81, 82, and 83)

The need for technology to recover precious metals from concentrated fractions of electronic scrap has been defined by a memorandum of agreement with the National Association of Recycling Industries. Hydrometallurgical techniques developed during this research will be demonstrated to secondary precious metal processors and assessments will be made. In addition, the Bureau's physical beneficiation pilot plant which concentrates the precious metal fractions of military and industrial electronic scrap will be transferred to the Defense Property Disposal Service for field testing and evaluation. (AV-83-MR-4)

NONMETALS

Fluorine and Lithium

Recovery of Fluorite from Marginal Resources (FY 82 and 83)

At the projected rate of consumption, known fluorite deposits of the world are expected to be depleted by the year 2000. In cooperation with the Western and Intermountain Field Operations Centers, and the U.S. Geological Survey, samples of large, low-grade fluorite resources are being characterized and chemically analyzed. A variety of preconcentration and beneficiation techniques are being investigated to see if a concentrate meeting at least metallurgical-grade specifications can be produced. (SL-83-ET-6)

Lithium

Lithium from Clay (FY 81, 82, and 83)

New battery systems and the development of fusion reactors for electrical power generation will greatly increase the need for lithium. However, domestic reserves of this metal will be insufficient early in the next century. This research project has demonstrated on a laboratory scale two technologically and economically attractive methods for extracting lithium from a vast deposit of clays situated in Nevada. A process demonstration unit is being operated for a more promising method to generate engineering and cost data for technology transfer. (SL-83-ET-2)

Phosphorus

Beneficiation of Dolomitic Phosphate Ores (FY 81, 82, and 83)

High-magnesia phosphate material is bypassed in current mining operations. To expand the domestic phosphate reserve base, new and improved beneficiation methods for recovering phosphate minerals from low-grade and marginal ores and wastes are being devised. Single fatty-acid flotation techniques are being applied to high-magnesia (dolomitic) Florida deposits and calcite-bearing North Carolina resources. (TU-83-ET-1)

Recovery of Water from Slurries of Fine Particles from Mineral Beneficiation (FY 82 only)

Because five tons of water are lost as slime tailings for each ton of phosphate concentrate produced, an efficient, economical method is needed to dewater the slimes and recover the water for reuse. A field test unit with a capacity of 1,000 to 2,000 gallons per minute is being used to test flocculation of the slimes with polyethylene oxide followed by screening. The long-term chemical and physical stability of the solids will be evaluated. (TU-82-MR-5)

Recovery of Phosphate from Dewatered Slimes (FY 83 only)

Technology is being devised to recovery phosphate values from phosphate-bearing clay wastes. Samples of slimes obtained from old ponds will be used to investigate flotation and selective flocculation as methods for phosphate recovery. Commercial extraction of phosphate from these slimes could extend domestic phosphate reserves up to 50 percent. (TU-83-MR-5)

Byproduct Recovery from Phosphate Wastes (FY 81, 82, and 83)

The goal of this research is to improve the technology for recovering vanadium, chromium, and other valuable byproducts from wastes generated during mining and processing of phosphatic materials. Techniques will be evaluated for the dissolution of byproducts as well as methods for byproduct separation and recovery. (AL-82-MR-12)

Beneficiation tailings are mixed with sulfuric acid and heat-cured at 100° to 200°C prior to leaching with water for vanadium recovery. If successful, commercial application of this technology could meet up to 80 percent of the domestic demand for vanadium. (AL-83-MR-9)

Uses for Phosphogypsum Wastes (FY 83 only)

High-volume end uses for phosphogypsum waste are being sought. The most promising use appears to be as an aggregate for highway paving applications. Aggregates containing phosphogypsum will be evaluated for aging, weathering, and suitability in bituminous and concrete paving mixtures. Such uses would eliminate further additions to existing phosphogypsum waste piles in central Florida and could begin to consume these piles currently estimated at over 300 million tons. (TU-83-MR-7)

Potassium

Recovery of Potash from Low-Grade Resources (FY 81 and 82)

Most domestic potash resources are in deposits containing higher clay concentrations and lower potash values than can be economically processed by currently available technology. The purpose of this project is to devise efficient beneficiation systems for separating and recovering potash from high-clay or complex ores, and to investigate methods for decreasing potash losses to the high-clay slimes. (SL-82-MR-8)

Sulfur

Use of Sulfur in Construction Materials (FY 81, 82, and 83)

There is potential excess of elemental sulfur as a result of increased use of pollution-abatement systems that remove SO_2 from stack gases. New uses for elemental sulfur and high-sulfur waste products in construction materials are being devised and evaluated. Promising applications include: the partial replacement of asphalt in paving mixtures; as a tempering agent in recycled pavement; as sulfur concretes for corrosion-resistant tanks, pipes, and floors; and as spray coatings for either the protection of concrete or stabilization of mineral processing tailings. Research emphasis is on plasticizers, uses for sulfur concrete, and evaluation of expansion joint materials and coated reinforcement bar for use in sulfur concrete installations. (BC-83-MR-1)

Use of Sulfur in Sulfur-Asphalt Pavement (FY 81 and 82)

Objectives are to evaluate the postconstruction performance of a sand-asphalt-sulfur pavement placed in Kenedy County, Texas, determine materials behavior and response characteristics for design and performance analysis of sulfur-asphalt pavements, and provide research support to Boulder City Engineering Laboratory. This includes freeze-thaw evaluations of new Bureau of Mines formulations. (Texas A&M Research Foundation/J0177146-BC)

CERAMICS

Alumina Refractories

Domestic Resources for Alumina Refractories (FY 81 only)

The metallurgy industry requires a wide variety of alumina-base refractories, some of which are based on imported ores. The current research centers on three specific problem areas: (1) development of a domestic substitute for imported refractory-grade bauxite, (2) evaluation of Alabama fireclay resources, and (3) evaluation of Nevada zunyite as a refractory mullite source. (TURC)

Gibbsite in Saprolites of East Central Alabama (FY 82 and 83)

The need for a domestic alternative for imported refractory-grade bauxite could be satisfied by abundant saprolite resources if a high-gibbsite concentrate were available. This work is directed toward the evaluation of a number of Alabama saprolite samples to determine their suitability for this purpose. (Geological Survey of Alabama/J0123066-TU)

Desilicated Kaolin for High-Alumina Refractories (FY 81, 82, and 83)

The difficulty in obtaining supplies of imported refractory-grade bauxite has created a need for a domestic alternative. This work is concerned with the use of chemical and beneficiation methods to eliminate undesirable silica and alkaline oxides from kaolin resources for this important application. (AL-83-MR-1)

Strontia

Phase Equilibria Studies of Refractory Oxide Systems (FY 81 and 82)

The objective is to study new systems in order to increase the use of abundant resources for use in refractories. Strontia-base systems are being investigated. (Ohio State University/J0100045-TU)

Zircon

Recycling Zircon from Investment Casting Molds (FY 83 only)

Investment casting methods which traditionally are used to produce precious metal parts at net shape are finding new applications in ferrous and high-alloy foundries. As investment casting technology replaces current production techniques, machining operations and the subsequent handling of machining wastes can be greatly reduced. If a method for recycling the expensive zircon used in investment mold sands could be devised, greater use could be made of this production technique. This work is directed toward developing methods for recycling zircon from current mold sands or, alternately, developing a new zircon mold sand mixture which is recyclable. (TU-83-MR-6)

Other and General

Domestic Resources for Basic Refractories (FY 81 only)

The United States has abundant resources of raw materials for basic refractories and making full use of these domestic resources would be beneficial to the nation. Current research centers on improving periclase refractories to eliminate the need for imported chromite and on exploring the possibility of increased use of abundant dolomite resources. (TURC)

Ceramic Materials from Mineral Wastes (FY 81 and 82)

Mineral waste products are being investigated for potential upgrading to forms that can be substituted for the raw materials normally used to make ceramics. Optimum compositions will be determined, as well as optimum nucleation and recrystallization parameters, for producing a variety of glass-ceramic materials. An algorithm and basic computer program will be devised to assist in determining these optimum compositions as well as any low-cost additions required. (TU-82-MR-6)

Critical Mineral Substitutes in Refractories (FY 83 only)

The metallurgical and ceramic industries utilize a wide variety of alumina-base and basic type refractories, some of which require imported ores. Alumina research centers on four specific problem areas: (1) domestic substitute for imported refractory-grade bauxite, (2) Alabama fireclay resources, (3) refractory evaluation and testing of magnesium aluminate spinel, and (4) impregnating alumina refractories. Basic studies are directed toward improving periclase refractories to eliminate the need for imported chromite and on exploring the possibility of increased use of abundant dolomite resources. (TU-83-MR-1)

Low-Temperature Rapid Solidification Technology for Ceramics (FY 81, 82, and 83)

The objective of this work is to explore the potential of the "evaporative decomposition of solutions" technique to provide homogeneous fine particles of complex compositions as novel precursors for high-purity ceramic products. The resultant particulate matter produced by rapid solidification technology can lead to significant property improvements. (Pennsylvania State University/J0225003-TU)

Use of Refractories for Severe Service Conditions (FY 81, 82, and 83)

There is a continual need for technical data on construction materials for severe thermal and corrosive process conditions. This research focuses on evaluation of acid-resistant refractories for hydrometallurgical processes, development and evaluation of refractories for resistance to high-temperature slags, and evaluation of refractories in high-temperature steam atmospheres. (TU-83-MR-3)

Nonoxide Ceramics (FY 83 only)

The objective is to determine the feasibility of producing nonoxide ceramics as substitutes/alternatives for critical metals. Fine particle nonoxide ceramic powders such as SiC, Si_3N_4, and Sialons will be produced by autogenous attrition grinding and rapid solidification techniques. The powders will be fabricated into ceramic test pieces for high-temperature service, wear, and abrasion evaluation. (TU-83-MR-2)

Fundamental Investigation of Phosphate Bonding (FY 83 only)

The importance of phosphate bonding is based on its use for chemically-bonding refractories. The energy requirements to produce chemically-bonded refractories are much lower than those for sintered refractories. The objective of this research is to improve the basic understanding of phosphate bonding in ceramics, particularly for refractories, in order to increase performance life and reduce dependence on imported raw materials. (Georgia Intitute of Technology/J0123041-TU)

Preparation of Asbestos Substitute Multi-Strand Glass Fibers (FY 83 only)

The objective of this work is to prepare 100 strand fibers of an experimental alkali-resistant glass fiber made from slate and limestone raw materials. Comparisons of the experimental fibers with those available commercially will be made to determine the suitability of the experimental materials as asbestos substitutes in reinforcing applications. (Manville Service Corporation/J0123050-TU)

Alkali Resistance of Silicate Glass Fibers (FY 83 only)

Because of toxicity problems in using asbestos as a reinforcement for cementatious materials, an investigation is being conducted on glass fibers which display the required chemical and physical properties and have the potential for use as a substitute in such applications. Superior fibers have been produced from waste slate and marble dusts, which result in calcium alumina silicate glasses highly resistant to alkali conditions. Research is continuing on studying the basic behavior of these new, novel glasses. (UCLA/J0123028-TU)

Appendix B

THE NATIONAL SCIENCE FOUNDATION'S MINERALS AND PRIMARY MATERIALS PROCESSING PROGRAM

The objective of this program (announced in March 1981) is to support research on physical and chemical phenomena that are associated with minerals production. Mineral processing involves ore preparation by size reduction followed by upgrading using physical and chemical beneficiation techniques. Primary materials processing covers chemical treatment of ores, concentrate, or other suitable raw materials to produce usable forms of metals, refractories, ceramics, or inorganic chemicals. The scope of the research extends to processing of scraps, waste solids, effluents, and subsequent safe disposal or unrecoverable wastes. The major goal of the program is to provide basic engineering knowledge for the development of vastly improved or radically new technologies. The emphasis is on the study of fundamental principles, experimental techniques, mathematical models, and process design.

The program addresses the following aspects of minerals and metal production research:

- Ore preparation and mineral beneficiation.
- Pyrometallurgy and high-temperature processes.
- Leaching and hydrometallurgy.
- Electrochemical processes including electrochemistry of ultrafines and colloids.
- Process design for minerals and primary materials production.

Some of the specific research opportunities in these areas follow:

ORE PREPARATION

Fundamental research to understand the processes of fracture of polycrystalline, polyphase minerals and ores; study of those factors which control the liberation of dissimilar mineral grains and mineral inclusions; study of non-impact methods of comminution; role of surface forces in dry and wet grinding; role of reagents to modify surface forces; size classifications; physics of solids in relation to energy requirement for fracture of intragranular and crystalline bonds; minimum energy requirement of comminution of various mineral species.

MINERAL BENEFICIATION

Study of the physical chemistry of the surfaces in order to improve flotation efficiency and to extend the capability of selective separation of ultrafine particles and oxide minerals; chemistry of reagents with improved specificity for adsorption for flotation, selective flocculation, leaching, and magnetic separation; micromechanisms of interactions between bubbles, oil droplets and particles; analysis of kinetics of mineral separation processes and the influence of process variables; physical-chemical principles of dewatering of slowly settling solids.

PYROMETALLURGICAL PROCESSES

Research on heat and mass transfer mechanisms to improve pelletizing, calcining, roasting, smelting, and metal refining operations; research opportunities in sintering include: heat transfer in packed beds; chemical/physical processes occurring in sintering beds; and development of formed coke substitutes for metallurgical coke. Research opportunities in other high-temperature processes include: thermodynamics of multicomponent systems, separation of slag from metal and matte, fugitive emission control, and recovery of by-products and co-products from process streams, theoretical and experimental studies of chemically complex, high-temperature systems; reactions far removed from equilibrium, e.g., flash pyrolysis, decomposition of complex salts, etc.; gas-solid reactions forming gaseous products like metal halides or compleses, etc.

HYDROMETALLURGICAL PROCESSES

The physical and chemical processes involved in solution mining, dump or heap leaching, hydrometallurgical extraction, and microbial applications are included in this category. Research is needed on basic physical-inorganic chemistry and unit processes, leachant-rock and leachant-ore mineral reactions, and the chemistry of high ionic-strength solutions; chemical reduction of metals from solutions; solvent extraction and high selective chelating reagents; interfacial phenomena at aqueous-organic interfaces; chemical transport membranes; bacterial reactions as applied to mineral recovery, desulfurization of coal, and restoration of the environment following resource recovery.

ELECTROCHEMICAL PROCESSES

Electrochemistry and electrochemical technology play an important role in mineral beneficiation, metallurgy and many industrial processes. Research areas include: electrochemistry of ultrafines and colloids; electrochemistry of mineral dissolution reactions, mass and heat transport phenomena correlations in novel particulate electrolytic processes; ion exchange membranes; fused salt electrolysis, anodic dissolution or chemical generation and displacement (cementation) processes, etc.

PROCESS DESIGN AND OPTIMIZATION

Many aspects of process design which are used routinely in the chemical industry can be profitably utilized in minerals and primary materials production. Such features as continuous operation, staged processes with countercurrent flow of metal and slag can increase throughout process yield, energy efficiency and environmental control. In this context, better knowledge of process chemistry, flow sheet design, and materials for new equipment is needed. The opportunities for fundamental research include: mathematical modeling and computer simulation; scale-up of processing machinery; on-line analysis and sensor applications; computer control; and optimization of flow systems involving two or more phases.

Appendix C

CURRICULA VITAE OF COMMITTEE MEMBERS

NATHANIEL ARBITER is Professor Emeritus of Mineral Engineering, Henry Krumb School of Mines, Columbia University. Prior to joining the Columbia faculty, he served as a research metallurgist with Battelle Memorial Institute and Phelps Dodge Corporation. From 1969 to 1977, he served as director of research and group consulting metallurgist with the Anaconda Company. He was elected a member of the National Academy of Engineering in 1977.

DONALD A. DAHLSTROM is Senior Vice President for Research and Development of EIMCO Process Equipment Company. He received a B.S. degree from the University of Minnesota and a Ph.D. degree in chemical engineering from Northwestern University. His professional experience includes service as a petroleum and chemical engineer with International Petrol Company in Peru, and as a member of the chemical engineering faculty at Northwestern University. He also has been Director of Research and Development for Eimco Corporation, Vice President and Director of Eimco Envirotech, and Vice President for Research and Development of the Process Machinery Group, Envirotech Corporation. He was elected a member of the National Academy of Engineering in 1975.

JOHN J. deBARBADILLO is Department Manager, Processing Research and Development, INCO Alloy Products Company Research Center, Suffern, New York. He received B.S., M.S., and Ph.D. degrees in metallurgy and materials science from Lehigh University. His areas of interest include metals reclamation (particularly superalloy scrap), alloy design, materials substitution, and wrought and cast high-strength steels and stainless steels.

HAROLD E. GOELLER currently is Senior Chemical Engineer, Oak Ridge National Laboratory, Oak Ridge, Tennessee. He has held various positions at the laboratory for the past 36 years, and also has authored and coauthored a variety of publications and books on substitutability, energy resources, resource assessment, nonrenewable resources, and related subjects.

JOHN C. HALL currently is a consultant for Freeport Minerals Company, New York, New York. Until 1980, he was the company's Executive Vice President and Director. Prior to that he was President of the Anaconda

Company and General Manager of the National Lead Company. A member of AIMME and an alumnus of the University of Utah, he also serves on the boards of several corporations.

HERBERT H. KELLOGG is Stanley-Thompson Professor of Chemical Metallurgy, Henry Krumb School of Mines, Columbia University. He has served on the Columbia faculty for 36 years, and his areas of interest include extractive metallurgy, thermodynamics and kinetics of metallurgical reactions, high-temperature chemistry, slag chemistry, and computer modeling of metallurgical processes. He was elected a member of the National Academy of Engineering in 1978.

MILTON E. WADSWORTH is Professor of Metallurgical Engineering and Dean, College of Mines and Mineral Industries, University of Utah. He holds B.S. and Ph.D. degrees in metallurgy from the University of Utah, and his areas of interest include hydrometallurgy, surface reactions in metallurgical processes, flotation, leaching, oxidation, reduction, and corrosion. He was elected a member of the National Academy of Engineering in 1979.