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By Stephen M. Jasinski

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	mt	metric ton
K	kelvin	mt/yr	metric ton per year
kg	kilogram		

BISMUTH—USES, SUPPLY, AND TECHNOLOGY

By Stephen M. Jasinski[1]

ABSTRACT

The development and industry adaptation of advanced technologies have led to many important uses for bismuth and its compounds. Bismuth-base alloys are essential for manufacturing jet engine turbine blades, lenses, and various safety devices, such as fire-protection sprinklers. The addition of bismuth to iron, steel, and aluminum imparts properties to these metals that makes them useful in diversified applications. Bismuth is also used widely in medicine, pigments, and electronics. The United States relies heavily upon imports from South America and Europe to meet its demand for bismuth, which is recovered chiefly as a byproduct of lead processing.

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INTRODUCTION

Bismuth compounds have been used for centuries to treat stomach disorders, but bismuth was not recognized to be a separate element until the mid-18th century. Uses for the metal remained relegated to type metal for printing presses and other lead alloys until the 1890's, when the low melting properties of bismuth alloys were found to be an excellent material for electrical fuses and as a triggering device for automatic fire sprinklers, both still important uses today. In the past 60 years, a variety of other important metallurgical uses have been developed that utilized bismuth's nontoxicity and low melting point.

Bismuth is recovered mainly as a byproduct of lead processing, except in Bolivia, the only country where it is mined for itself. The largest producers of bismuth are Australia, China, Mexico, and Peru. Because the United States must rely on imported supply, bismuth has been included in the National Defense Stockpile (NDS) since World War II to insure a dependable supply in a national emergency.

This report describes the important past and present applications, industry structure, the processing cycle, supply, and trade of bismuth. It also updates and expands on information presented in the chapter on bismuth from the U.S. Bureau of Mines publication, Mineral Facts and Problems 1985.

USES

Table 1 and figure 1 illustrate the consumption of bismuth in the United States for 1981-90, by major end-use category.

PHARMACEUTICAL

The treatment of digestive disorders with bismuth compounds began in the 16th century, and, before 1930, this application accounted for almost 90% of world consumption. For centuries, physicians have recognized that the high density of bismuth compounds allows for better adherence to mucous surfaces and have utilized bismuth compounds for many uses such as a mild, nonirritating, antiseptic coating for the digestive tract to treat diarrhea and stomach ulcers, as a treatment for syphilis before the development of penicillin, and in antiseptic dusting powders for skin wounds. Diagnostic X-ray examinations of the digestive system that currently employ barium sulfate formerly used a bismuth paste. Certain burn dressings, antinausea preparations, hemorrhoid medications, and veterinary medications also still use bismuth compounds, but many related uses are now obsolete (*30*).[2]

In the past 30 years, modern faster acting compounds, such as aluminum hydroxide and magnesium hydroxide or antibiotics, have replaced bismuth for internal use. During this period, the U.S. military also has gradually phased out medications containing bismuth. This was one consideration for reducing the goal for bismuth in the NDS in 1989 from 997,903 kg to 480,808 kg.

The following bismuth compounds are commonly used in medicine (*20*):

Bismuth subcarbonate—used in treating stomach disturbances and as a radiopaque pigment added to catheters, to make them apparent on X-rays.

Bismuth subgallate—used in anti-inflammatory skin medications and to deodorize stools in colostomy patients.

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[2] Italic numbers in parentheses refer to the list of references at the end of this report.

Table 1.—U.S. bismuth metal consumption, by use

(Metric tons)

Use	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Chemicals[1]	630	519	501	714	601	663	748	679	659	577
Fusible alloys	298	259	283	276	277	290	334	332	272	249
Metallurgical additives	139	57	237	192	303	350	494	493	396	424
Other[2]	19	16	16	19	19	21	21	27	25	24
Total	1,086	852	1,037	1,201	1,200	1,324	1,597	1,531	1,352	1,274

[1] Includes industrial and laboratory chemicals, cosmetics, and pharmaceuticals.

[2] Includes experimental uses and other alloys.

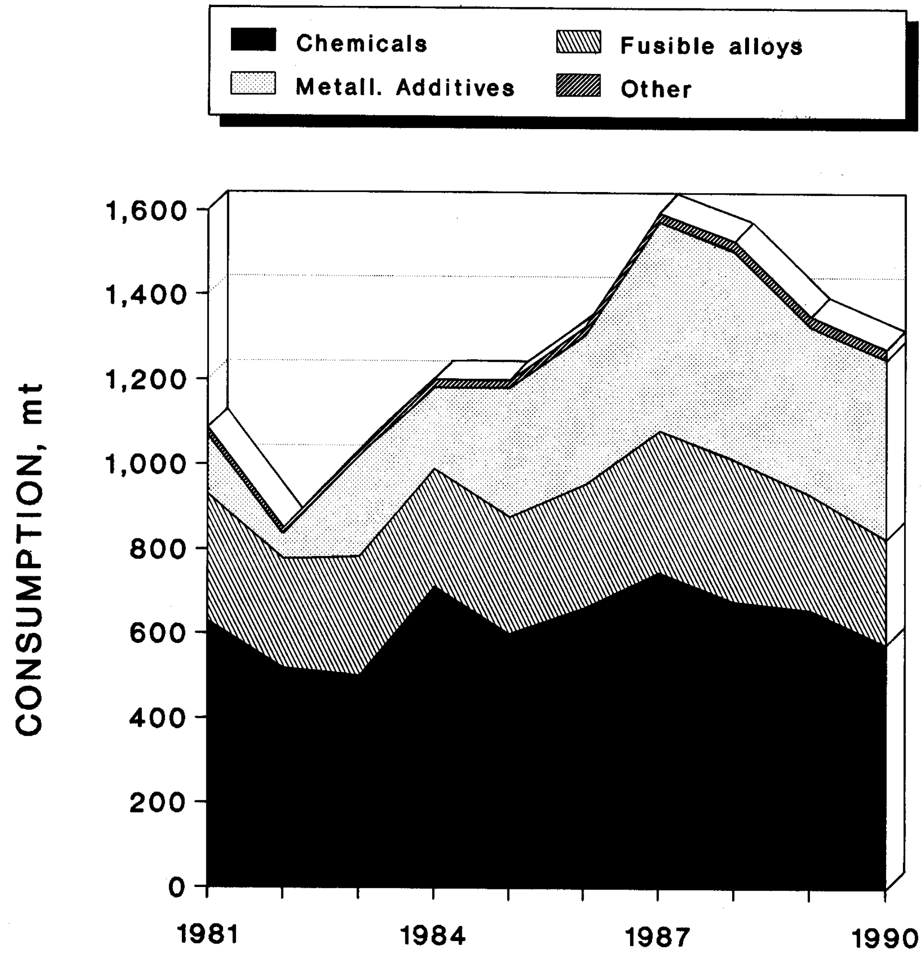

Figure 1.—U.S. consumption of bismuth, 1981-90.

Bismuth subnitrate—used to treat skin inflammation and stomach disorders.

Bismuth subsalicylate—active ingredient in over-the-counter medications for indigestion, nausea, and diarrhea.

When properly administered, bismuth compounds are safe and nontoxic, but two incidents attributed to the imprudent prescription of bismuth in the 1970's contributed to a worldwide decline in pharmaceutical usage. In 1972, Australian health officials first reported ill effects from bismuth drugs used in large doses to deodorize stools of colostomized patients. After a 2-year investigation, the Australian Government restricted over-the-counter sales of certain preparations in 1974. Yet, most medications remained available by prescription (*30*).

France banned orally administered medications containing bismuth in 1978 after 16 people died during 1974 and 1975 from the effects of ingesting abnormally large quantities of bismuth during long uninterrupted periods. This was due in part to some physicians allegedly prescribing massive doses of bismuth medications for use against constipation and other digestive ailments, apparently overlooking well-documented warnings. The excess substance involved was absorbed into the bloodstream and tissues, thus causing serious but reversible neurological disorders and, in exceptional cases, death. The French Government lifted the ban in 1981, but classified bismuth as a suspended substance subject to review every 2 years. Bismuth medications remain available only by prescription. Before the restrictions, France was the leading consumer of bismuth for pharmaceutical uses, reaching 1,000 mt/yr in 1975 (*6*).

PIGMENTS

The most widely used bismuth-base pigment, bismuth oxychloride, is utilized to produce a pearlescent luster in plastics and cosmetics. It replaces natural pearl luster extracted from guanine, a component of certain fish scales, which is expensive and time consuming to produce. Materials such as titanium-coated mica flakes, which can be costly to manufacture, and lead carbonate, a toxic material, have been used as replacements. However, the development of bismuth oxychloride provided a low-cost, nontoxic pigment for use in many applications. It produces the luster by crystallizing into thin plates with a high index of refraction. It is inert in most plastics, insoluble in most liquids, and nontoxic.

The pigment was first successfully tested in plastic materials in the 1950's, but the cosmetic industry became the first widespread consumer when, in the 1960's, it was used in lipstick and eye shadow. The development of a higher luster bismuth oxychloride pigment for nonsettling (the pigment remains in suspension after drying) nail polishes provided another big boost for bismuth in cosmetic pigment usage in the early 1970's.

Also in the 1970's, the U.S. Environmental Protection Agency (EPA) classified the dust generated from producing plastic buttons containing lead carbonate pigments as hazardous waste. This prompted button manufacturers to become the first large plastic industry to switch to bismuth oxychloride pigments. After 1980, the pigment was adapted for use in all types of polyester resins and, as a result, it became a commercially successful replacement for lead carbonate in the United States and Asia. The only drawback is that bismuth pigments darken when exposed to ultraviolet light, but the addition of ultraviolet absorbing compounds corrected the problem (*26*). Bismuth compounds are used in various types of automobile and truck paint as pigments and drying agents. Bismuth oxychloride is used to produce the luster in some metallic paints, and bismuth vanadate-molybdate yellow pigment is used for cars and school buses primarily in Europe (*38*).

INDUSTRIAL CATALYSTS

In the early 1960's, Standard Oil of Ohio (SOHIO) developed a highly successful bismuth phosphomolybdate catalyst for the production of acrylonitrile, which is used primarily as the monomer in the production of synthetic fibers, acrylonitrile-butadiene rubber, and acrylonitrile-butadiene-styrene plastics. This became a major use for bismuth, reaching a peak of an estimated 300 mt/yr in 1966. Consumption declined from 1967 to 1969, when most domestic producers switched to a less expensive, depleted-uranium-base catalyst also developed by SOHIO. The company developed a new catalyst containing iron, phosphorus, and smaller amounts of bismuth in the early 1970's, but consumption never reached the level of 1966 (*27*). Consumption of bismuth for catalysts had tapered off to a small part of domestic usage by 1990.

METALLURGICAL ADDITIVES

A large domestic use of bismuth is as an additive to improve the machinability of steel. Bismuth was chosen as a substitute for lead and tellurium in free-machining steel because, like lead, it has a low melting point and acts as a lubricant during the machining process. It also has a very limited solubility in solid iron, and, like tellurium, it segregates readily upon solidification, causing embrittlement. This allows chips of steel to break off, permitting increased cutting speed and heat dispersal. Bismuth has the distinct advantage in that the difference between its specific gravity and that of iron is 24%, while that between lead and iron is 44%. Thus, there is a more uniform distribution of the bismuth in steel castings (*19*). A proprietary process, used by Inland Steel Corp. since 1978, prevents volatilization of the bismuth, which is added at a temperature close to its boiling point (1,565° C). The final steel product contains either 0.1% or 0.2% bismuth, depending upon the specifications. Bismuth costs more than lead and tellurium additives, and it is used primarily in applications that require nontoxic components, such as water-system valves. It is highly unlikely to become a total replacement for lead because of bismuth's limited supply (*23*).

The Waukesha Foundry of Waukesha, WI, produces a patented, unique stainless steel alloy containing 3% to 5% bismuth. It is used in applications that require sanitary conditions, such as in the rotors of food and beverage pumps. The alloy has excellent resistance to corrosion and can be machined to a very smooth surface, which does not allow bacteria and minuscule food particles to become trapped in the metal, thus reducing the risk of contamination. The composition of the metal also prevents the rotors from galling or seizing (*34*).

The addition of bismuth to malleable cast iron stabilizes the carbides and prevents the formation of graphite flakes, thus preventing mottling or brittleness. Very small amounts, between 0.004% to 0.02% total weight, are used. The actual amount usually increases with the thickness of the casting (*1*).

As in steels, and through the same mechanisms, bismuth-lead alloy additives improve the machinability of aluminum. The addition of 0.2% to 0.4% bismuth to aluminum-magnesium alloys prevents cracking of the metal during the rolling process and improves corrosion resistance (*5*).

Metallurgical additive uses reached a high of 32% of total domestic consumption in 1988, but dropped slightly in 1989 to 29%. Free-machining steel and aluminum products accounted for nearly all the growth.

Figure 2 shows a bismuth-base fusible alloy being poured into an ingot mold.

FUSIBLE ALLOYS AND SOLDER

Fusible alloys usually contain bismuth and melt at temperatures below 300° C. Combining bismuth with various other low-melting-temperature metals such as cadmium, indium, lead, or tin produces the desired melting point. Bismuth is one of a few metals that expands as it cools. Thus, when it is used for casting purposes, the metal does not shrink from the pattern, allowing for precise detail. Alloys that contain more than 55% bismuth expand, while those containing between 48% to 55% are considered stable (*16*). Uses include triggering devices in fire sprinkler systems; jigs for holding lenses in the grinding of optical glass; as a filler material in tubing, which allows the tube to be bent without wrinkling or collapsing; and in mold and patternmaking.

Low-melting-point alloys are essential in the machining process during production of jet engine turbine blades for commercial and military aircraft. In the process, the blade is placed in a holding device, and molten metal is poured around the part. As the metal cools, the blade becomes firmly secured for machining. After machining, the alloy is melted from the part with hot water, steam, or hot oil and separated. It can be reused indefinitely, but is analyzed frequently and treated to maintain the proper composition and melting point.

Trucks and military vehicles use a fusible alloy plug to prevent explosion of the diesel fuel tank in a fire. The plug acts as a pressure relief device that melts at a specific temperature to release the fuel. Aircraft escape hatches also incorporate a low-melting-point seal for easy removal.

Figure 3 is of a typical fire sprinkler head unit. This model uses a bismuth alloy as the triggering device.

Figure 2.—Fusible alloy production.

For nearly a century, since the 1890's, most commercial fire sprinkler systems have used a bismuth-base alloy for the triggering device. A small slug or strip of the metal holds a plug in the sprinkler. At a certain temperature, the alloy melts, thus starting the flow of water to extinguish the fire.

Low-temperature solders may contain bismuth, usually in a tin-bismuth eutectic alloy or with indium. Some miniature parts are unable to withstand the temperatures associated with the conventional tin-lead solder process and require a solder that melts at a lower temperature. Bismuth-base solders may grow in usage as electronic components decrease in size, but their brittleness and inability to withstand large variations in temperature may limit their applications.

Custom-made shields of bismuth-base alloys are used to protect healthy tissue from radiation during treatments for cancer.

Table 2 shows examples of low-melting alloys, with their compositions and melting points.

Table 2.—Examples of low-melting-point bismuth alloys

Composition	Melting point, ° C
44.70Bi-22.60Pb-19.10In-8.30Sn-5.30Cd	47
49.00Bi-21.00In-18.00Pb-12.00Sn	58
50.00Bi-26.70Pb-13.30Sn-10.00Cd	70
42.50Bi-37.70Pb-11.30Sn-8.50Cd	74
38.14Bi-31.67Sn-26.42Pb-2.64Cd-1.07Sb-0.06Cu	83
55.50Bi-44.50Pb	124
58.00Bi-42.00Sn	138

Source: ASM Metals Handbook.

Formable metallized plastic (FMP) is a plastic laminate containing a vacuum-deposited layer of a tin-bismuth alloy. Unlike other plastic parts, which are first formed and then coated, FMP is metallized before forming. Therefore, a highly ductile alloy is required for the coating. Although most bismuth alloys tend to be brittle, the 15% bismuth-85% tin alloy is highly ductile and can be stretched 250%

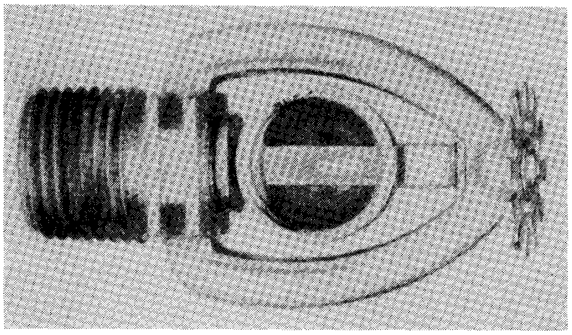

Figure 3.—Fire sprinkler.

without breaking; it is also highly corrosion resistant. FMP is used on satellite dishes for receiving television signals, and it provides shielding of electronic components from electromagnetic interference and acts as an electrically conductive coating. Other uses include decorative trim for toys, automobiles, household appliances, and electronic devices (*8*).

SUPERCONDUCTORS

In January 1988, scientists at the National Research Institute for Metals in Tsukuba, Japan, and at the University of Houston separately announced development of a "high-temperature" superconductor, having a critical temperature above 90 K (-183° C) and containing oxides of bismuth, strontium, calcium, and copper sintered into a monocrystalline structure (*36*). The material has also been formulated successfully through screen printing, in which the oxides of the metals are ground and mixed with a resin, applied to a single crystal magnesia substrate, and heated. Thick films can be made rapidly and successfully with this technique and could lead to the production of a practical superconductor. Japanese researchers have reached zero resistance at temperatures as high as 110 K (-163° C) with material produced by both methods (*21*).

The bismuth-bearing superconducting compounds are less expensive to produce than lanthanide- and thallium-base superconducting compounds, but are still experimental. The magnetic flux lattice of these materials begins to "melt" or "creep" at temperatures above 77 K in the presence of a magnetic field. This causes resistance to the current, limiting the current-carrying capacity. Bismuth and thallium superconductors may not be practical for use in applications above 77 K, (the boiling point of the nitrogen coolant) unless a method of stabilizing the magnetic field can be found (*29*).

Total worldwide consumption of bismuth for superconductors has been negligible to date.

OTHER USES

Electronic ceramic materials are a growing use for bismuth chemicals. Small quantities of bismuth oxide are added to zinc oxide varistors that are used as lightning and surge protectors in high-voltage applications. Bismuth oxide increases the ability of the varistor to absorb voltage surges and lowers the temperature required to produce the ceramic (*17*). This use was developed in 1970 in Japan, the world leader in the use of bismuth in electronic materials. The electronic ceramics are often classified in the ferrite category, which includes magnetic materials, varistors, magnetic recording media, and other electronic applications. Bismuth oxide is also used as a sintering aid in the production of barium titanate capacitors.

Bismuth oxide has a variety of other applications. It is added to ceramic permanent magnets (ferrites) to increase their magnetic field and strengthen the ceramic, combined with silver to form a durable contact material in certain switches, and used for some video screens as a coating on the shadow mask, which is a thin perforated steel sheet located behind the screen that directs the electrons to the proper phosphors and absorbs excess electrons. Electronic glasses for radar and color video screens used in high technology or defense applications may contain varied amounts of bismuth oxide, which increases the durability, specific gravity, and refractive index of the glass. Infrared detection systems often use lead or cadmium bismuthate glass windows. Other electronic uses include bismuth germanate crystals for radiation detectors (*30*).

Bismuth telluride is an important constituent of thermoelectric coolers (TEC), which are self-contained, solid-state cooling devices. TEC's are used to stabilize the temperatures of lasers and infrared detectors in space telescope cameras, heat-seeking missiles, thermal rifle sights, medical lasers, and thermal detection devices. They are also used to cool small electronic components and small-volume air-cooling devices (*21*). The National Aeronautics and Space Administration used bismuth-telluride elements to control the temperature of the instruments on the *Voyager 2* spacecraft (*9*).

RESEARCH AND DEVELOPMENT

Bismuth compounds have been tested as flame retardants for plastics (*13*). Research has been sporadic owing to periodic uncertainty of the supply, wide fluctuations in the price, and the abundance of other lower cost materials, such as antimony oxide.

Some silver oxide button cells, zinc-nickel rechargeable batteries, and silver-lithium cells use bismuth as a cathode material. This application is not expected to grow unless current materials, such as nickel-cadmium, suffer a downturn in usage (*7*).

Bismuth compounds are being tested as a possible cure for stomach ulcers linked to the *Helicobacter pylori* bacterium. In 1983, the bacterium was discovered to be associated with stomach ulcers. Proctor & Gamble Co. provided funding for a project at the University of Virginia to develop a medication against ulcers. Preliminary tests have shown encouraging results in treating ulcers with a combination of bismuth medications and antibiotics (*12*, *37*).

It has been discovered that the addition of an organic bismuth compound, triphenylbismuth, to plastics makes them detectable by X-rays. It can be used in medical devices such as catheters, implants, and dental restorations to make them visible in X-ray diagnosis. This development also could be helpful in making plastic gun parts and explosives formulated with plasticizers containing the compound detectable by airport security systems. In tests, triphenylbismuth has shown no deterioration from heat or moisture (*2*).

The International Bismuth Institute, located in Grimbergen, Belgium, has been instrumental in promoting new uses for bismuth. Incorporated in 1973, it is a nonprofit organization funded by several major world producers. The Institute publishes a bulletin several times a year highlighting major research involving bismuth.

RESOURCES

The most important mineral sources of bismuth are bismite (Bi_2O_3), bismuthinite (Bi_2S_3), and bismutite [$(BiO)_2CO_3 \cdot H_2O$], but these minerals usually do not occur in sufficient quantities in large deposits to be mined as principal products, except in Bolivia. Bismuth is usually recovered as a byproduct of lead and copper processing, but in China and Korea it is associated with tungsten deposits. The largest producers of bismuth during the past 10 years have been Australia, China, Mexico, and Peru.

Although the United States has a reserve base comparable to producers such as Mexico and Canada, most U.S. production is from imported lead concentrates. Historically, bismuth in the United States has been recovered from copper, lead, molybdenum, and zinc deposits in Arizona, Colorado, and Idaho. Lead ores in Missouri, which account for the majority of lead produced in the United States, are essentially bismuth-free. The bismuth content of Western lead ores varies greatly, from about 0.35% to 2.0% (*14*). ASARCO Incorporated, the only domestic producer, recovers bismuth from both domestic and imported lead ore at its refinery in Omaha, NE. If necessary, bismuth could be recovered on a larger scale in the Western United States. Other potential sources include recovery from subeconomic sources such as bituminous coal ash in the Appalachians or tungsten deposits in California.

Table 3 shows the estimated world bismuth reserves.

RECOVERY TECHNOLOGY

Lead

Most bismuth is recovered from the processing of lead ore. The two most common methods of recovery are the Kroll-Betterton process and the Betts electrolytic process.

Figure 4 illustrates the bismuth processing and use cycle.

The Kroll-Betterton debismuthizing process is a pyrometallurgical separation and treatment of magnesium-bismuth-containing dross generated in the process of refining lead bullion. Molten lead bullion, at 485° C, is treated with metallic calcium and magnesium to form insoluble bismuth compounds. These compounds have a lower specific gravity than lead and rise to the surface of the molten lead forming a dross that is skimmed off. The dross is treated first with chlorine or lead chloride and then with caustic soda to remove the calcium, magnesium, and remaining lead. This process is the only one currently used in the domestic lead industry and yields byproduct bismuth of 99.99% purity (*18*).

Table 3.—Estimated world bismuth reserves and reserve base[1]

(Metric tons, bismuth content)

	Reserves	Reserve base[2]
Africa:[3]	500	1,000
Asia:		
China	20,000	40,000
Japan[4]	9,000	18,000
Korea, Republic of	4,000	5,000
Total	33,000	63,000
Australia:	18,000	27,000
Europe:[5]	15,500	39,000
North America:		
Canada	5,000	30,000
Mexico	10,000	20,000
United States	9,000	14,000
Total	24,000	64,000
South America:		
Bolivia	5,000	10,000
Peru	11,000	42,000
Total	16,000	52,000
World total (rounded)	110,000	250,000

[1] Data were derived in collaboration with the U.S. Geological Survey and include the bismuth content of lead and copper reserves.

[2] The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those currently subeconomic (subeconomic resources).

[3] Includes Mozambique, Namibia, and Uganda.

[4] Reserves revised in 1990 by the Geological Society of Japan.

[5] Includes Bulgaria, France, Greece, Romania, the U.S.S.R., and Yugoslavia.

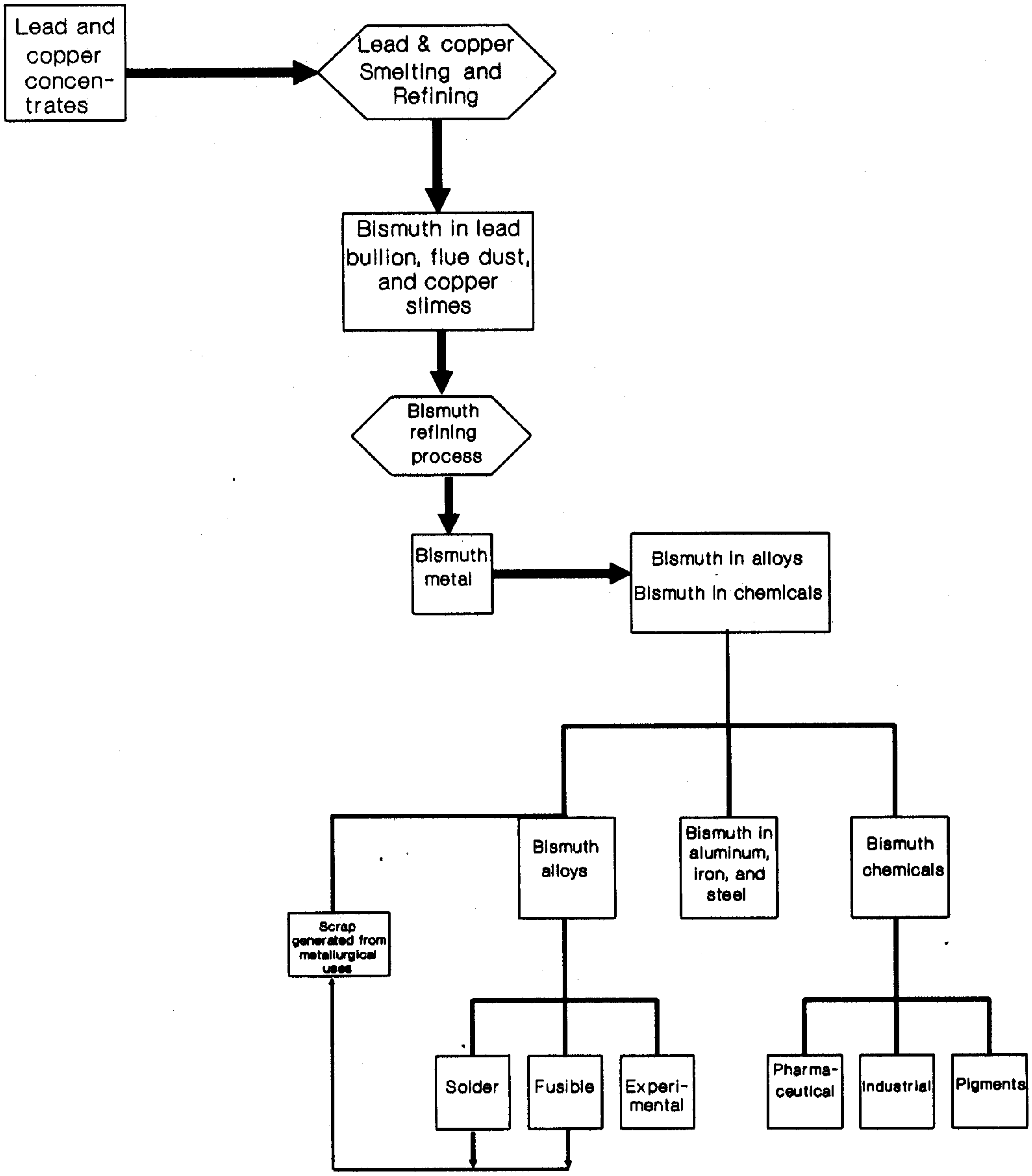

Figure 4.—Bismuth processing cycle.

The Betts electrolytic refining process treats lead bullion containing at least 90% lead. In this method, bullion is cast into anodes, which are set up in parallel in an electrolytic cell. Anode sheets of pure lead are hung between the anodes. The electrolyte is a solution of lead fluorosilicate and fluosilicic acid plus a small amount of glue, which promotes cohesion of cathode deposits. The lead dissolves from the anode and deposits on the cathode as current is passed through the solution. Bismuth, copper, and other metals do not transfer to the cathode, but form anode slimes, which are collected, washed, and remelted to produce slag. The slag is mixed with sulfur and reduced with carbon to form a copper matte and a metal containing 20% to 25% bismuth. The crude bismuth metal is then refined by treating with caustic soda and niter to 99.995% purity (*33*). The Betts process is common in foreign bismuth production.

Copper

Currently in the United States, bismuth is not recovered from copper, but, in the past, was removed from copper smelter flue dusts and from anode slimes generated in the electrolytic refining of copper. The flue dust, along with a bismuth-lead dross formed in the processing of the slimes, was shipped to lead smelters for actual recovery of the bismuth (*28*).

A potential domestic source of bismuth is the flue dust at the sites of former copper smelters. A new process to extract metal value from the wastes was developed in the early 1980's and tested at the Bureau of Mines Reno Research Center. The process involves the chloride-oxygen leaching of complex sulfide ores and other materials such as oxides and scrap. In the process, the valuable metals are recovered while the worthless or toxic materials are removed as a stable leach residue. The leaching and separation occur in a single-step leaching reactor. The process has been tested as effective in extracting up to 10 different metals and compounds, including bismuth, from a variety of feed materials (*32*). In July 1989, a comprehensive study was begun of the feasibility of applying the process to stockpiled flue dust at the former Anaconda Company smelter in Anaconda, MT. Results from the pilot plant have been promising, and recovery on a larger scale is expected to begin in 1992. Preliminary studies indicate that, during the life of the project, 7,000 mt of bismuth metal or metal contained in oxychloride can be recovered from the site (*4, 15*).

Secondary

Secondary production of bismuth is primarily derived from the reprocessing of fusible alloys. A large amount of U.S. bismuth scrap is sent to Europe for recovery of the metal.

Table 4 shows world bismuth mine and refinery production from 1985-90.

Table 4.—Bismuth: World mine and refinery production, by country

(Metric tons)

Country[1]	1985	1986	1987	1988	1989[p]	1990[e]
MINE OUTPUT, METAL CONTENT						
Australia[e]	1,400	1,000	350	400	500	400
Bolivia	159	45	1	13	41	50
Canada[2]	201	153	165	181	164	165
China[e]	260	500	600	750	750	750
France	70	95	[e]90	[e]90	[e]100	110
Japan[3]	[e]195	[e]190	[e]165	[e]160	[e]150	135
Korea, Republic of[3]	[e]135	[e]136	[e]145	[e]132	[e]96	90
Mexico	970	749	1,012	958	883	750
Mozambique	1	([4])	0	0	0	0
Peru	785	605	412	363	687	585
Romania[e]	80	80	75	65	60	70
U.S.S.R[e]	83	84	85	85	85	80
United States	W	W	W	W	W	W
Yugoslavia	68	[e]21	[e]73	23	40	15
Total	4,407	3,658	3,173	3,220	3,556	3,200
REFINED METAL						
Belgium[e]	610	1,000	865	1,000	800	800
Canada[2]	180	212	218	225	272	280
China[e]	260	500	600	750	750	750
Germany, Federal Republic of[e]	[e]400	[e]100	[e]300	0	0	0
Italy	54	66	43	32	[e]30	30
Japan	642	640	546	524	502	442
Korea, Republic of	135	136	145	132	96	90
Mexico	925	519	561	622	597	475
Peru	738	569	387	[e]340	[e]650	521
Romania[e]	80	80	75	65	60	65
U.S.S.R.[e]	83	84	85	85	85	80
United Kingdom[e]	150	150	180	300	200	125
United States	W	W	W	W	W	W
Yugoslavia	68	21	73	23	40	15
Total	4,325	4,077	4,078	4,098	4,082	3,673

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[e]Estimated. [p]Preliminary. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

[1] In addition to the countries listed, Bulgaria, Greece, and Namibia are believed to have produced bismuth, but available information is inadequate for formulation of reliable estimates.

[2] Figures listed under mine output are reported as production of refined metal and bullion plus recoverable content of exported concentrate.

[3] Mine output figures have been estimated based on reported metal output figures.

[4] Less than 1/2 unit.

WORLD SUPPLY AND DEMAND

PRODUCTION

Australia

Australia was the largest producer of bismuth contained in concentrates from 1974 until 1986. However, since then, mine output has been reduced significantly because of lower prices for bismuth, copper, and gold and the depletion of bismuth reserves. Peko-Wallsend Ltd. recovers bismuth from gold-copper ore at the Warrego Mine in the Northern Territory. Before 1981, bismuth-gold concentrates were reportedly shipped to the Federal Republic of Germany for removal of the gold and then to the United Kingdom for refining of the bismuth. Currently, most of the bismuth concentrates are refined in the United Kingdom. Australia is estimated to have the largest reserve base of bismuth, more than 27,000 mt.

In 1990, Australian companies Dragon Resources and Austmelt entered into a joint venture to recover bismuth, gold, and copper from 4,740 mt of flue dust from Peko-Wallsend's operations at the Warrego Mine. The plant will use the Sirosmelt process, developed by the Commonwealth Scientific Industrial Research Organization of Australia, to extract the metals (*25*).

Bolivia

Bolivia is the only country where bismuth is mined as a primary product; however, production has almost ceased since 1979 when Corporación Minera de Bolivia (COMIBOL), the State-run producer, was unable to make a profit because of depressed prices and demand. COMIBOL formerly recovered bismuth at three mines, and the major mine, Tasna, currently only produces copper and tin. The materials were processed at the Telamayo smelter, which was constructed jointly with Société Industrielle d'Etudes et d'Exploitations Chimique (Sidech S.A.), the major producer of bismuth in Belgium. COMIBOL closed the smelter and sold the remaining stocks of bismuth in 1980. From 1979 to the present, several small independent mining companies have recovered bismuth concentrates and sent them elsewhere for refining. In 1989, when prices reached $7.00 per pound, COMIBOL contemplated resuming bismuth mining, but canceled its plans when the price began to decline.

Canada

The major producer of bismuth in Canada is Cominco Ltd. It produces the metal as a byproduct of processing domestic and imported lead concentrates at Trail, British Columbia. Brunswick Smelting and Refining Co., a subsidiary of Noranda Minerals Inc., produces bismuth-lead alloys containing 6% to 50% bismuth at its facility in Belledune, New Brunswick. These alloys are usually sent to Europe to be used to produce bismuth ingots or to be used as metallurgical additives for aluminum castings. Brunswick operated the smelter intermittently in 1990 owing to shortages of lead concentrates and to disputes between management and labor (*3*).

China

The Guangzhou and Zhuzhou smelters and several other Government metallurgical complexes recover bismuth as a byproduct of processing lead, copper, and tungsten. Very few details are known concerning the actual production or plant capacities. Representatives of the 10 major bismuth smelters created the Chinese Bismuth Institute in 1988. They plan to work with the International Bismuth Institute in Grimbergen, Belgium, to promote the metal (*10*).

Japan

Japan was a leader in world bismuth production from 1964 to 1975, but lower lead and copper production, from which bismuth is recovered, and decreasing bismuth content of ores led to a decline in output. Mitsui Mining & Smelting Co. Ltd. and Dowa Mining Co. Ltd. are the largest producers. Japanese demand for bismuth has been steadily increasing, especially for use in electronic materials. In 1988, Japan became a net importer of bismuth, relying heavily upon China.

In 1990, the Geological Society of Japan revised the country's estimated reserves of bismuth from 57,000 mt to 8,745 mt (*31*). The new amount was based on an average bismuth content of 0.114%, derived from ore samples taken at lead-zinc mines throughout the country. The highest concentrations of bismuth were recorded in Kuroko and skarn deposits, the main source of lead and zinc production, of which bismuth is a byproduct.

Mexico

The main producer, Met-Mex Peñoles SA de CV, produces bismuth as a byproduct at its lead refining and smelting complex at Torreón, Coahuila. In 1989, the lead facility operated at 98% capacity using about 50% concentrates from its own mines, about 40% from other mines in Mexico, and 10% from Peru and Australia (*11*). The other producer, Indústria Minera México SA (IMMSA), produces crude bismuth as a byproduct of lead production at its smelter in Monterrey, Nuevo León. IMMSA has sent a large amount of its output to Europe for refining in past years.

Peru

From 1965 to 1986, Peru was one of the three largest producers of bismuth in the world, but numerous disputes between management and labor have closed mines and halted shipments, causing a 20% drop in the output of bismuth from 1986 to 1990. The state-run Empresa Minera del Centro del Péru, the major producer, recovers bismuth as a byproduct of lead processing at its La Oroya smelter-refinery complex (*30*).

U.S.S.R.

Bismuth is recovered as a byproduct of processing lead bullion and flue dust at smelters in Balkhash, Kazakhstan, Kirovgrad, and Mednogorsk. It has also been recovered as a byproduct of tungsten and molybdenum at mines in the Northern Caucasus. Bismuth reportedly is mined as primary metal at the Ustarassy mine in the Chaktal Mountains (*30*). The U.S.S.R. relies heavily upon imports of bismuth, estimated to be 70% of domestic consumption, but actual trade figures are not available (*24*). Estimated production is 100 mt/yr.

Table 5 lists the major world producers of bismuth and their annual production capacity.

Table 5.—World bismuth producers and estimated annual production capacity, December 31, 1990

(Metric tons)

Location	Producer	Capacity	
		Mine	Metal
Australia	Peko-Wallsend Ltd.	1,800	0
Belgium	Sidech S. A.	0	900
Do.	Metallurgie Hoboken-Overpelt	0	200
Bolivia	COMIBOL	700	300
Canada	Brunswick Mining & Smelting Corp.	100	0
Do.	Cominco Ltd.	600	300
China	Zhuzhou	500	500
Do.	Guangzhou	500	500
Germany, Federal Republic of	Norddeutsche Affinerie AG	0	400
Italy	Sameton S.p.A.	0	100
Japan	Mitsubishi Mining Co. Ltd.	700	100
Do.	Mitsui Mining & Smelting Co. Ltd.		350
Do.	Toho Zinc Co. Ltd.		200
Do.	Nippon Mining Co. Ltd.		200
Do.	Sumitomo Mining Co. Ltd.		60
Do.	Dowa Mining Co. Ltd.		240
Do.	Furukawa Co. Ltd.		50
Korea, Republic of	Korea Tungsten Mining Co.	200	200
Do.	Korea Mining and Smelting Co. Ltd.	50	50
Mexico	Industrias Penoles S.A.	700	1,000
Do.	IMMSA	400	0
Peru	Centromin-Peru S.A.	900	800
Romania	Intreprinderea Metalurgia de Metale Neferoase	100	100
United Kingdom	Capper Pass Ltd.	0	200
Do.	Mining and Chemical Products Ltd.	0	200
United States	ASARCO Incorporated	700	500
U.S.S.R.	Usche-Kamenogoroskii	50	50
Do.	Chimkentskii Smelter	50	50
Yugoslavia	Trepca Mining & Smelting Complex	150	150
Do.	Zletovo Mining Co.	(1)	(1)
Total		8,200	7,700

[1] Included with Trepca.

Other Countries

Korea Tungsten Ltd. recovers bismuth as a byproduct at its tungsten processing operations. In Yugoslavia, the state-run Rudarsko-Metalursko-Hemijski Kombinat Trepca lead-zinc complex recovers bismuth as a byproduct.

REFINERY PRODUCTION

Several European companies refine bismuth from imported concentrates. In 1989, Belgium was the world's largest producer of refined bismuth and the largest supplier to the United States. The two producers, Métallurgie Hoboken-Overpelt S.A. and Sidech S.A., use lead concentrates primarily from Mexico and South America. Until 1987, Norddeutsche Affinerie AG of the Federal Republic of Germany produced crude bismuth from Australian copper-gold concentrates. Mining and Chemical Products Ltd. in the United Kingdom produces bismuth as a byproduct of Australian bismuth-copper-gold concentrates (*30*).

Tables 6 and 7 show U.S. trade statistics for 1981-90.

Table 6.—U.S. imports for consumption of bismuth metal, 1981-90

(Kilograms)

Country	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Belgium	71,154	412	7,301	34,385	209,034	384,404	435,009	340,157	835,675	668,071
Bolivia	0	0	0	0	0	0	0	0	32,001	0
Canada	18,933	22,811	81,027	110,033	58,000	33,175	52,161	82,057	23,120	130,071
China	0	0	0	5,082	20,361	24,607	7,497	204,309	35,082	54,229
France	0	0	0	0	0	2,000	0	0	0	0
Germany, Federal Republic of	35,000	53,783	14,870	35,002	43,572	2,150	9,211	278	62,717	17,260
Hong Kong	0	0	0	0	3,504	5,093	2,150	22,801	700	0
Italy	0	0	0	0	0	0	3,255	5,083	0	0
Japan	56,288	18,761	30,972	94,888	45,101	99,624	16,257	13,163	1,068	339
Korea, Republic of	17,035	6,084	24,998	56,673	13,499	21,995	54,227	38,861	12,000	0
Mexico	328,424	317,309	320,496	195,280	307,606	362,896	391,267	448,541	390,815	404,821
Netherlands	0	0	0	0	0	5,500	25,153	20,090	6,161	0
Peru	389,783	391,949	296,522	177,723	78,610	106,979	440,440	188,942	271,444	262,705
Poland	0	0	5	0	0	0	0	0	0	0
Spain	0	0	0	224	0	0	0	0	0	0
Switzerland	0	0	0	0	0	0	0	17,997	0	0
United Kingdom	188,446	107,980	118,274	174,485	127,382	80,856	144,011	259,147	209,538	74,336
Total	1,105,064	919,089	894,464	883,777	906,670	1,129,279	1,580,639	1,641,426	1,880,321	1,611,832

Source: Bureau of the Census.

Table 7.—U.S. exports of bismuth, bismuth alloys, and waste and scrap, by country, 1981-90

(Kilograms)

Country	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Argentina	1,134	0	67	0	0	0	0	25	0	0
Australia	0	49	12	0	0	0	10	0	0	0
Bahrain	0	126	0	0	0	0	0	0	0	0
Belgium	3,377	0	0	0	18,983	98	0	741	8,382	0
Bermuda	0	173	0	0	0	0	0	0	0	0
Brazil	4,802	411	369	0	171	1,639	0	0	0	0
Canada	7,379	5,350	11,317	20,799	7,818	15,295	17,014	23,205	15,554	36,882
Chile	0	0	0	0	354	0	0	0	54	0
China	0	0	17,457	0	3,267	0	0	0	0	0
Colombia	0	230	0	44	0	0	0	0	0	0
Denmark	195	0	0	0	0	0	0	0	0	0
Egypt	0	0	0	0	0	1,003	0	0	0	0
France	5,441	13	3	0	0	0	116	381	787	425
Germany, Federal Republic of	208	629	62	21,632	0	331	2,934	20,191	17,914	158
Greece	0	454	1,814	907	0	0	11	136	0	0
Hong Kong	456	11	0	5	172	17	1,008	0	18,696	2,331
India	811	1,565	0	0	556	0	60	0	300	0
Ireland	2,926	0	186	45	15	44	0	0	0	449
Israel	684	2	75	111	434	0	29	136	1,964	0
Italy	263	899	195	0	111	0	5	0	0	1,706
Jamaica	0	0	0	0	0	0	0	113	0	0
Japan	1,896	2,332	3,360	1,117	3,416	2,179	86	26,291	18,755	0
Korea, Republic of	130	5	4	85	0	0	626	2,086	50	108
Malaysia	0	111	45	0	0	0	476	0	0	0
Mexico	593	0	291	544	0	45	485	399	121	117
Netherlands	0	0	29,287	0	0	727	0	162	0	0
New Zealand	0	0	0	18	0	0	0	34	0	0
Panama	0	0	0	0	0	0	0	702	0	0
Peru	0	93	0	136	0	47	0	0	0	0
Portugal	0	348	0	0	0	0	0	0	0	0
Saudi Arabia	0	0	0	0	0	0	0	233	0	0
Singapore	555	512	404	391	628	1,179	784	470	220	2,217
South Africa, Republic of	2,225	368	31	62	112	0	0	0	0	0
Spain	167	1,288	664	10,100	40	0	0	0	0	0
Sri Lanka	0	0	0	0	0	0	0	0	100	0
Sweden	0	121	0	0	0	0	0	0	55	0
Switzerland	8	181	13,658	30,133	0	0	31	133	46	0
Taiwan	320	0	571	498	240	1,454	2,767	1,080	1,455	1,057
Thailand	1,400	173	0	15	0	231	0	0	0	0
Trinidad	0	239	0	0	0	0	0	0	0	0
United Arab Emirates	0	0	0	0	0	0	200	0	0	0
United Kingdom	387	7,639	58,940	54,656	85,018	17,852	11,317	69,813	37,278	76,227
Venezuela	195	498	0	0	776	0	0	454	440	0
Other	146	111	46	0	0	0	0	0	0	0
Total[1]	35,699	23,931	138,857	141,299	122,111	42,141	37,959	146,785	122,171	121,677

[1] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TRADE

The Harmonized Tariff System includes only imports and exports of bismuth metal, which compose the bulk of trade in bismuth. All bismuth compounds are placed in miscellaneous categories. Trade statistics do not include bismuth ores or concentrates either because they are usually contained in lead concentrates. U.S. import and export statistics for bismuth compounds are available from the U.S. Department of Commerce. Since 1984, Belgium and Mexico have replaced Peru as the largest suppliers of bismuth metals to the United States.

U.S. exports of bismuth have increased substantially since 1986 because of the shipment of bismuth scrap to the United Kingdom for reprocessing.

Table 8 shows U.S. tariffs on bismuth.

Table 8.—Tariffs

Tariff	Number	Most favored nation (MFN) 1/1/91	Non-MFN 1/1/91
Bismuth articles thereof, including waste and scrap.	8106.00.000	Free	7.5% ad valorem.

STRATEGIC FACTORS

Bismuth has been part of the NDS since 1945. The Defense Logistics Agency (DLA), part of Department of Defense (DOD), maintains the Stockpile. Defense uses are mainly for fusible alloys. Bismuth was last purchased for the NDS in the early 1960's, and quantities in excess to the stockpile goal were sold during the 1970's to bring the inventory to 914,603 kg. Military demand for bismuth has been decreasing; therefore, in 1989, DOD recommended reducing the goal from 997,903 kg to 480,808 kg. DOD planned to sell the excess during an 8- to 10-year period (*35*). The new stockpile goal was approved by the DLA in June 1990, and the sales of the excesses began in August 1990. Table 9 shows NDS statistics.

Table 9.—NDS status, September 30, 1991

(Kilograms)

Material	Goal	Total inventory	Excess to goal authorized for disposal	Sales, 9 months
Bismuth	480,808	828,239	0	56,880

CONCLUSION

Bismuth is considered nontoxic and therefore remains unaffected by direct EPA regulations. Its use is expanding as a replacement for lead in pigments, alloys, steel, and other applications that require nontoxicity. Its use in advanced electronics is growing and could become significant in the near future. Although DOD has approved reducing the amount in the stockpile, bismuth remains a material essential to many industries. This is evidenced by the growing rate of consumption worldwide during the last 10 years. The U.S. supply is secure despite a shift in major suppliers from South America and Australia to Europe and Mexico. The world supply is expected to be supplemented with bismuth produced from accumulated smelter flue dust and waste material in the United States and Australia. With world production capacity more than twice the current world production, a sudden surge in consumption is not expected to have a significant effect on the supply.

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