



PB97-120752

Innovation

**A SUMMARY OF
SIGNIFICANT ACHIEVEMENTS
IN MINERALS AND MATERIALS
SCIENCE**

U.S. DEPARTMENT OF THE INTERIOR

*Bureau of
Mines*



ESTABLISHED 1910

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“By scientific innovation,
we mean the process
by which new knowl-
edge and skills are generated
and applied to the social,
economic, and intellectual
operations of society. Inno-
vation, then, is more than
discovery and theorizing,
more than speculation and
invention, and more than
engineering design. For until
the new “know-how” is incor-
porated into what is done by
our economy and our society,
innovation in our sense has
not occurred.”

Donald F. Hornig
“The Role of Government in
Scientific Innovation”
Technological Innovation in the '80s

James S. Coles, Editor

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FOREWORD

Since its founding in 1910, the Bureau of Mines has acted as innovator in the development and advancement of world technology.

Research conducted by the Bureau of Mines encompasses all aspects of the mineral cycle, with special emphasis on advanced materials and materials classified as strategic and critical. With America's growing need to remain competitive in world markets and a growing dependence on foreign sources for these vital minerals, these phases of our research program have become increasingly urgent.

The Bureau's mission is to help assure an adequate and dependable supply of minerals at acceptable economic, environmental, and social costs. This mission is pursued through the acquisition and analysis of minerals data on a worldwide basis, and through research to make mining and mineral processing safer, more productive, and more compatible with the wise and efficient use of all our Nation's resources.

In space exploration, medical technology, national defense, private industry, and in day-to-day living, minerals and materials technologies transferred from Bureau of Mines laboratories to private industry have set the standard for innovation in scientific research and technological advancement.

This booklet summarizes significant achievements in mineral processing and metallurgy technology by the Bureau of Mines. It reflects both the scope of the Bureau's mission, and the success with which that mission has been and is being carried out.

Chronology of Significant Achievements

1913

- Public Law 62-386, Established a Bureau for Mining, Metallurgy, and Mineral Technology

1917

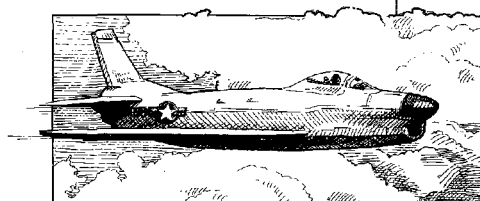
- Potash Recovery From Cement-mill Dust, Greensand, and Brines

1922

- Improved Brick-making Technology
- Electric Brass Furnace Development

1930

- In Cooperation with USGS, Bureau of Mines Discovered Large Reserves of Polyhalite While Also Developing Process for Extraction of Potash. Domestic Industry Developed Rapidly Thereafter



1958

- Metal-encased Magnesite-Chrome Brick for Open Hearth Furnace
- New Washing Technique for Alabama Iron Ores

1959

- Recycling Metals From Cadmium-Magnesium Bomb Casings by Vacuum Distillation

1960

- Aluminium-Silicon Alloys
- Light Weight Aggregate

1961

- Prereduced Iron Ore Pellets

1963

- Increased Blast Furnace Efficiency
- Chemical Vapor Deposition of Tungsten/Refractory Metals

1964

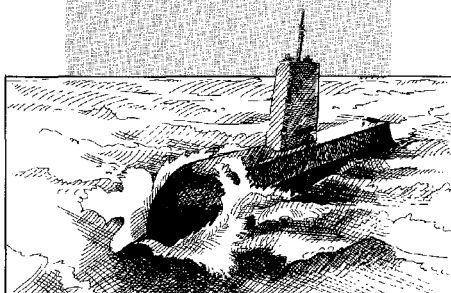
- High-purity Uranium Metal
- Bulletin on Corrosion of Titanium and Its Alloys
- Preheating Charge Materials for Steelmaking
- High-purity Beryllium

1966

- Mineral Byproduct Recovery at Desalination Plants
- Flame Spraying of Catalytically Active Pulverized Metal Oxides
- Silver Recovery From Waste

1910

Public Law 61-179, Established Bureau of Mines



1948

First Contribution to Uranium: Process for Monticello Uranium Mill
First Commercial Production of Ductile Titanium

1951

Production of Ductile Zirconium

1954

Solvent Extraction/Separation of Tantalum and Columbium

1961

Ion Exchange Separation of Rare-earth Elements

1962

New Analytical Techniques (Book, "Treatise on Analytical Chemistry" by John Wiley & Sons)

1963

Flotation Treatment of Iron Ores by Selective Flocculation

1966

1915

- Gold Chloridization Technology
- Demonstrated Feasibility of Concentrating Molybdenum Sulfide

1920

- Application of Electrostatic Precipitation to Mineral Processing

1923

- Minerals Beneficiation of Lead Ores

1932

- Thermodynamics Bulletin 350 — K.K. Kelley

1940

- Electrolytic Chromium
- Electrolytic Cobalt

1945

- Electrolytic Manganese

1948

- Synthetic Garnet Technology
- Heavy Medium Concentration of Alabama Iron Ore

1950

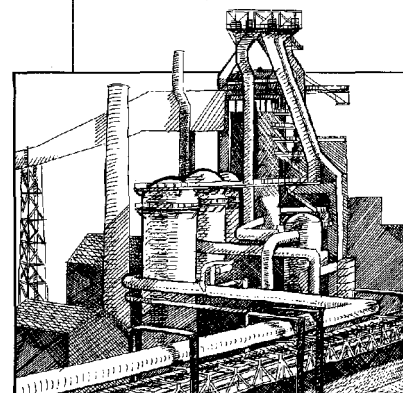
- Recovery of Vanadium and Fluorine From Idaho Phosphate

1953

- Ductile Chromium

1955

- Development of Synthetic Mica
- Titanium Ingot Production Techniques
- Skull Casting Titanium
- Wet-magnetic Separator



1965

- Improved Fluorspar Recovery
- Continuous Attrition Grinding of Coarse Kaolin

1967

- Lithium Mineral Recovery

- Active Pulverized Metal Oxides
- Silver Recovery From Waste Photographic Solutions
- Selective Flotation of Mica
- Carbon Black From Coal

1970

- Cast Carbide Cutting Tools

1971

- Density Separation by Using Magnetic Fluids
- Reclamation of Refractory Carbides From Carbide Materials
- Rhenium and Molybdenum From Low-grade Sulfide Concentrates
- Soldering With Zinc Alloys

1975

- Molybdenum Casting Technology
- Geobrine Work at Imperial Valley

1977

- Casting Titanium and Zirconium in Zircon Sand Molds
- Nonferrous Materials From Automobile Scrap
- Sulfur Extended Asphalt Paving Materials
- Reclamation of Used Refractories Containing Chromium

1979

- Municipal Refuse Recycling

1980

- One-step Electrolytic Process to Regenerate Chromic Acid Solutions
- Tungsten-specific Ion Exchange Resin

1981

- Investment Molds for Titanium Casting
- Recycling of Stainless and Specialty Steel Wastes

1984

- Hardfacing of Ferrous Castings
- Electrodeposition and Electroforming of Alloys From Particle-Solution Mixtures

1985

- Electromechanical Control of the Flotation Response of Sulfide Minerals Shown Feasible Under Mill Conditions

1986

- Automated Method for Scrap Metal Identification Based on Optical Spectra of Grinding Wheel Sparks
- Low-maintenance, Variable Bubble Size Gas Sparger for Column Flotation Cells

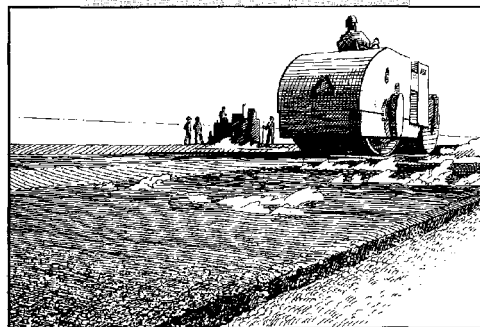
1987

- Cobalt Recovery From Missouri Lead Ores
- Hardfacing of Aluminum Castings

1966 Improved Phosphate Rock Beneficiation

1971

Electro-oxidation of Refractory Carbonaceous Gold Ores



1976

Sulfur Concrete

1981

Agglomeration for Leaching Silver and Gold From Low-grade Ores

1983

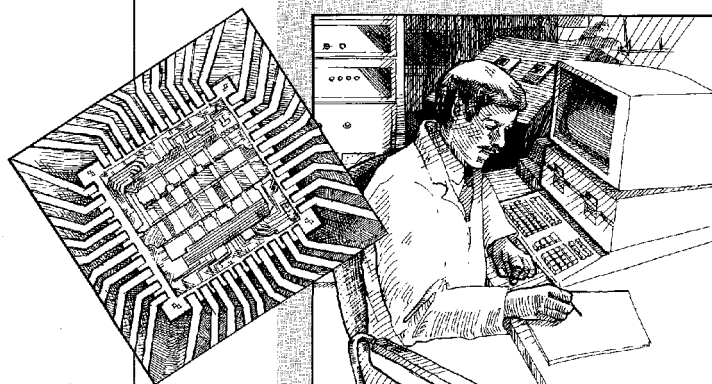
Soft Soldering Aluminum

1984

Formation of Tungsten Carbide by Gas Sparging

1987

Explosive Compaction and Joining of Rapidly Solidified Alloy Powders



- Lithium Mineral Recovery
- High-grade Talc

1969

- Heap Leaching Gold Ores
- Kyanite Flotation
- Induction Slag Melting Process for Titanium

1973

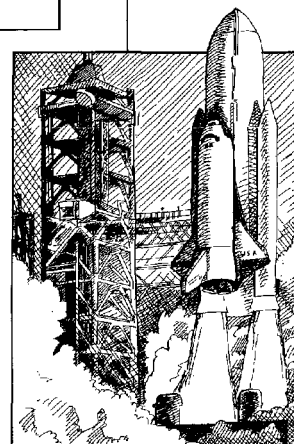
- Improved Carbon-in-Pulp Gold Recovery

1974

- Pollution-free Junk Car Incinerator
- Stabilization of Mine Tailings and Waste Piles
- Potash From Domestic Resources
- Ductile Cast Iron
- Recovery of Lead by Ferric Chloride
- Leaching of Lead Sulfide Concentrates

1976

- Dewatering Phosphatic Clay Wastes
- Silver From Obsolete Aircraft Components



1982

- Methanol Catalysts
- Electrolytic Recovery of Lead From Scrap Batteries

1983

- Magnesium Oxide for Deep Bed Filtration of Water
- Development of Chromium-free Grades of Constructional Alloy Steels
- Recovery of Precious Metals From Electronic Scrap
- High-performance Rare-earth Magnets
- Protective, Low-porosity Platinum-group Metal Coatings
- Production of High-purity Ultrafine Nonoxide Ceramic Powders

ACHIEVEMENTS

Because of the broad scope of its program and the variety of interdisciplinary skills available to support it, the Bureau of Mines provides a constant pool of minerals and materials technology, knowledge, and research know-how. Past achievements in solving problems of national significance and in developing new mineral supplies at progressively lower costs demonstrate the credibility and usefulness of its activities. The importance of metallurgical and advanced materials research in furthering the competitive position of the United States and the well-being of the Nation is also proven through the Bureau's many accomplishments in these areas.

In its research, the Bureau has continually been in the forefront of new scientific and engineering developments which later became established technology. In many cases, industrial processes are readily identifiable with Bureau-developed technology and are the principal indicators of the program's success and recognition.

Through the years, the Bureau's research activities have had financial support and cooperation from private industry, as well as other Government agencies. This indicates the high regard in which the Bureau of Mines research achievements are held.

While there have been many significant accomplishments in the field of minerals and materials technology, much remains to be done if the Nation is to be assured an adequate future supply of mineral raw materials.

Presented here is a chronological summary of the Bureau of Mines' significant achievements in minerals and materials science since its founding.

CHARTER:

MINERALS AND MATERIALS SCIENCE

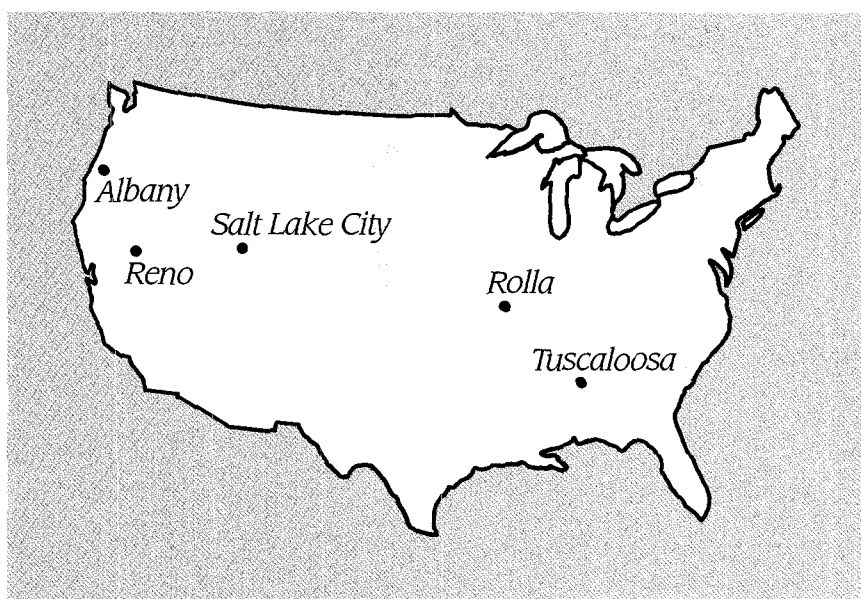
The Bureau of Mines was established within the Department of the Interior by an act of Congress in 1910. This act specifically identified the need to conduct programs concerned with mineral and metal processing as a responsibility of the Bureau of Mines, which was clearly intended to serve as the mineral science and technology arm of the Federal Government.

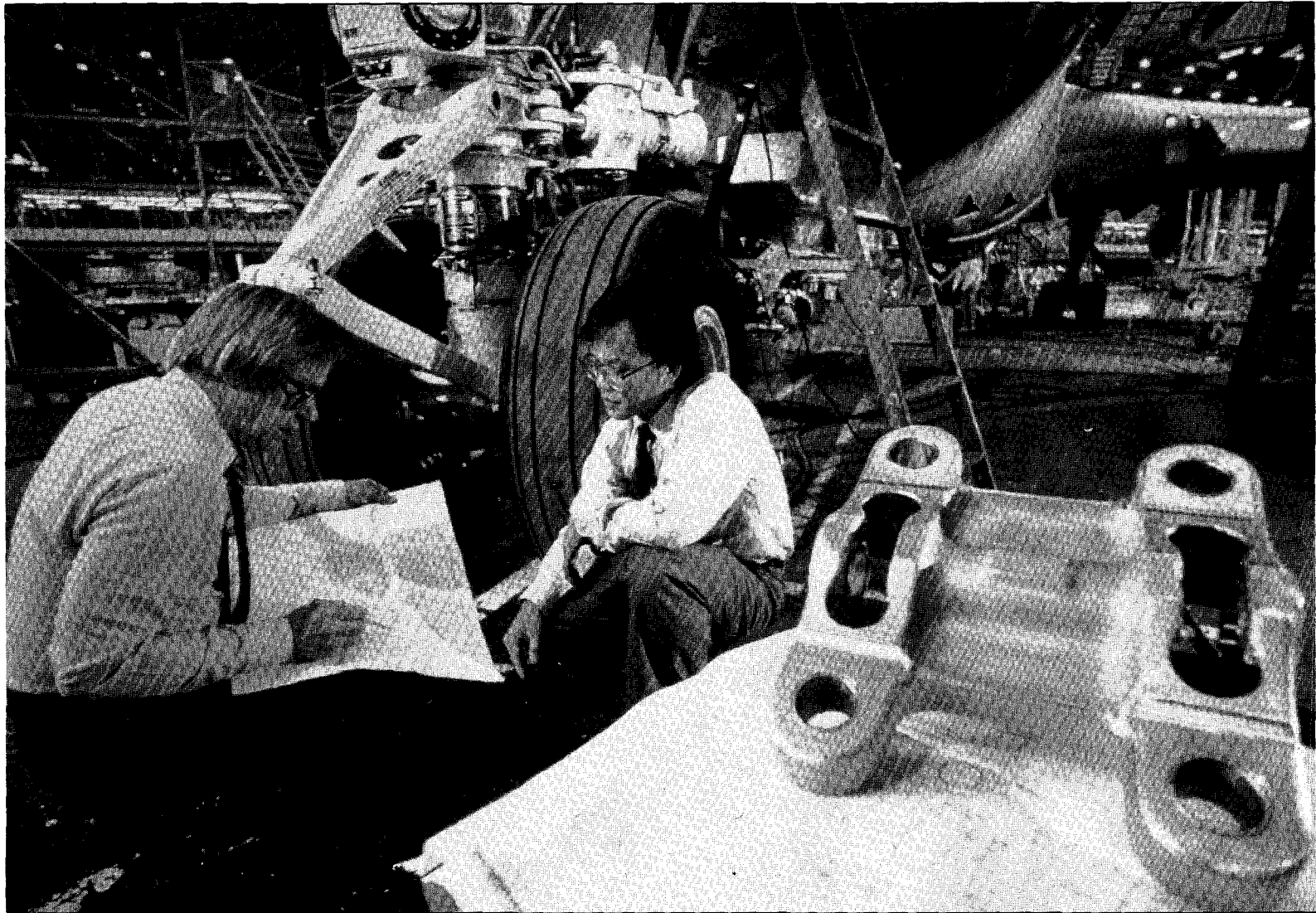
Minerals and materials research has been an integral and recognized part of the Bureau of Mines since shortly after it was formed. Public Law 62-386, approved February 25, 1913, amended the Organic Act (P.L. 61-179, May 16, 1910) to read, in part:

"... there is hereby established in the Department of the Interior a bureau of mining, metallurgy, and mineral technology, to be designated the Bureau of Mines ... to conduct inquiries and scientific and technologic investigations concerning mining, and the preparation, treatment, and utilization of mineral substances with a view to improving health conditions, and increasing safety, efficiency, economic development, and conserving resources through the prevention of waste in the mining, quarrying, metallurgical, and other mineral industries..."

Today, minerals and materials research carried on by the Bureau of Mines provides fundamental scientific and technical information essential to accelerate advances in nonfuel minerals production technology. The program emphasizes basic and applied studies designed to determine new fundamental scientific concepts in extractive metallurgy, materials, and recycling technologies. Such work also provides on-the-shelf technology that could be used in time of national emergency to treat otherwise uneconomic domestic resources, thereby helping to offset shortfalls in supply caused by the cutoff of foreign sources.

U.S. Bureau of Mines
Minerals and Materials Research Facilities





Parts made from advanced materials improve the performance of products in which they are used, including aircraft, autos, and computers.

High Temperature Materials

Titanium

The Bureau of Mines developed titanium processing from a laboratory curiosity to the basis for an entire new industry. Titanium and its alloys are used in the aerospace, chemical, mining, and manufacturing industries. Because it is strong, lightweight, and resistant to corrosion, titanium is finding a growing acceptance in such diverse applications as medical equipment, spacecraft components, and sporting goods. Commercial production based on Bureau-patented technology began in the early 1950's. Today, Bureau researchers are seeking ways to reduce production costs, improve energy efficiency in processing, and increase the machinability of titanium metal and its alloys.

Zirconium

Bureau research to recover zirconium from ores began in 1946. In 1949, the Atomic Energy Commission and the Bureau of Ships contracted with the Bureau of Mines to supply zirconium for atomic reactor use. The program was successfully operated until 1954 to stockpile sufficient additional material for wartime needs. Pure zirconium metal, produced by the Bureau of Mines, made possible one of the Nation's finest technological achievements — the first atomic powered submarine, the Nautilus. Private commercial production of zirconium based on Bureau research began in 1955.

Tungsten

Recently, the Bureau of Mines developed a selective ion-exchange resin for recovering tungsten from brines, nearly doubling our Nation's reserves of this important metal. This development earned the

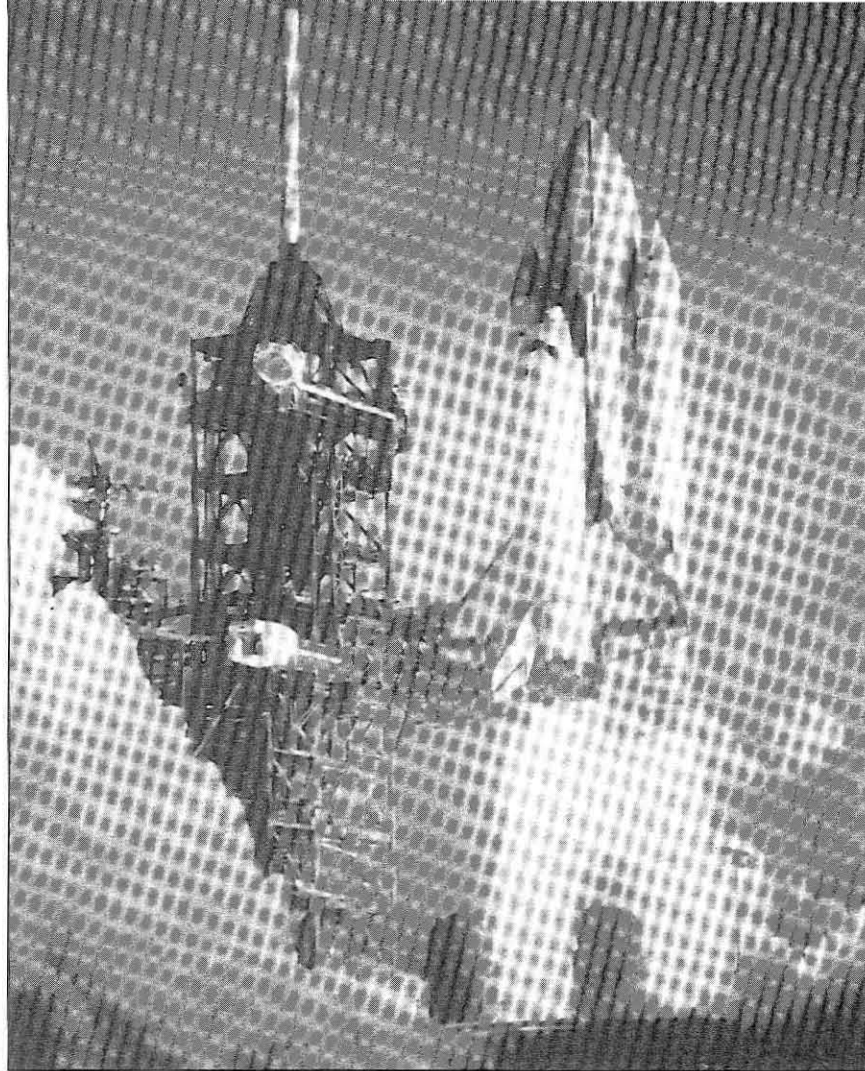
COMMODITIES

Titanium
Zirconium
Tantalum
Columbium
Molybdenum
Tungsten
Beryllium
Chromium
Ceramics

NEW TECHNOLOGY

Consumable Electrode
Arc Melting
Induction Slag Melting
Vacuum Casting
Graphite Casting Molds
Investment Casting Molds
Sand Casting Molds
Molten Salt
Electrorefining
Powder Metallurgy — RSA
Joining Technology —
INEL Explosive Joining

Bureau research led to the development of numerous "space age" metals used in high speed aircraft and space vehicles.



Bureau a prestigious IR-100 Award from Research and Development magazine. This was just one of numerous such awards garnered by the Bureau through the years for its innovative work in minerals and metallurgical technology.

"Space Age" Metals

The search for viable melting and casting technologies for high temperature metals and alloys has resulted in notable achievements by the Bureau of Mines. The Bureau-developed vacuum melting and casting process has been the basis for the development of an entire family of "space age" metals — beryllium, titanium, tungsten, and hafnium, among them — that made possible the production of high speed aircraft and space vehicles. Prior to this development, no casting technology for refractory and reactive metals was available. With the development of induction slag melting and zirconium sand casting technologies during the 1970's, the Bureau has remained a recognized leader in this area.

Tantalum and Columbium

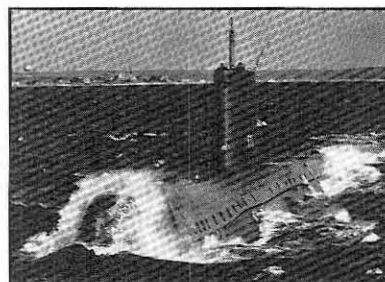
In 1950-1954, Bureau researchers developed an innovative process for producing high-purity tantalum and columbium oxides via a chemical separation process. Soon after publication of the technical data describing this new technique, each of the companies producing our Nation's requirements for high-purity columbium and tantalum chemicals and metals converted their entire production operations to the Bureau's new process.

Advanced Materials

Advanced materials improve the performance of products in which they are used. Parts made from advanced materials are incorporated into subassemblies which become airplanes, automobiles, and computers. As a result, advanced materials have a profound impact on the competitive position of the United States.

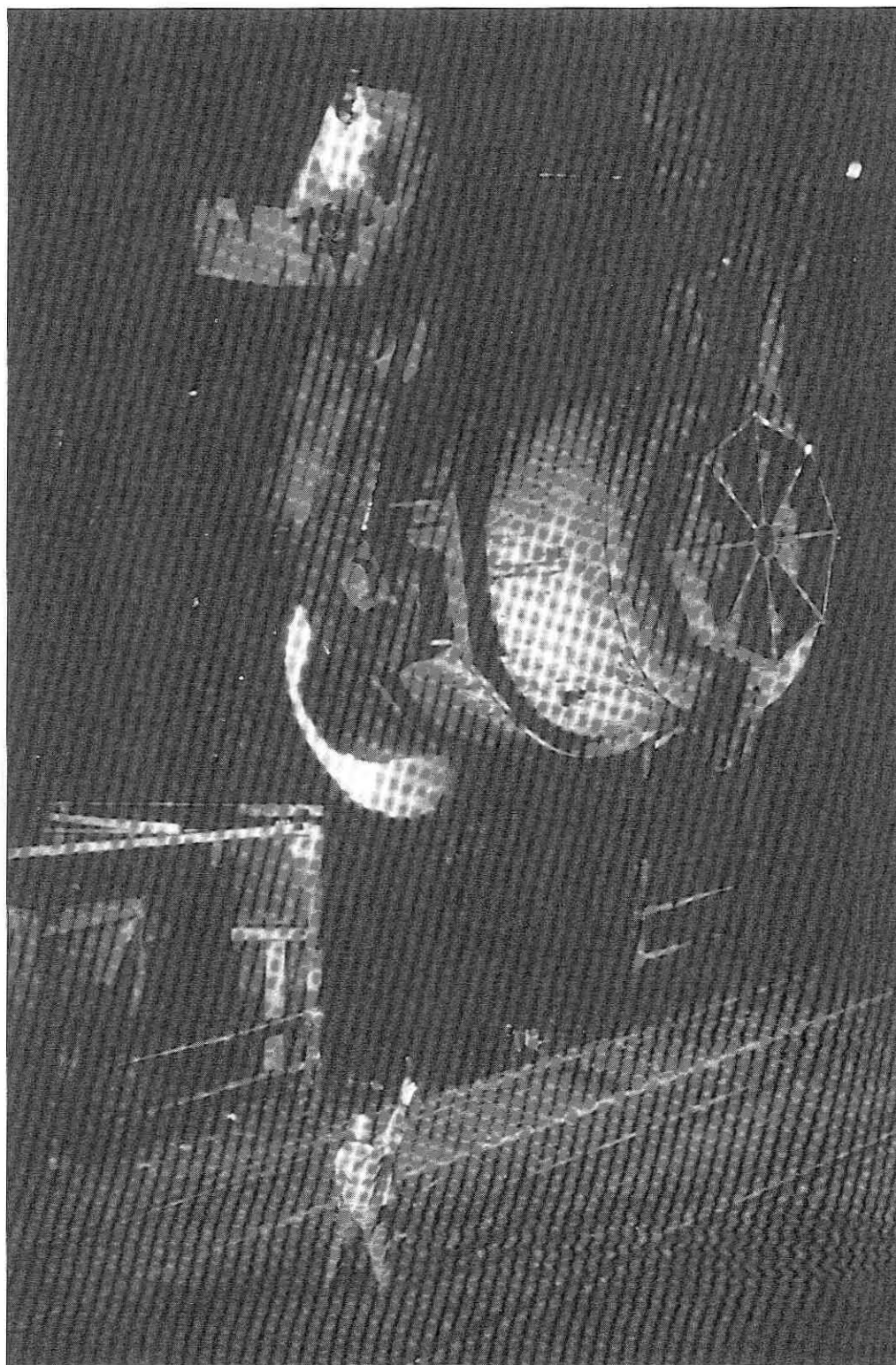
Utilization of the unique properties of advanced ceramics and rapidly solidified alloys (RSA) were often limited by the inability to join separate pieces into complex shapes without destroying the unique properties. Bureau research performed at the Idaho National Engineering Laboratory showed that two pieces of advanced ceramic could be brazed together with oxynitride glass. The joint is strong and tough at elevated temperatures.

Investigators found that explosive joining can be used to connect two pieces of RSA material without the crystallization that would accompany welding. Research and Development magazine recognized this accomplishment with an IR-100 award in 1987.



The U.S.S. Nautilus—the world's first atomic powered submarine—was made possible through Bureau-developed zirconium production process.

Bureau-developed technologies have led to significant fuel savings and production increases among the Nation's iron and steel producers.



Iron and Steel Technology

Iron and Steel

While the more exotic metals may receive more public attention, iron and steel remain the backbone of American industry.

In 1963, the Bureau of Mines undertook blast furnace research with the construction of an experimental furnace. The project was initiated in cooperation with a consortium of 22 steel companies that contributed about 60 percent of the operating costs.

The Bureau's search for technological innovation in iron and steelmaking has been near continuous since the first results from experimental blast furnace research were announced. For example, preheating charge material for steelmaking was pioneered by the Bureau of Mines. Preheating the raw materials conserves furnace time, thus lowering overall energy costs, and also permits an increased proportion of scrap in the charge to basic oxygen furnaces. Scrap preheating for arc furnaces increased production by 17 percent; scrap preheating for basic oxygen furnace steelmaking increased scrap utilization by 32 percent.

The technique of adding supplemental fuel to the blast furnace by injection through tuyeres was perfected by the Bureau of Mines shortly after the close of World War II. Because of its availability and ease of injection, natural gas was selected from among many potential fuels. And the results were spectacular. Not only did a substantial coke savings result, but the lower flame temperature permitted a 30-percent increase in iron production by allowing higher blast temperature without adversely affecting the normal movement of materials through the furnace stack. By 1961, 27 furnaces in the United States

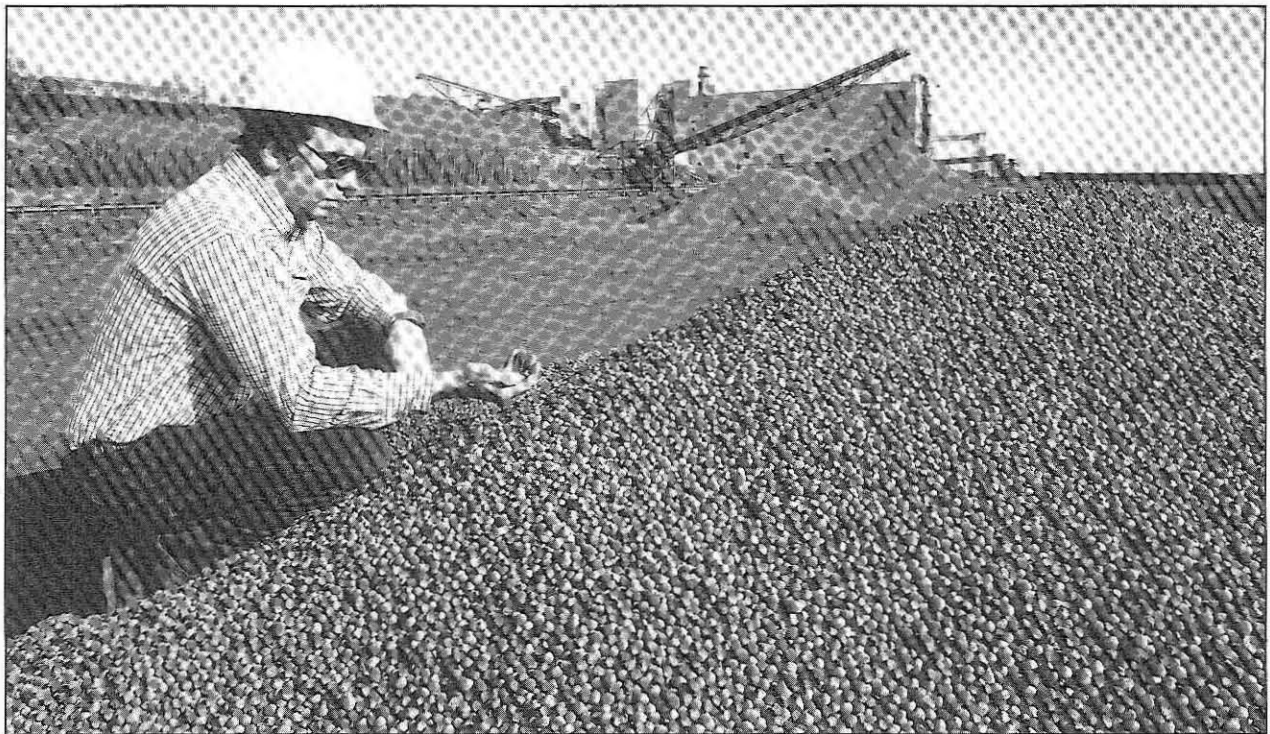
COMMODITIES

Steel
Pig Iron
Iron Ore
Coal

NEW TECHNOLOGY

Preheating Charge Materials
Flotation Technology
Tuyere Fuel Injection
Low-BTU Gas Pellet Hardening
Prerduced Iron Ore Pellets
Heavy Medium Concentration of Iron Ore
New Washing Techniques for Iron Ore
Oxygen Enriched Blast Furnace Technology

were using fuel injection. By 1964, the number had reached 90. By early 1971, 102 furnaces were engaged in this practice. Today, nearly all blast furnaces are using injection, resulting in considerable savings of high-grade coke per year.



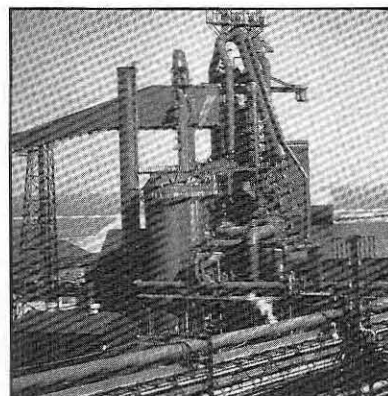
An economical process to recover iron ore from non-magnetic taconite expanded U. S. production substantially. Here, iron ore pellets are stockpiled to feed a blast furnace.

Low-BTU Coal Gas

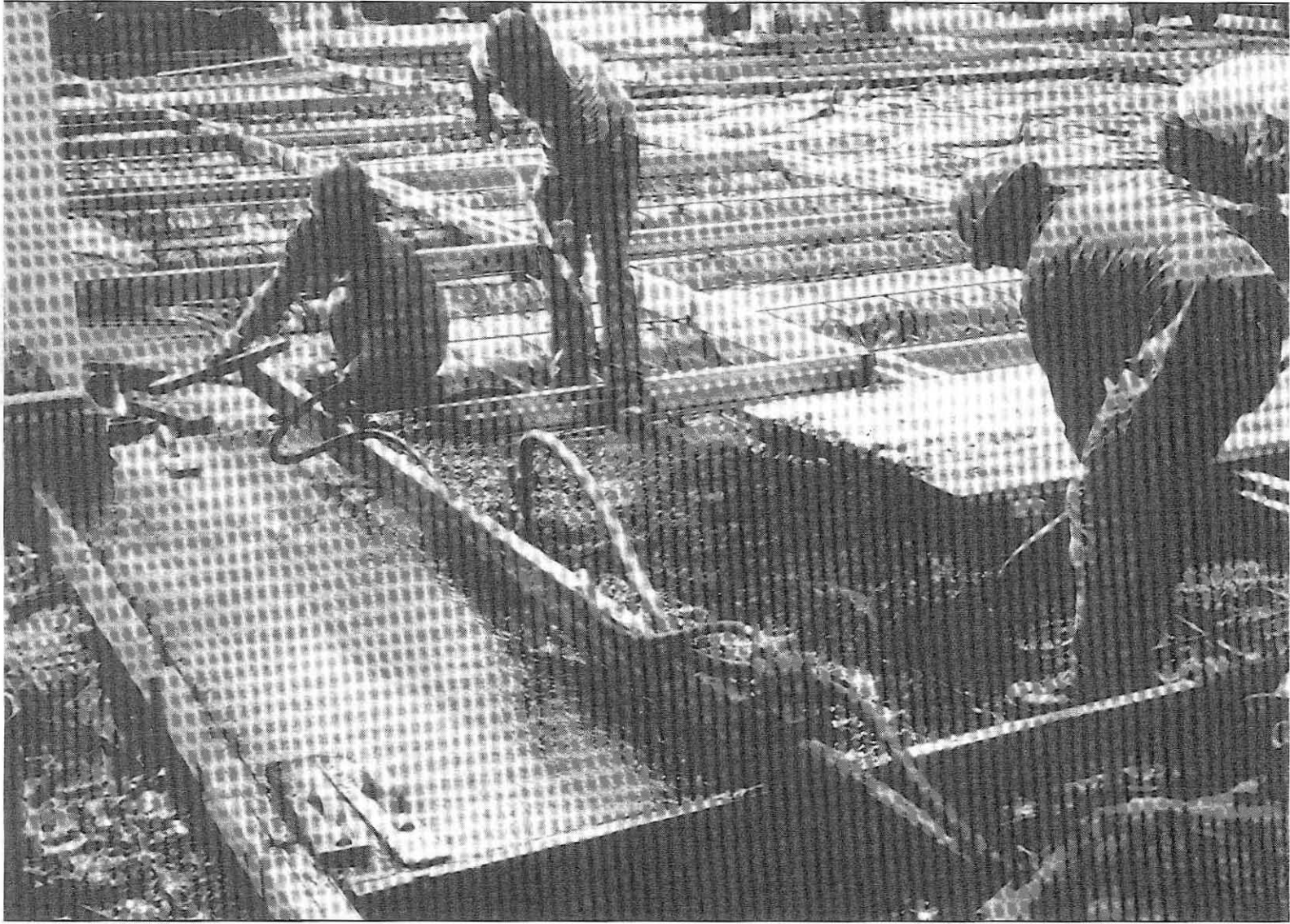
The increasing cost and lack of stability in the supplies of natural gas and oil prompted the Bureau of Mines to examine alternative fuels for mineral and metallurgical processes. The Bureau, in cooperation with the Department of Energy and 20 interested U. S. firms, has formed a cooperative, cost-sharing group known as the Mining and Industrial Fuel Gas group to promote development and demonstration of low-BTU coal gas as an alternative fuel for mineral processes and other industrial applications. Eight different coals, including Kentucky bituminous, Colorado and Montana subbituminous, and Texas and North Dakota lignite, have been evaluated in gasification-pelletizing tests since the program began. The work has demonstrated that raw, low-BTU gas can be used to harden iron ore pellets.

Iron Ore Recovery

The Nation's capacity to produce iron ore was increased substantially in 1974 as a result of research to economically concentrate and recover iron ore from nonmagnetic taconite, which, up until then was a useless mineral. After cooperative studies between the Bureau of Mines and private industry, a commercial plant was constructed at Ishpeming, Michigan and subsequently expanded, resulting in a total plant capacity of eight million tons per year of iron ore pellets. About one billion tons of ore can be processed by this new technology, based on known U.S. reserves of nonmagnetic taconite ores.



The Bureau of Mines has led the way in developing innovative new technologies for the iron and steel industry since building the first experimental blast furnace in 1923.



A 50,000 square foot sulfur concrete floor will provide superior corrosion resistance in this copper electrorefining tank house under construction.

Construction and Transportation

Lightweight Aggregates

The Bureau of Mines began evaluating domestic clay and shale resources in 1938. Data from the research demonstrated that shales and clays could be used to make lightweight aggregate suitable for structural concrete applications where weight reduction is an important consideration. This resulted in the establishment of an industry to produce lightweight aggregate for concrete. In related research begun in 1979, the Bureau, working with the Federal Highway Administration, pioneered the use of synthetic ceramic aggregates such as waste slate and copper mill tailings to improve wear and skid resistance on paved road surfaces.

Sulfur Concrete and Paving Materials

Portland cement will deteriorate in a short time under salt or acidic conditions. Bureau research to address this problem — which is prevalent in the mining and minerals industry — resulted in a high performance, corrosion resistant sulfur concrete. Sulfur concrete is a construction material based on plasticized sulfur and mineral aggregates. Full-scale industrial floors (20,000 square feet) have been successfully installed at major electrolytic metal refineries. To date, seven U.S. companies have been licensed to produce sulfur concrete.

Sulfur-extended asphalt — another Bureau-developed product — has been used to pave more than 200 roads during the past 10 years. By using sulfur as a replacement for part of the asphalt binder, sulfur-asphalt pavements may be designed with properties ranging from flexible surface-paving materials to stiff base-paving materials. Sulfur also is used

COMMODITIES

Sulfur
Clay
Shale
Asphalt
Aluminum
Tin
Lead

NEW TECHNOLOGY

Salt- and Acid-Resistant
Concrete

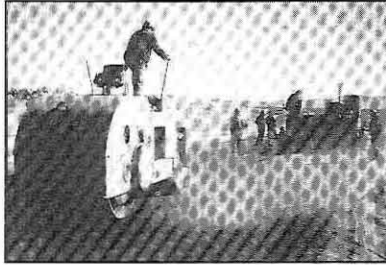
Recycling Asphalt
Pavement

Data Base for
Materials Used in
Geothermal Applications

Joining Technology

Isokinetic Sampling Probe

Improved Technology
for Linear Polarization
Measurements



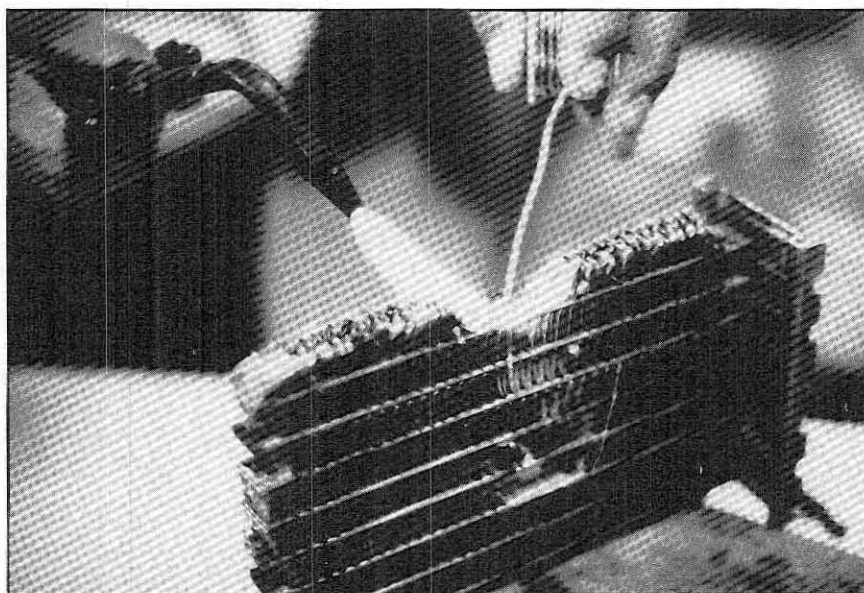
to rejuvenate the oxidized asphalt in old pavements to conserve their asphalt and graded aggregate contents. This recycled paving has physical properties comparable to new pavement.

Construction Materials Analysis

Between 1972 and 1981, the Bureau of Mines conducted extensive research to solve some of the severe materials corrosion problems inhibiting the development of liquid-dominated geothermal resources for energy and mineral values. This research provided an extensive data base for the selection of materials for constructing geothermal plants. Bureau research scientists are frequently contacted by major geothermal facilities contractors for specific materials recommendations.

Soft Soldering Techniques

Until recently, no practical soft soldering system was available to repair broken items made of aluminium. Consequently, the broken part was scrapped and replaced by a new one — a wasteful and costly practice. Recently, a system was developed by the Bureau of Mines that permits repair of many aluminum items with common tin-lead "soft" solders. The National Automotive Radiator Service Association has conducted regional workshops to demonstrate the new soldering method to its 15,000 members. The method is simple enough to be readily used in the home workshop. Additional research indicates that this soldering technique can be used to overcome the problems encountered in joining aluminum to copper electrical conductors.



Bureau-developed soft soldering technique allows continued use of aluminum items that would otherwise be scrapped.



Bureau of Mines research addresses the entire spectrum of process steps for precious metals.

Gold and Silver Recovery

Gold From Arsenical Ores

Since its inception, Bureau of Mines research has addressed the entire spectrum of process steps for precious metals, from ore crushing and grinding to tailings reprocessing. By 1941, a Bureau-developed process for recovering gold from arsenical ores using a sulfatizing roast and cyanidation was a standard practice in the industry. Subsequently, several innovative metallurgical processes have been developed and transferred to private industry.

When the use of mercury for gold recovery was discontinued for environmental reasons, gold losses for a typical producer amounted to over a half million dollars per year. In 1971, Bureau scientists, who were testing a carbon-in-pulp process for gold recovery, showed that the carbon-in-pulp process would recover the lost gold. In this process, gold is dissolved by conventional cyanide methods and then adsorbed from the solution by activated carbon. Not only did this process recover the lost gold, but could replace the earlier precipitation stages in the plant with a less costly process. Savings resulted from elimination of the need to clarify solutions before precipitating the gold.

By eliminating the need for clarification of gold solutions, heap leaching became a practical reality. However, for gold ores containing a large amount of clay, the heap would rapidly become plugged up. By pelletizing the fine gold ore with Portland cement, Bureau scientists were able to keep leach solutions circulating through the heap until recovery was complete. The Bureau's pelletizing technology is used today wherever "clayey" ores are encountered.

COMMODITIES

Gold
Silver

NEW TECHNOLOGY

Cyanidation Process

Carbon-in-Pulp
Recovery Process

Oxidation of
Carbonaceous Ores

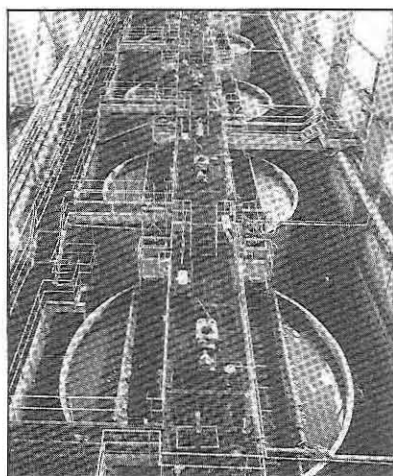
Heap Leaching

Improved Efficiency
of Wetting Agents

Particle Agglomeration
Technique



Clayey gold ore that is too fine to let leach solution flow through is pelletized by Bureau process.



Top view of commercial carbon-in-pulp columns.



A simple process for recovering silver from waste photographic solutions spurred a new entrepreneurial industry in the U.S.

Carbon-In-Pulp Recovery

The ability of carbon to adsorb gold has been investigated intermittently since around the turn of the century. The two chief obstacles to commercial application of the process appear to have been the low adsorption capacities and the attrition of the carbon particles.

The Bureau has succeeded in increasing carbon loading capacity from about 40 ounces of gold per ton of carbon to as much as 800 ounces per ton. Such improved loadings offered more favorable economics with respect to carbon handling, carbon wear, investment in stripping plant, and inventories of gold and carbon. Improvements in carbon abrasion characteristics and loading capacities have subsequently led directly to commercial application of the carbon-in-pulp process.

Oxidation of Carbonaceous Gold Ores

Carbonaceous ore deposits found in Nevada, Idaho, Utah, and California had been uneconomical to treat by conventional cyanidation processing. The procedure developed and patented by the Bureau to alter these materials consisted of oxidizing the carbonaceous materials, then subjecting the pulp to the conventional cyanidation treatment to recover the gold.

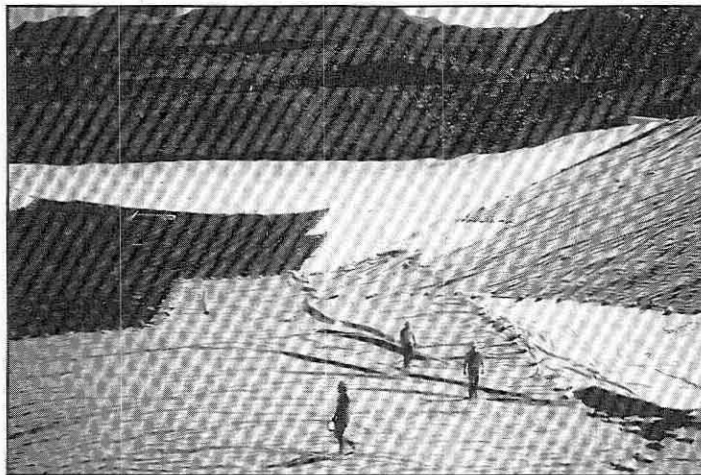
Silver From Photographic Solutions

Bureau research has shown that the silver in waste photographic solutions can be efficiently recovered by draining through cartridges containing inexpensive steel wool or window screen. These simple and low cost cartridges are easy to install and use, and the crude silver product recovered is readily marketed. A news service report describing the Bureau

silver recovery device received national distribution and stimulated hundreds of letters of inquiry from large and small film processing firms and individuals.

Heap Leaching of Gold Ores

The gold heap-leaching process was an innovative combination of the chemistry of leaching gold with cyanide solutions and the dump-leaching technology that is used on low-grade copper ores. The process permits the treatment of very coarse, low-grade ores that would otherwise require prohibitively expensive grinding and agitation-leaching equipment. The modest capital cost for the heap-leach installations is



Heap leaching of gold ore with cyanide solutions is carried out in carefully constructed areas that are lined with advanced polymer materials to prevent escape of cyanide to the environment.

only about 10 percent of the plant investment needed for conventional milling operations. The recent revival of the domestic gold industry is due, in part, to this technological development. The technique has allowed new, nontraditional mining companies to enter a field from which they previously had been excluded. The process was selected by Chemical Engineering magazine as one of the top technical developments in the chemical process industries for the period October 1969 to April 1970.

21

Today, computers that identify metal by color of spark are used to sort superalloy scrap.



Recycling

Smokeless Incinerators

In the late 1960's the problem of junk automobiles received a great deal of public attention. Part of the problem was the open burning of the car bodies before they could be sold as steel scrap. The Bureau of Mines designed an incinerator that could burn the cars without smoke emissions. Based on this design, 29 commercial incinerators were built and operated around the country, burning a significant portion of the 10 million autos scrapped each year. The smokeless incinerator served as an economical interim solution to a nagging national problem.

Nonmagnetic Materials Recovery

As the use of automobile shredders became more prevalent and the magnetically separated fraction of the shredded scrap was effectively recycled, the Bureau directed its research toward recovering the values from the millions of tons of nonmagnetic materials that were simply being landfilled. Techniques adopted at commercial shredder installations were developed by the Bureau for recovering the aluminum, copper, stainless steel, zinc, and plastics contained in this material.

From 1965 to 1979 the Bureau conducted research on the recovery of magnetic and nonmagnetic metals, glass, plastics, and paper from municipal solid wastes. Two plants based on Bureau of Mines patented technology have been constructed: one in Rochester, New York processes 2,000 tons of municipal solid waste per day; the other, in Towson, Maryland processes 750 tons per day.

COMMODITIES

Titanium
Aluminum
Copper
Zinc
Stainless Steel
Silver
Glass
Tungsten
Iron
Chromium
Cobalt
Plastics
Gold
Paper
Lead
Carbide

NEW TECHNOLOGY

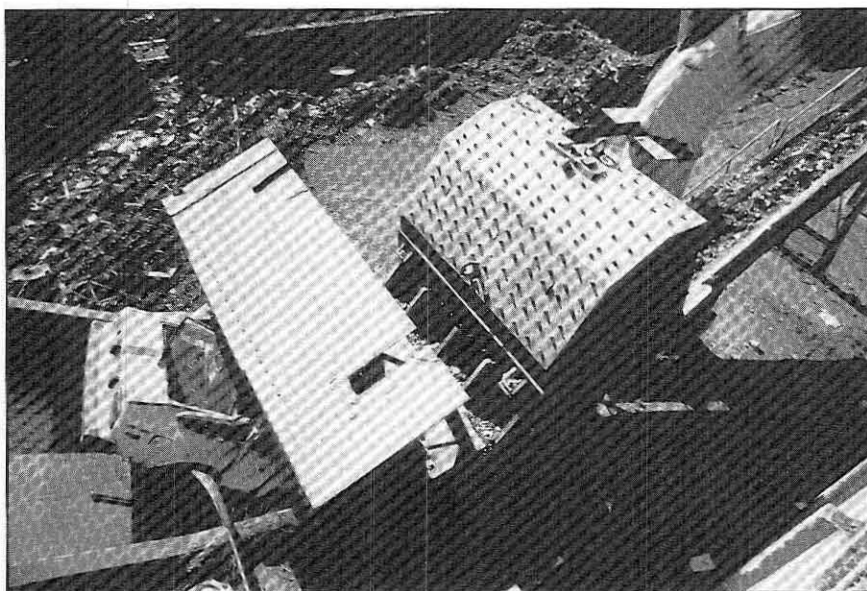
Solid Waste Recycling
Electronic Scrap Recycling
Tungsten Carbide Recycling
Smokeless Incinerator
Water Elutriator
Separation by Magnetic Fluids

Recovering Valuable and Precious Metals

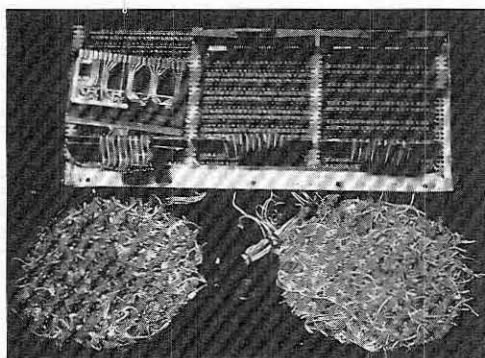
Millions of pounds of obsolete military electronic hardware must be disposed of each year. Adequate technology had not been available for separating and concentrating the precious metals and valuable base metals from this type of scrap. The Bureau of Mines has developed and tested a dry beneficiation process that separates certain military and commercial electronic scrap into fractions that are sufficiently concentrated that commercial refiners can recover the gold and silver contents.

Worn cutting and drilling bits comprise a very high-value scrap containing cobalt and cemented carbides. Although some of these high-value materials can be processed for recycling, the methods are either slow or expensive, and recover only 70 percent of the contained hard constituents as usable products. In 1971, the Bureau of Mines developed a simple, inexpensive and efficient process using molten zinc to separate the desired components. This technology — which has been commercially adopted by seven firms — produces high-purity products with no wastes. An additional advantage is that the zinc reagent is recovered for recycling in the process.

A low-cost technique to continuously separate a mixture of nonmagnetic material such as aluminum, titanium, copper, and diamonds has been commercially adopted. Nonmagnetic materials of different densities can be separated by using a magnetic fluid (liquid) subjected to an external magnetic field. Separation is accomplished by changing the electric current through the electromagnet, which alters the magnetic field strength and quickly floats the lighter material.



Automobile enters shredder to be separated into various metal and plastics fractions for reuse.



Several processes have been developed by the Bureau of Mines for recovering valuable nonmagnetic materials from electronic scrap.



Bureau solid-liquid separation technology successfully removes environmentally undesirable particulates from placer gold mining effluents in Alaska.

Environmental Technology

Recycling Scrap Batteries

More than 90 percent of the metal supplied to secondary lead smelters — which accounts for about 45 percent of domestic production — is in the form of scrap batteries. It is not only difficult, but costly for these smelters to comply with stringent air pollution regulations for sulfur and lead emissions, and to limit lead exposure for workers. Bureau research has resulted in the development of an economically and environmentally acceptable combination electrorefining-electrowinning method for recycling scrap batteries as an alternative to the current high-temperature smelting process. Lead of 99.99 percent purity, which can be used in maintenance-free batteries, is recovered.

Conserving Chromium

Etching solutions containing chromium are used for various types of surface treatments. With use, the effectiveness of the solutions decreases until etching is no longer satisfactory and the spent solutions are treated and discarded, sometimes daily. The Bureau has developed technology for the economic regeneration and recycling of the spent solutions, thereby greatly reducing the amount of chromium required during etching operations and minimizing waste disposal problems. Two industrial facilities have installed commercial units following successful Bureau in-plant demonstrations.

COMMODITIES

Lead
Water
Magnesium Oxide
Chromium
Phosphate

NEW TECHNOLOGY

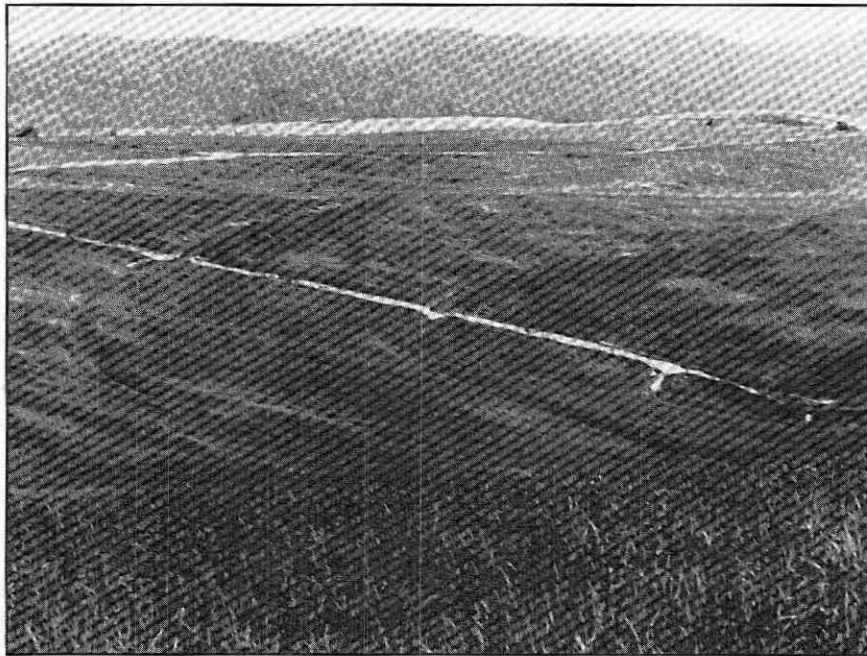
Electrorefining-
Electrowinning
Etching Solution
Regeneration
Tailings Stabilization
Filtration Media
Flocculation Agents

Improved Waste Water Filtering Processes

Waste mineral processing waters frequently contain suspended solids that must be removed before discharging. This is generally accomplished by percolating the waste water through a granular bed, where the suspended particles become attached to the grains. Bureau research has shown that using magnesium oxide as the filter medium increases the overall filter capacity from 50 to 80 percent without equipment modifications. For most waters tested, the magnesium oxide filter can either operate for longer periods before backwashing is required, or flow rates can be increased as much as 1.5 times without degrading the filtrate quality. At comparable flow rates the filtered water contains about 25 percent fewer residual suspended particles when magnesium oxide is used. This is attributed to the attraction of the negatively charged particles to the positive surface of the magnesium oxide.

Processing of ores for the recovery of minerals generally results in the production of ultrafine waste materials called "slimes" that require up to 10 years to settle by natural means. Today, phosphate slime ponds cover more than 80,000 acres.

The Bureau has developed a novel technique to improve water reclamation and to rapidly produce a dewatered solids product suitable for disposal. The versatility of the Bureau-developed method has been demonstrated on a variety of mineral processing slimes. Technology transfer is currently underway at two Florida phosphate mining operations and at a placer gold operation in Alaska.



Bureau research addresses and evaluates various land reclamation methods. Here, a surface coal mine has been regraded and revegetated.

Developing fundamental knowledge to stimulate America's minerals and raw materials is the most important part of Bureau of Mines research.



Basic Research

Fundamental Thermodynamic Data

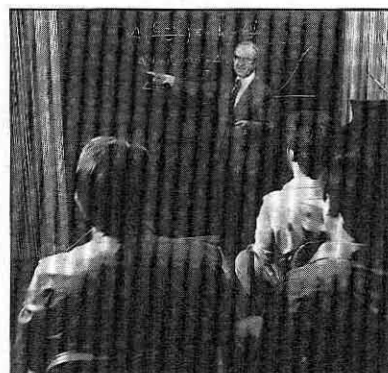
Underpinning the entire Minerals and Materials research effort is a program of directed basic research to gain a fundamental understanding of the physical and chemical processes that govern each of the steps in metal production. This program synthesizes and builds upon knowledge developed by the University community in many diverse fields of science and engineering to obtain further knowledge of the new concepts and principles in terms of minerals processing problems.

For most of the first half of the 20th century, the Bureau of Mines has stood alone in the development of fundamental thermodynamic data as a key element in the evolution of a modern efficient industrial society. By 1950, the Bureau's thermodynamic research group had produced — in just 24 years — between 50 and 70 percent of the basic thermodynamic data used to design and operate smelters and reaction vessels, and to develop new high technology metal alloys. The publication of these data has taken many forms, notably the Bureau of Mines Bulletins, Volumes I-XII, titled, "Contributions to the Data of Theoretical Metallurgy." These were compiled by K. K. Kelley, et al., in the periods 1932-1940 and 1949-1954, and are periodically updated.

Chemical Analysis of Silicates

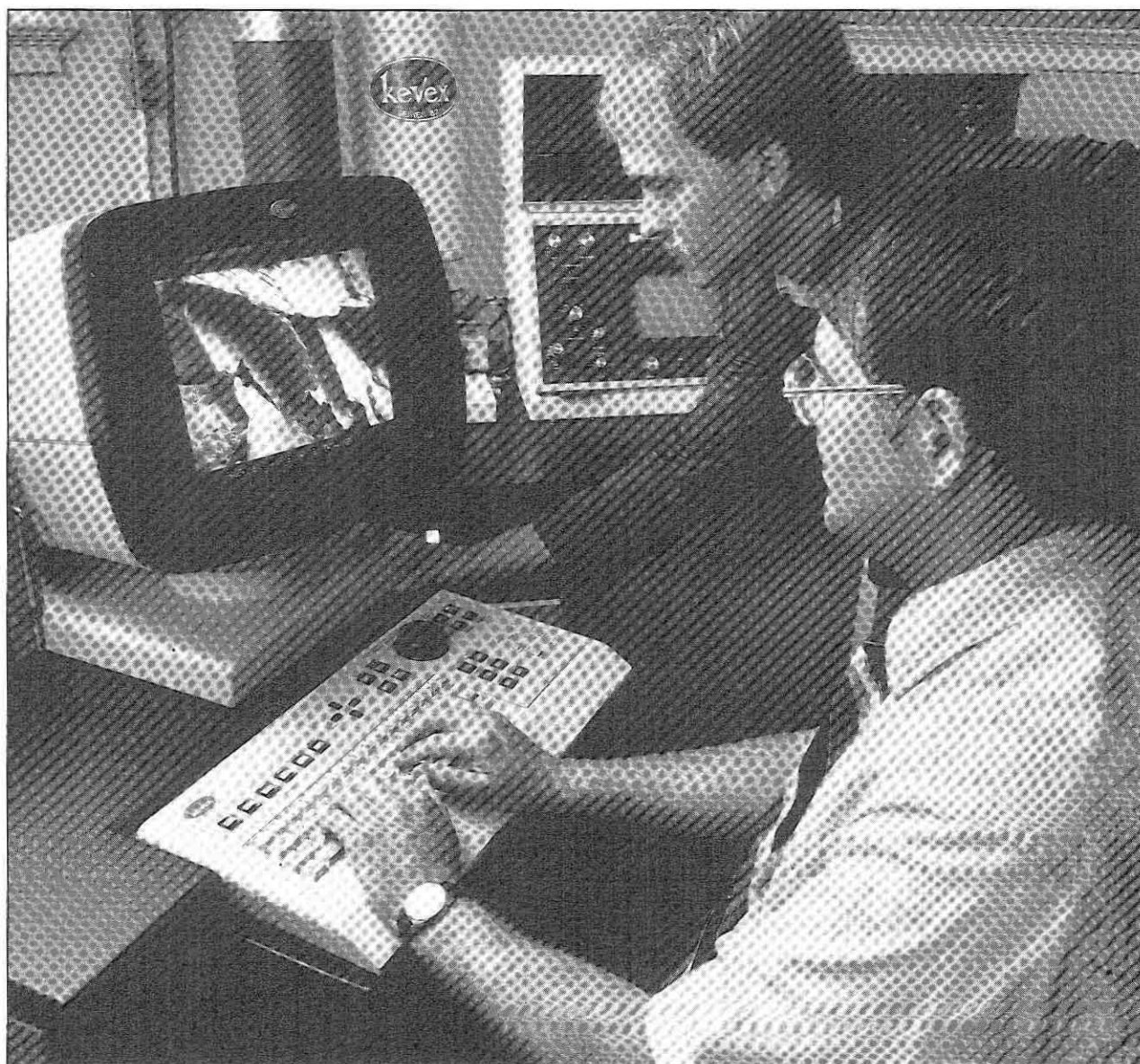
Bureau research, published in 1962 by John Wiley and Sons in "Treatise on Analytical Chemistry," developed new methods of chemical analysis for silicates, fluorosilicates, and fluoro-boron-silicates. These analytical techniques were the most significant

**NEW
TECHNOLOGY**
Thermodynamics
Analytical Techniques,
Flotation
Mineralogical
Characterization
Corrosion Fundamentals



The development and dissemination of thermodynamics research findings is critical to continued technological evolution. The Bureau of Mines is the Nation's largest single source of thermodynamic data.

advances in the field since the original work of Berzelius in 1816 on the analysis of fluorine-containing silicates, and are standard laboratory procedures worldwide today.



State-of-the-art techniques using computerized image analysis in conjunction with both optical and scanning electron microscopy allow Bureau researchers to analyze particles as fine as talcum powder.

Froth Flotation Technology

Froth flotation is the most important method used by the minerals industry to separate values from the waste rock. The separation process depends on the surface chemical properties of the minerals to be separated. Using state-of-the-art surface analytical equipment, such as ESCA, PIXE, and other electron and optical spectroscopies, in conjunction with electrochemical measurements, Bureau scientists have produced data on the electrochemistry of flotation that is opening the way for revolutionary technology in this area. These surface analytical methods are currently being applied to leaching and metal corrosion problems as well as flotation.

Mineralogical Analysis of Ultrafine Particles

The efficiency of all physical separation methods such as froth flotation, magnetic separation, and gravity separation is limited by the fraction of single particles that are made up of both mineral phases that are to be separated. To help establish grinding parameters to minimize the number of these composite particles, the Bureau has developed state-of-the-art techniques for mineralogical analysis of particles as fine as talcum powder. Using modern computerized image analysis techniques in conjunction with both optical and scanning electron microscopy, Bureau researchers have provided identification and information on particles such as asbestos to other Federal agencies and state and local regulatory authorities.



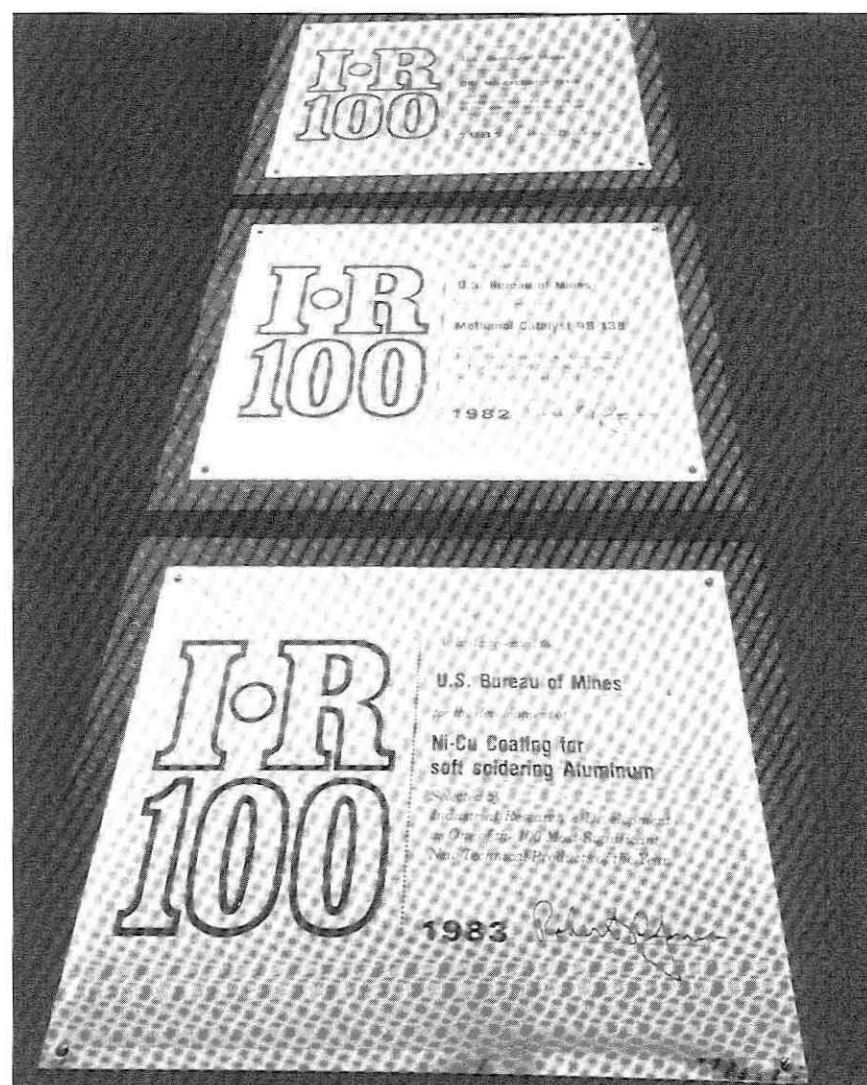
Bureau research is opening the way for revolutionary technology in mineral separation processes.

IR-100 Awards

BUREAU OF MINES

MINERALS AND MATERIALS SCIENCE

1981	QRF Ion Exchange for Tungsten Recovery
1982	Methanol Catalyst
1983	Soft-soldering of Aluminum
1984	Electrolytic Process to Recover Lead From Scrap Batteries
1986	Sulfur Concrete
1987	Recovery of Cobalt From Domestic Resources



Patents

Patent No.	Title
1938: 2,119,560	Electrolytic Process for the Extraction of Metallic Manganese
1939: 2,169,540	Purification of Manganese Sulphate Solutions
1940: 2,185,224 2,215,484	Purification of Rock Minerals Sonic Flocculator and Method for Flocculating Smoke or the Like
1941: 2,255,069	Method and Apparatus for Separating and Concentrating Gases
1942: 2,288,610 2,294,532 2,297,689	Treatment of Ores Method and Means for Extinguishing Burning Molten Magnesium and the Like Separation of Feldspar From Quartz
1943: 2,317,413:	Process for the Concentration of Boron Chemically Combined From Its Ores by Autoflotation
1944: 2,346,661 2,353,193 2,355,130 2,358,812 2,359,794 2,364,778	Estimating Molybdenum Content of Scheelite or Calcium Tungstate by Visual Color of Its Fluorescence Recovery of Metallic Magnesium Separation of Molten Magnesium From Molten Salt Baths Matte Smelting of Manganese Temperature Determination Concentration of Oxidized Iron Ores
1945: 2,366,184 2,368,209 2,374,674 2,380,406 2,383,467 2,385,819	Production of Potable Water From Saline Solutions Art of Extinguishing Burning Magnesium and the Like Method for Thermal Decomposition of Metallic Nitrates Production of Low Sulphur Sponge Iron Flotation of Iron Ores Beneficiation of Beryllium Ores

Patent No.**Title****1946:**

2,392,385	Purification of Manganese Electrolytes
2,395,475	Beneficiation of Beryllium Ores
2,403,481	Method of Concentrating Iron Ore
2,407,651	Concentrating Fluorspar by Froth Flotation
2,410,043	Process for Manufacturing Calcium Fluoride
2,411,157	Means for Collecting Gas Analysis Samples
2,412,217	Froth Flotation of Chromite With Fluoride

1947:

2,414,118	Synthesis of Fluorene and its Derivatives
2,414,815	Beneficiation of Beryllium Ores
2,415,416	Froth Flotation of Silica From Iron Ore With Anionic Collector
2,419,945	Froth Flotation of Silica From Iron Ore
2,424,552	Froth Flotation of Nonmetallic Minerals
2,424,844	System for Heating Liquids
2,424,975	Process for Separating Potassium Sulfate From Alkali Carbonates

1948:

2,439,805	Method for Electrowinning Manganese
2,443,176	V-Opening Screen

1949:

2,459,203	Production of Shaped Articles From Fluorite
2,462,900	Reduction Accelerator for the Sponge Iron Rotary Kiln Process
2,464,267	Dehydrating Alumina in the Production of Aluminum
2,469,413	Process for Preparing Barium Aluminate
2,407,106	Process for Reducing Iron Ores
2,473,534	Production of Magnesium Oxide
2,476,284	Cobalt Solution Purification
2,476,979	Process for Preparing Alumina From Clays and Other Silicates for Aluminum
2,482,127	Apparatus for Refining Metals

1950:

2,493,763	Method of Producing Lightweight Aggregate From Clay
2,495,225	Method for the Production of Low Sulfur Sponge Iron
2,497,863	Method for Concentrating Fluorspar Ores
2,508,427	Ore Separation
2,519,361	Production of Magnesium Carbonate or Magnesium Oxide Containing Little or No Calcium
2,520,958	Nickel Recovery

Patent No.	Title
2,522,537	Dithionate Process for Production of Zinc Hydroxide From Zinc Oxidized Ores
2,526,707	Process for the Production of a Cobalt Salt From Arseniferous Ores
2,533,246	Production of Lithium Chloride From Spodumene
2,534,259	Recovery of Alcohol from a Ternary Solution
2,535,042	Preparation of Iron Carbides
2,536,021	Material Feeding Unit
2,537,034	Purification of Commercial Soda Ash
2,548,897	Process for Melting Hafnium, Zirconium, and Titanium Metals
2,549,798	Production of Magnesium Chloride From Magnesium Silicate Ore
1951:	
2,550,708	Removal of Silica From Alkaline Carbonate Brines
2,563,903	Electrolytic Cell for the Deposition of Gold and/or Silver From Solutions
2,574,469	Method of Utilizing Aqueous-Organic Chemical Wastes From the Fischer-Tropsch Process
2,577,833	Process for Electrowinning Chromium
2,579,531	Process for Extracting Gold and Silver
1952:	
2,593,431	Reagent Conditioning for Electrostatic Separation of Minerals
2,600,456	Promotion of Dithionate Ion Formation in Leaching Oxidic Manganese Ores with Sulfur Dioxide Solutions
2,601,306	Method for Dissolution of Chromium From Chromite Ores
2,603,423	Method for the Removal of Sulfur From Sponge Iron
2,616,800	Method for Making Cupro-Titanium
2,621,234	Instrument for Measuring the Carbon Content of Steel
1953:	
2,653,134	Process for Removing Scale From Zirconium Metal and Alloy Thereof
2,655,472	Process for Extracting and Recovering Metals by Leaching and Electrolysis
2,663,686	Production of Electrolytic Chromium From Ferrochrome
1954:	
2,666,269	Method of Drying Solids in a Fluidized Bed
2,666,587	Beneficiation of Beryllium Ores by Froth Flotation
2,666,588	Flotation Process for Separation of Silica and Rhodonite
2,675,853	Fabrication of Synthetic Fluorine-Micas
2,687,952	Cyclic Process for Producing High-Grade Synthetic Manganese Ores by Oxidation of Molten Iron-Manganese Alloys

Patent No.

Title

1955:

2,701,057	Concentration of Iron Ores by Froth Flotation
2,702,239	Magnesium Vapor Arc Melting of Zirconium
2,711,435	Electric Furnace and Electric Melting and Crystallizing Method for Minerals
2,714,960	Wet-Magnetic Separator

1956:

2,731,355	Process of Producing a Crystalline Magnesium-Aluminum- Silicate Material
2,735,546	Thermal Conditioning for Electrostatic Separation of Garnet
2,750,255	Process for Rendering Titanium Minerals and Ores Soluble in Acids
2,755,178	Electric Smelting Process for Production of Silicon- Aluminum Alloys
2,763,478	Apparatus for Drying Solids in a Fluidized Bed
2,769,536	Reagent Conditioning for Electrostatic Separation of Beryl

1957:

2,784,075	Method for Recovering Vanadium From Leach Liquors
2,790,713	Process for Obtaining Nickel and Cobalt From a Mixed Sulphide Matte
2,799,574	Electric Smelting Process for Manganese Ores
2,810,637	Method of Extracting Aluminum From Aluminum-Silicon Alloys by Low Pressure

1958:

2,825,641	Method for Melting Refractory Metals for Casting Purposes
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1959:

2,890,111	Method of Manufacturing Titanium and Titanium Alloys
2,892,924	Electrode for Melting and Arc Welding Zirconium Metal
2,923,754	Method and Apparatus for Manufacturing Synthetic Mica

1960:

2,934,443	Impact-Resistant Ceramic Dielectric and Method of Making Same
2,948,629	Impact-Resistant Ceramics From Synthetic Fluoramphiboles and Processes of Making Same

1961:

3,005,690	Multiple Compartment Rotary Drum for the Leaching of Ores or Related Products in a Continuous Counter-Current System
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Patent No.	Title
3,008,802	Recrystallizing a Reconstituted Fluorine-Mica Sheet
3,012,668	Device, Electrostatic Separator Carrier Electrode
1962:	
3,016,296	Method for Reduction of Refractory Metal Oxide to Metal by Calcium Carbide
3,027,750	Apparatus for Studying Phase Relationship of Gases and Gas Mixtures
3,028,008	Separation of Spodumene and Beryl by Flotation
3,028,183	A Flexible Vacuum-Tight Electrode Seal
3,046,215	Electrolytic Cell with Vertical Mercury Electrode
3,069,255	Production of High Purity Titanium by Metallic Sodium Reduction of Titanic Halide
1963:	
3,017,523	Method for Electrowinning Molybdenum From Molten Electrolytes
3,075,710	Process for Wet Grinding Solids to Extreme Fineness
3,075,900	Method for Separating Molybdenum From Tungsten by Electrolysis From a Fused Electrolyte Bath
3,078,997	Flotation Process for Concentration of Phenacite and Bertrandite
3,088,805	Method for Producing Zirconium Diboride
3,107,215	Flotation Process for Concentration of Pollucite Ores
3,113,017	Method for Reacting Titanic Chloride With an Alkali Metal
1964:	
3,117,000	Activation of Inert or Passive Metals
3,126,327	Electrolytic Method for Extracting the Chromium Values From Chromium Oxide Bearing Ores
3,137,648	Pretreatment of Minerals for Electrostatic Separation
3,138,637	Process for Recovering Ethylenediamine-Tetraacetic Acid (EDTA) From Copper-EDTA-Ion Exchange Effluent Solutions
3,140,170	Process-Magnesium Reduction of Titanium Oxides in a Hydrogen Atmosphere
3,148,974	Method for Segregating Copper-Ores
3,149,006	Prevention of Embrittlement of Metals
3,154,381	Progressive Melting and Crystallization of Synthetic Mica
1965:	
3,179,514	Upgrading Primary Manganese Matte
3,184,302	Removal of Oxygen and Aluminum From Metals Prepared by Alumino-Thermic and Similar Processes
3,185,564	Method of Agglomerating Iron Ore Fines
3,192,012	Process for Separating the Rare Earth Elements by Means of Solvent Extraction

Patent No.**Title**

3,221,906	Sealing System for Blast Furnace Bells for High Pressure Top Operation
3,222,142	Synthesis of Large Crystals of Fluorrophlogopite
1966:	
3,228,750	Process for Separating Rare-Earth Elements by Ion Exchange
3,236,682	Process for Preparation of Caustic-Resistant Containers for High Temperature Use
3,244,475	Solvent Extraction Process for Separating Rhenium From Molybdenum
3,244,480	Synthesis of Fibrous Silicon Nitride
3,259,472	Fraction Separation of Aqueous Rare Earths Using Amines
3,260,658	Process for the Recovery of Rhenium
3,271,128	Prerefining Blast Furnace Iron
3,273,993	Reduction Roasting With Iron
3,273,995	Recovery of Zinc From Zinc Die-Cast Scrap
3,278,028	Flotation of Mica
3,282,678	Smelting Reduced Iron Ore Pellets in the Blast Furnace
3,292,780	Iron Ore Separation
1967:	
3,298,935	Preparation of Reactive Metal Solutions by Electrodeposition Methods
3,301,634	Process for Decomposing Manganese Sulfate to Form Manganous Oxide and Sulfur Dioxide
3,309,292	Method for Obtaining Thick Adherent Coatings of Platinum Metals on Refractory Metals
3,313,412	Recovery of Molybdenite From Copper Sulfide Concentrate by Froth Flotation
3,316,058	Process for the Extraction of Tungsten From Aqueous Solution
3,321,009	High Temperature Heat Exchange Using Liquid Metal
3,321,271	Synthesis of Aluminum Silicate Whiskers
3,323,857	Selective Extraction and Separation of Lanthanides With a Quaternary Ammonium Compound
3,329,265	Flotation of Mica
3,330,646	Method for Producing Molybdenum From Molybdenite (MoS)
3,336,161	Biochemical Method for Producing Electricity
3,347,370	Process for Washing and Removing Organic Heavy Liquids From Mineral Particles
3,350,166	Synthesis of Aluminum Borate Whiskers
3,357,819	Preparation of Homogeneous Powders Composed of Ultrafine Particles
3,357,896	Decaking of Caking Coals
3,360,333	Fluor-Micas and Fluor-Amphiboles and Methods for Making Same
3,360,364	Process for Producing Nodular Graphite in a Metal

Patent No.**Title****1968:**

3,361,559	Method for Antimony Precipitation of Mercury
3,362,894	Anodic Method for Cleaning Nickel and Other Metal Surfaces for Electroplating
3,396,168	Frequency Conversion System Utilizing Modulation
3,396,978	Electrodeposition of Molybdenum
3,373,097	Method for Separation of a Metal-Containing Halide Phase From a Gangue-Containing Silicate Phase and Electrolysis of Halide Phase to Obtain the Metal
3,375,180	Electrochemical Preparation of Metal Sulfides
3,378,336	Sulfate Removal From Brines
3,382,977	Magnetic Separator With a Combination Field
3,385,669	Method of Preparing Zirconium Carbide Fibers and the Product Thereof
3,390,045	Method of Making Paper From Mica Flakes Which Have Been Subjected to Hot Aqua Regia
3,390,985	Consolidation and Forming by High-Energy-Rate Extrusion of Powder Material
3,397,130	Process for Manganese Recovery From Leach Solutions
3,397,946	Method of Producing Anhydrous Chromous Chlorine From Chromium Metal
3,399,033	Crystallization of Tungsten Disulfide From Molten Slags
3,402,041	Process for Removing Phosphorus From Iron Ores
3,409,757	Controlled Thermal Environment Apparatus

1969:

3,425,793	Process for Fractionating Lanthanide Mixtures Containing Cerium
3,427,683	Apparatus for Forming Spherical Pellets
3,429,657	Method for Recovering and Producing Potassium Salts
3,431,766	Device for Drawing Wire Which Eliminates Chatter
3,435,668	Method of Determining Preferred Orientation in Metals
3,441,404	Extraction of Copper From Molten Metal Melts
3,443,891	Method and Apparatus for Growing Large Monocrystals of Nonmetallics
3,446,720	Preparation of High-Purity Nickel and Cobalt
3,463,607	Method of Synthesizing Asbestos

1970:

3,507,629	Extraction of Aluminum From Silicate Rocks and Minerals Containing Aluminum
3,508,431	System for Calibration of a Differential Pressure Transducer
3,514,266	Separation of Aluminum, Calcium, and Magnesium From the Alkali Metals by Solvent Extraction

Patent No.**Title**

3,516,810	Glass-Bonded Crystalline Minerals and Method of Production
3,524,800	Method for the Production of Samarium Alloys
3,525,589	Production of Boron Carbide Whiskers
3,532,330	Seal and Trommel for a Rotary Kiln
3,533,779	Method for Smelting Low-Sulfur Copper Ores
3,542,540	Carbonion Leaching of Heavy Metal Ores
3,545,920	Process for Extracting Aluminum From Solutions
3,547,789	Electrodeposition of Thick Coatings of Palladium

1971:

3,573,182	Process for Separating Zinc and Copper
3,574,595	Method for Producing Prerduced Iron Ore Pellets
3,574,600	Process for Recovery of Gold From Carbonaceous Ores
3,575,697	Acid Leaching of Manganese From Siliceous Ores and Slags
3,576,621	Vanadium-Base Alloy
3,577,232	Removing Nickel From Cadmium
3,589,987	Method for the Electrolytic Preparation of Tungsten Carbide
3,591,332	Process for Recovery of Sulfur From Gypsum
3,595,484	Reclamation of Refractory Carbide From Carbide Materials
3,600,284	Method of Adding Refractory Metal Halides to Molten Salt Electrolytes
3,607,236	Reclaiming of Superalloy Scrap
3,615,173	Separation of Rare Earth Elements by Ion Exchange
3,615,190	Oxidation of Lead Blast Furnace Matte
3,620,715	Steel Scrap Oxidation Acceleration by Surface Impregnation Techniques
3,622,304	Ferrothermic Extraction of Copper
3,622,491	Electrolytic Apparatus for Molten Salt Electrolyte
3,630,675	Selective Oxidation of Ferrous Scrap

1972:

3,634,070	Process for Recovery of Copper and Other Metals From Source Materials
3,635,697	Recovery of Gold
3,639,222	Extraction of Mercury From Mercury-Bearing Materials
3,639,925	Recovery of Gold From Carbonaceous Ores
3,649,220	Recovery of Zinc and Nickel From Waste Phosphate Liquor
3,649,377	Process for Improving Creep Resistance of Zinc-Copper Alloys
3,650,931	Purification of Reactive Metals
3,653,875	Recovery of Metals and Phosphate From Waste Phosphate Sludge
3,660,022	Recovery of Copper
3,666,444	Electrowinning of Beryllium
3,675,310	Soldering Method
3,676,107	Refining of Iron-Bearing Wastes
3,697,390	Electrodeposition of Metallic Boride Coatings

Patent No.	Title
3,700,766	Method for Producing Solutions of High Alumina Concentration by Alkaline Extraction of Aluminum Containing Oil Shale
1973:	
3,711,386	Recovery of Metals by Electrodeposition
3,714,325	Recovery of Molybdenite
3,716,615	Process for the Production of Cuprous Oxide
3,725,221	Recovery of Niobium and Tantalum
3,729,306	Purification of Rare-Earth Metals
3,730,781	Method for Improving Creep-Resistance of Alloys
3,736,239	Neutralization of Metal Containing Wastes
3,739,061	Manufacture of Synthetic Rutile
3,743,695	Uranium Recovery
3,755,106	Electrolytic Oxidation of Sb_2S_3
3,764,402	Creep-Resistant High-Strength Zn-Al and Zn-Al-Mg Alloys
3,764,493	Recovery of Nickel and Cobalt
3,764,540	Magnetofluids and Their Manufacture
3,764,650	Recovery of Gold From Ores
3,767,378	Production of Rutile and Iron From Ilmenite
3,769,185	Electrolytic Preparation of Zirconium and Hafnium Diborides Using A Molten, Cryolite-Base Electrolyte
3,773,889	Ion Exchange Process
3,775,091	Induction Melting of Metals in Cold, Self-Lined Crucibles
3,775,096	Production of Niobium and Tantalum
3,775,271	Electrolytic Preparation of Titanium and Zirconium Dioborides Using a Molten, Sodium Salt Electrolyte
3,776,718	Recovery of Copper and Steel From Scrap
1974:	
3,783,116	Decomposition of Carbonyl Sulfide (COS) in Electric Charge
3,784,669	Recovery of Metal Values From Chrome Etching Solutions
3,788,465	Device and Process for Magneto-Gravimetric Particle Separation Using Non-Vertical Levitation Forces
3,798,140	Process for Production Aluminum and Silicon From Aluminum Silicon Alloys
3,812,232	Solvent Extraction Procedure for Separating Samarium From Neodymium
3,821,036	Oxyreaction Strengthening of Metals
3,825,651	Recovery of Gold From Ores
3,826,128	Surface Deformation Indicating Apparatus
3,826,808	Process for Recovering Tungsten From Alkaline Brine
3,827,954	Electrodeposition of Metallic Boride Coatings
3,829,309	Process for Smelting Ilmenite to Produce Pig Iron and Titania- Containing Slag
3,834,896	Recovery of Gold
3,943,540	Production of Magnetic Fluids by Peptization Techniques

Patent No.

Title

3,848,813	Continuous Process for Mechanically Separating Materials Contained in Urban Refuse
3,949,265	Electro-Oxidative Method for the Recovery of Molybdenum From Sulfide Ores
3,852,060	Formation of Metal Filaments by Solid State Reactions
3,854,936	Smelting of Nickel Oxide Ores to Produce Ferronickel
3,857,701	Smelting of Copper Oxides to Produce Blister Copper
3,857,767	Recovery of Copper From Chalcopyrite Ore Concentrates
1975:	
3,862,292	Recovery of Rhenium
3,864,327	Removal of Mercury From Solutions
3,873,307	Process for the Preparation of Yttrium-Silicon Compounds or Master Alloys by Sili on Carbide Reduction of Yttria
3,875,777	Upgrading Primary Manganese Matte
3,877,932	Pressure Cementation Process for Recovery of Copper From Solution
3,888,703	Method of Producing Creep Resistance of Pb-Sb Alloys
3,888,970	Double Layer Catalyst Bed for Removing SO ₂ From Waste Gases
3,890,007	Chemical Mining of Copper Porphyry Ores
3,891,430	Recovery of Lead
3,892,639	Extraction of Metal Values From Laterite Ores
3,899,569	Preparation of Highly Pure Titanium Tetrachloride From Ilmenite Slag
3,900,532	Preparation of Highly Pure Titanium Tetrachloride From Perovskite or Titanite
3,900,696	Charging and Electric Furnace
3,902,865	Fe-Cu Duplex Metal Filaments
3,902,973	Electrolytic Preparation of Lanthanide and Actinide Hexaborides
3,909,251	Prevention of Surface Cracking Due to Formation of Copper Alloys of Tin and Antimony During Reheating of Steel
3,912,330	Chemical Mining of Copper Porphyry Ores
3,920,403	Method of Desorbing Gold From Activated Carbon
3,925,068	Preparation of Alloys
3,929,459	Charging an Electric Furnace
3,929,468	Process for Recovery of Non-Ferrous Metals From Oxide Ores and Concentrates
1976:	
3,932,170	Use of Scavenger in Recovery of Metal Values
3,933,608	Method for the Decomposition of Hydrogen Sulfide
3,933,635	Method for Removing Soluble Selenium From Acidic Waste Water
3,935,006	Process for Eluting Adsorbed Gold and/or Silver Values From Activated Carbon

Patent No.	Title
3,940,265	Recovery of Lead From Battery Scrap
3,950,163	Quaternary Fluxes for Electroslag Remelting Ferrous Alloys and Superalloys
3,956,116	Process for Separating Liquids From Suspensions
3,958,983	Decomposition of Chalcopyrite
3,961,942	Hydrometallurgical Process for Copper Recovery From Sulfide Ores
3,962,050	Recovery of Zinc From Zinc Chloride by Fused Salt Electrolysis
3,962,408	Dehydration of Magnesium Chloride
3,976,761	Preparation of TiO_2 and Artificial Rutile
3,985,555	Hydrothermal Alteration of Chalcopyrite with Acid and Electron Donors
3,985,556	Reduction of Laterite Ores
3,985,855	Recovering Copper Values From Oxidized Ores
3,988,240	Alternating Field Magnetic Separator
3,992,327	Production of Solid Catalysts and Adsorbents by Mechanical Means
3,996,332	Synthesis of Rutile From Titaniferous Slags
3,997,332	Steelmaking by the Electroslag Process Using Prerduced Iron Ore Pellets
3,999,980	Fluxless Recovery of Metallic Aluminum From Wastes
4,000,067	Method for Rapid Sedimentation of Fine Particles from Suspensions
1977:	
4,022,626	Structural Material
4,026,786	Preparation of PbO Anode
4,032,613	Removal of Iron From Aluminum Nitrate
4,039,625	Beneficiation of Olivine Foundry Sand by Differential Attrition Grinding
4,043,946	Production of Supported Raney Nickel Catalysts by Reactive Diffusion
4,044,115	Production of Alumina Monohydrate From Aluminum Nitrate Solutions
4,049,580	Method for Producing Supported Raney Nickel Catalyst
4,053,302	Synthetic Fluorspar for Conditioning Electric Furnace Slags
4,053,305	Recovery of Copper and Silver From Sulfide Concentrates
4,053,377	Electrodeposition of Copper
4,053,575	Sulfur Recovery From H_2S and SO_2 — Containing Gases
4,058,668	Cold Crucible
4,062,744	Extraction of Copper From Sulfide Ores
1978:	
4,071,473	Preparation and Use of High Surface Area Transition Metal Catalyst
4,072,587	Separate Recovery of Silver and Gold From Cyanide Solutions
4,080,430	Decomposition of Cupric Oxide Using A Reducing Scavenger
4,085,017	Recovery of Copper and Nickel From Alloys
4,087,287	Method for Providing Ferritic-Iron-Based Alloys
4,089,812	Massive Catalyst

Patent No.

Title

4,090,935	Process for Recovering Silver, Copper, and Stainless Steel From Silver Brazed Stainless Steel Sections
4,094,955	Acid Process for Recovery of Alumina From Clay
4,098,956	Spectrally Selective Solar Absorbers
4,104,132	Method for Eliminating Solution-Level Attack on Cathodes During Electrolysis
4,107,266	Production of Pure Alumina From Iron Contaminated Sulfate Liquors
4,110,107	Process for Reducing Molten Furnace Flags by Carbon Injection
4,120,694	Process for Purifying a Titanium-Bearing Material and Upgrading Ilmenite to Synthetic Rutile With Sulfur Trioxide
1979:	
4,133,967	Two-Stage Electric Arc-Electroslag Process and Apparatus for Continuous Steelmaking
4,135,921	Process for the Preparation of Rare-Earth Silicon Alloys
4,138,465	Selective Recovery of Nickel, Cobalt, Manganese From Sea Nodules With Sulfurous Acid
4,142,417	Multichannel Infrared Pyrometer
4,156,656	Preparation of Hydrosulfides
4,157,371	Method of Agglomerating Fine Powders
4,159,231	Method of Producing a Lead Dioxide Coated Cathode
4,164,460	System for the Dielectrophoretic Separation of Particulate and Granular Materials
4,167,459	Electroplating With Ni-Cu Alloy
4,167,477	Separation of Plastics by Flotation
4,167,555	Extraction of Tungsten From Ores
4,174,937	Powder Agglomerator and Its Method of Use
4,174,966	High Coercive Force Rare Earth Metal-Cobalt Magnets Containing Copper and Magnesium
4,180,628	Resin for Sorption of Tungsten
1980:	
4,181,588	Method of Recovering Lead Through the Direct Reduction of Lead Chloride by Aqueous Electrolysis
4,181,607	Removal of Asbestos Fibers From Water
4,181,630	Catalyst for Synthesis of Methanol
4,184,884	Process for Producing a Metastable Precursor Powder and for Producing Sialon From This Powder
4,192,737	Froth Flotation of Insoluble Slimes From Sylvinitic Ores
4,192,738	Process for Scavenging Iron From Tailings Producing by Flotation Beneficiation and for Increasing Iron Ore Recovery
4,208,275	Froth Flotation Using Lanolin Modifier
4,208,294	Dilution Stable Water Based Magnetic Fluids
4,208,378	Desorption of Gold From Activated Carbon

Patent No.	Title
4,208,379	Recovery of Metals From Atlantic Sea Nodules
4,239,547	Recycling Spent Asphaltic Concrete
4,231,859	Molbydenite Flotation
4,231,866	Recovery of Organic and Aqueous Phases From Recovery of Metallurgical Solvent Extraction Emulsions
4,231,993	Recovery of Metal Values From Lead Smelter Matte
4,231,994	Separation of Zirconium From Hafnium by Solvent Extraction
4,239,735	Removal of Impurities From Clay
4,241,028	Sorption of Tungsten From Alkaline Solutions
4,242,192	Electrolytic Stripping Cell
4,242,312	Removal of Sodium Sulfate From a Sulfate-Containing Sodium Chloride Solution in a Process for Separating Zirconium and Hafnium
1981:	
4,256,557	Copper Electrowinning and Cr^{+6} Reduction in Spent Etchants Using Porous Fixed Bed Coke Electrodes
4,256,587	Siliceous Adsorbent for Heavy Metals
4,256,653	Preparation and Use of High Surface Area Transition Metal Catalyst
4,256,705	Leaching Agglomerated Gold-Silver Ores
4,256,706	Leaching Agglomerated Gold-Silver Ores
4,256,707	Selective Removal of Mercury From Cyanide Solutions
4,258,016	Process for Recovering Ni(II), Cu(II), and Co(II) From an Ammoniacal-Ammonium Sulfate Leach Liquor
4,259,296	Recovery of Chromium From Scrap
4,259,311	Decomposition of $\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$ in H_2 Atmosphere
4,260,589	Production of Alumina From Aluminum Nitrate Solutions
4,272,340	Electrowinning of Lead From H_2SiF_6 Solution
4,272,491	Ferric Leaching of Uranium Values From Lignite
4,285,784	Process of Electroplating a Platinum-Rhodium Alloy Coating
4,285,912	Recovery of Bismuth From Chloride Process Solutions
4,285,914	Recovery of Lithium From Low Grade Ores
4,287,095	High Surface Area Transition Metal Catalysts and Method of Preparing Same
4,290,877	Sputtering Apparatus for Coating Elongated Tubes and Strips
4,295,971	Method for Clarifying Slimes
4,301,032	Thorium Oxide-Containing Catalyst and Method of Preparing Same
4,301,676	Method for Measuring the Ionic Activities in Water With a Differential Pressure Transducer
4,303,532	Dewatering of Slimes
4,306,905	Production of Ferrochromium Alloys
4,307,066	Extraction of Metals From Mixtures of Oxides or Silicates
4,307,964	System for Maintaining High Resonance During Sonic Agglomeration

Patent No.**Title****1982:**

4,311,584	Amine Flotation of Chromite From Acidic Pulps
4,311,826	Modified Sulfur Cement
4,330,090	Method for Wrought and Cast Aluminum Separation
4,330,509	Separation of Zirconium and Uranium
4,337,129	Regeneration of Waste Metallurgical Process Liquor
4,337,226	Recovery of Platinum-Group Metals From Ores
4,337,227	Recovery of Chromium From Waste Solutions
4,362,557	Purifying Titanium-Bearing Slag by Promoted Sulfation
4,362,615	Froth Flotation of Rutile
4,340,253	Preflush Lixiviant Process for Solution mining of Uranium Ore Beds
4,348,313	Concrete Formulation Comprising Polymeric Reaction Product of Sulfur/Cyclopentadiene Oligomer/Dicyclopentadiene

1983:

4,377,410	Chromium Recovery From Superalloy Scrap by Selective Chloride Leaching
4,381,287	Separation of Zirconium and Uranium
4,385,998	Removal of Suspended Solids From Water
4,386,518	Apparatus and Method for Measuring Low Concentrations of High Molecular Weight Polymers in Solution
4,388,280	Extraction of Aluminum From Clay
4,391,969	Modified Sulfur Cement
4,394,368	High Temperature Hydrolysis of Aluminum Sulfate Solutions
4,401,632	Recovery of Arsenic From Flue Dust
4,402,932	Thermal Decomposition of Aluminum Chloride Hexahydrate
4,407,775	Pressureless Consolidation of Metallic Powders
4,409,020	Recovery of Metals From Grinding Sludges
4,409,189	Recovery of Tungsten From Brines
4,410,496	Recovery of Metal Values From Complex Sulfides

1984:

4,435,302	Concentrating and Reclaiming Magnetic Fluids
4,442,072	Selective Recovery of Base Metals and Precious Metals From Ores
4,445,931	Production of Metal Powder

1985:

4,498,928	Ductile Duplex Iron-Based Alloy Containing Aluminum
4,500,398	Production of Lead From Sulfides
4,554,058	Electrolytic Production of Precious Metals

Patent No.**Title**

1986:

4,568,652	Soluble Additives to Improve Temperature Properties of Alumina Refractories
4,588,565	Separation of Lithium Chloride From Impurities
4,601,795	Alloy Coating Method
4,613,069	Method for Soldering Aluminum and Magnesium
4,615,874	Process for Producing Chlorine from Ferric Chloride

1987:

4,692,875	Metal Alloy Identifier
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