

BISMUTH IN THE UNITED STATES

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BISMUTH IN THE UNITED STATES

By Franklin H. Persse

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ABSTRACT

Domestic bismuth supply was projected from production figures for the ores in which it occurs--copper, lead, zinc, and tungsten. Published and unpublished data concerning host ores were examined to determine bismuth reserves and resources, and mine production. Potential recoverable bismuth occurring with reserves and resources of copper, lead, and zinc was estimated to be 36.3 million pounds. A bismuth availability diagram was developed from quantity estimates and ratios of production cost to value for these host ores. Additional recoverable bismuth occurring with domestic tungsten reserves was estimated to be 1.5 million pounds. Domestic byproduct production of bismuth will approximate 1.3 million pounds annually by 1980. This quantity will provide about 37 percent of the 3.5-million-pound estimated requirement for that year. Known world supply of bismuth appears to be sufficient for world demand to the end of this century. The study indicates that bismuth reserves and potential resources in the rest of the world have not been adequately reported.

INTRODUCTION

Because the United States consumes more bismuth than it produces, it is dependent upon imports for about 75 percent of its requirements. Bismuth is a byproduct from processing cobalt, copper, gold, lead, molybdenum, silver, tin, tungsten, and zinc ores. Most of the domestic production, however, is a refinery byproduct from copper, lead, and zinc ore processing. Domestic sources of supply were classified according to categories of measured, indicated, and inferred reserves and "potential resources" of the "host ore" with which bismuth occurs. It should be noted that potential resources as used here does not include latent resources (undiscovered deposits), and host ore is the mineralized rock mined principally for metals other than bismuth.

Interviews were conducted, and a search of literature and records was made to ascertain the bismuth content and the location of host ore deposits from which bismuth is almost entirely produced as a byproduct. From the bismuth content and the amount of host ore (copper, lead, zinc, and tungsten)

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produced, mine output of domestic bismuth was estimated for 1962-66, projected to 1980. The bismuth content, or assay, was also used to determine the amount of bismuth available in the domestic reserves and potential resources of the host ores; an availability diagram was developed from these data. Significantly, supply does not vary with price because bismuth production is dependent upon host ore production, rather than the price of bismuth.

The President's Materials Policy Commission (20)² completed a study of bismuth supply in 1952, but at that time the detailed evaluation of copper, lead, and zinc reserves and potential resources, compiled in 1964 by the Bureau of Mines (9), was not available. However, for this study, these 1964 data were used to estimate the bismuth reserves and potential resources and to construct an availability diagram.

ACKNOWLEDGMENTS

The author gratefully acknowledges the many individuals and companies who assisted in furnishing information, particularly The Anaconda Co., American Smelting and Refining Co. (ASARCO), Hecla Mining Co., International Smelting & Refining Co., Rico Argentine Mining Co., Shattuck Denn Mining Corp., Standard Oil Company of Ohio (Sohio), Union Carbide Corp., and United States Smelting Refining and Mining Co. (USSR&M Co.).

HISTORY

Bismuth, not recognized as a metal before the Middle Ages, was later referred to by many names, among them female antimony, imperfect tin or silver, and wisnat (white mass or metal). In the 15th century, Basil Valentine called it wismut; Georgus Agricola Latinized the German wismuth to bisemutum. In 1557, Andreas Libavius discovered that bismuth nitrate would relieve certain intestinal disorders, and soon after, bismuth salts were used as a salve for wounds. Bismuth salts for face powder, called pearl powder, was the next reported use. In the middle of the 18th century J. H. Potts, C. J. Geoffrey, and T. Bergman produced the pure metal, ultimately recognized as a new element (11). However, because the pure metal was brittle, its first use was only in alloys of lead and tin to impart fusibility. In the 19th century it was used in type, stereotype, and bearing metal. A British patent was granted October 28, 1833, to H. L. Pattinson for "An Improved Method of Separating Silver From Lead," which included debismuthizing lead bullion. Methods of separating bismuth continued to be improved until we now have 99.999-percent-pure commercial bismuth.

STRUCTURE OF THE INDUSTRY

Refined bismuth production in the United States is from one of four bismuth refineries; three of these are associated with a lead refinery, one with a chemical separation plant. With the exception of the bismuth refinery associated with the chemical separation plant, bismuth refineries are supplied

²Underlined numbers in parentheses refer to items in the list of references at the end of this report.

from their associated lead refineries and from other lead refineries where bismuth is removed. The chemical separation plant supplies a crude bismuth to its associated refinery, recovered mainly from spent bismuth phosphomolybdate catalyst. Copper or zinc ores containing bismuth also contain lead and other impurities. Partial removal is done at the smelter and the remainder at the refinery. These elements--contained in either flue dust, slag, or dross--are sent to a lead smelter and processed the same as a primary lead ore. At the smelter, lead from byproduct sources and primary sources is combined and sent to a lead refinery. Bismuth, the last impurity removed in the lead refining process, is extracted as a crude product which must be refined at a bismuth refinery. A small amount of lead used for fusible alloys is marketed without removing the bismuth. Figure 1, a simplified flow chart of the domestic bismuth industry, depicts the main steps for the recovery of bismuth from the host ores or concentrates to its end uses.

Until 1964, bismuth consumed in fusible alloys accounted for the greatest single use. Since then, pharmaceutical uses have become most important; bismuth phosphomolybdate used as a catalyst in the acrylonitrile manufacturing process and increased use of bismuth in cosmetics caused this change.

Because secondary sources are limited, bismuth recovery from scrap or waste has been small. Many fusible alloys, used repeatedly by the original

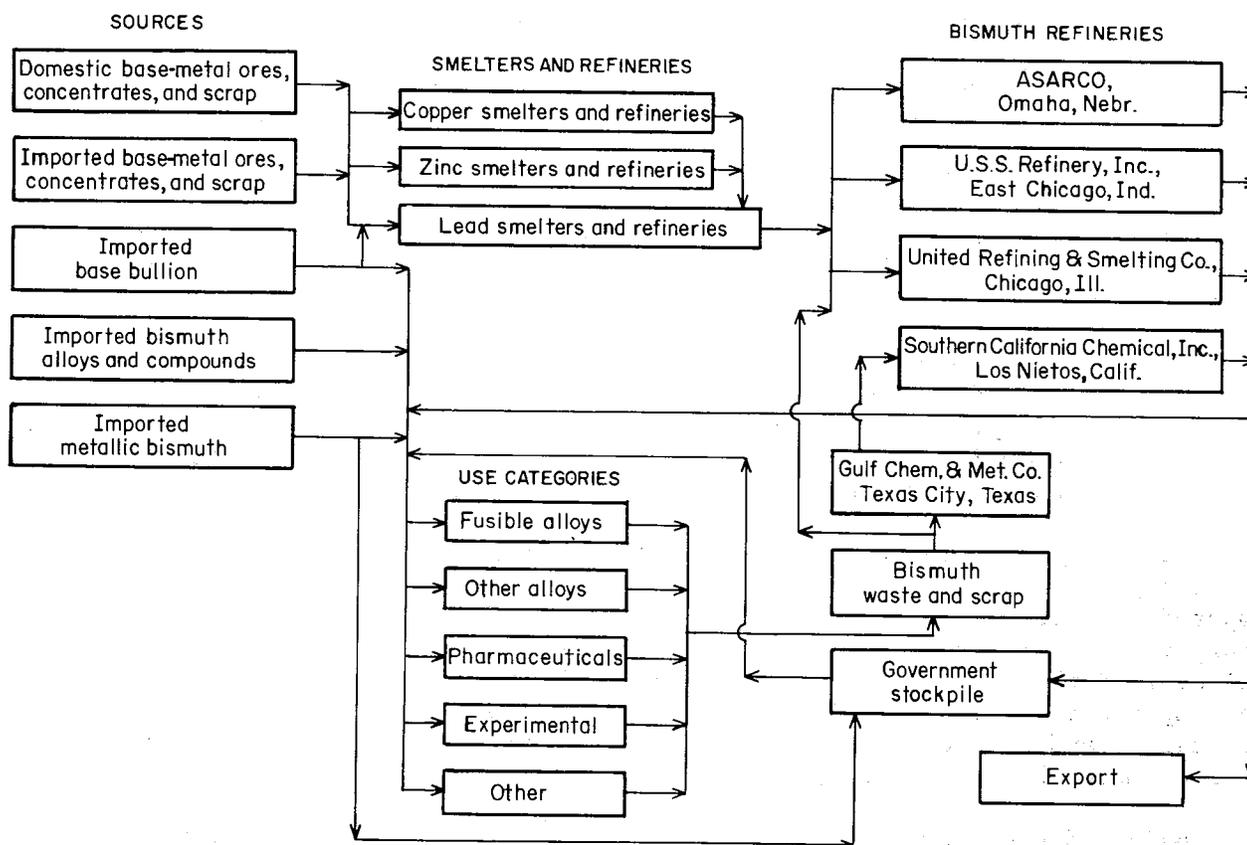


FIGURE 1. - Flow Chart of the Bismuth Industry.

purchaser, do not reenter the metal production stage; therefore, only small amounts of fusible alloys are scrapped. Scrap aluminum, carbon steel, or malleable iron to which bismuth had been added does not offer an economical source; bearing metal and similar alloys, however, are reclaimed for the bismuth content. Pharmaceuticals offer the greatest source of secondary bismuth from spent catalysts, spent industrial chemicals, and overage medicines. Experimental and other uses do not contribute as a secondary source because only small quantities were used originally.

SUPPLY

Ore Reserves and Potential Resources

Bismuth occurs naturally as both metal and mineral, but is seldom found in sufficient concentration to be exploited as a straight bismuth ore. Although bismuth minerals occur worldwide, only the United States and 15 other countries report bismuth reserves and potential resources. Domestic bismuth occurrences (fig. 2) have been reported in 23 States; only eight States are considered to have reserves and potential resources.

Associated with cobalt, copper, gold, lead, molybdenum, silver, tin, tungsten, and zinc, bismuth generally occurs in small quantities. Recovery has been mostly as a byproduct of these metals. Small pockets of bismuth ore have been mined from pegmatite dikes, quartz veins, and contact replacement deposits; such deposits, however, are relatively insignificant. Because bismuth is recovered as a byproduct, classification of reserves and potential-resources estimates were made on the basis of the host ore that would be exploited.

Classification of Reserves and Potential Resources

Mineral (ore) reserve: Material that can be mined, processed, and marketed at a profit under the economic and technologic conditions prevailing at the time of inquiry.

Potential resources: Material that cannot be mined, processed, and marketed at a profit under the economic and technologic conditions prevailing at the time of inquiry. It is a material that may become a mineral (ore) reserve with changed economic conditions or advancement in mining and metallurgical methods. For purposes of this study, latent resources are not included.

Measured ore: Ore for which tonnage is computed from dimensions revealed in outcrops, trenches, workings, and drill holes; and for which the grade is computed from the results of detailed sampling. The sites for inspection, sampling, and measurement are so closely spaced and the geologic character is so well defined that the size, shape, and mineral content are well established. The computed tonnage and grade are judged to be accurate within limits which are stated, and no such limit is judged to differ from the computed tonnage or grade by more than 20 percent.

Indicated ore: Ore for which tonnage and grade are computed partly from specific measurements, samples, or production data and partly from projection

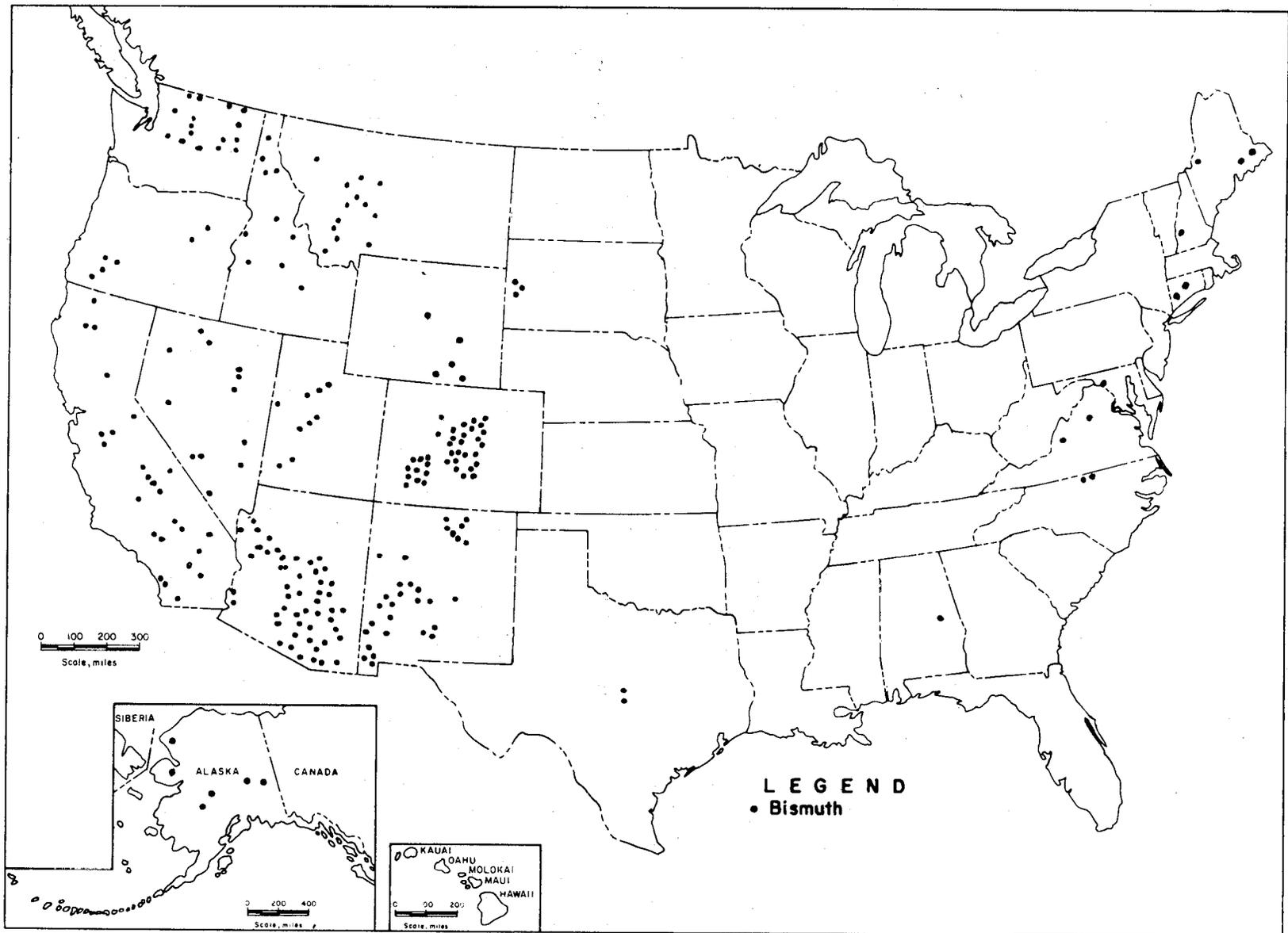


FIGURE 2. - Location of Bismuth Occurrences in the United States. Adapted from U.S. Geological Survey (8, 23).

for a reasonable distance on geologic evidence. The sites available for inspection, measurement, and sampling are too widely or otherwise inappropriately spaced to outline the ore completely or to establish its grade throughout.

Inferred ore: Ore for which quantitative estimates are based largely on a broad knowledge of the geologic character of the deposit and for which there are few, if any, samples or measurements. These estimates are based on an assumed continuity or repetition for which there is geologic evidence; this evidence may include comparison with deposits of similar type. Bodies that are completely concealed may be included if there is specific geologic evidence of their presence. Estimates of inferred ore should include a statement of the special limits within which the inferred ore may lie.

Domestic Reserves and Potential Resources

Recoverable bismuth in reserves and resources are associated with deposits of copper, lead, and zinc in Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, and Utah. Bismuth is also associated with tungsten in these States; however, the only appreciable recovery has been from California deposits.

Bismuth reserves and potential resources occurring in the United States with copper, lead, and zinc ores were estimated to be 36.3 million pounds: reserves were estimated at 26.4 million pounds, and potential resources at 9.9 million pounds. This determination was made from bismuth assays obtained from literature, records, and interviews concerning deposits known to contain recoverable bismuth; then applying these assays to the quantities of host ore estimated in a 1964 Bureau of Mines evaluation of reserves and potential resources of copper, lead, and zinc (9). Table 1 lists by States and type of host ore the estimated amount of bismuth reserves and potential resources.

Recoverable bismuth associated with the domestic tungsten reserves and potential resources (14) was estimated to be 1.5 million pounds: 1.3 million pounds occurring in the reserve deposits, and 200,000 pounds in submarginal or potential-resource deposits. However, only minor amounts of bismuth have been recovered from domestic tungsten ores because the amount present seldom exceeds the maximum impurity allowance; hence, its value would not warrant the cost of separation. Because of this only copper, lead, and zinc deposits containing recoverable bismuth were considered in estimating the domestic supply potential.

This potential, 36.3 million pounds of recoverable bismuth, was estimated to be contained in only 2.2 billion tons of copper, lead, and zinc reserves and potential resources. In 1964, the total domestic reserves and potential resources of copper, lead, and zinc were estimated to be in excess of 27.8 billion tons (9); therefore, only about 7.9 percent of the domestic copper, lead, and zinc reserves and potential resources contain recoverable bismuth.

TABLE 1. - Recoverable domestic bismuth reserves and potential resources associated with copper, lead, and zinc ores, pounds

State and type of ore	Reserves			Potential resources			Total
	Measured	Indicated	Inferred	Measured	Indicated	Inferred	
Arizona:							
Copper.....	(¹)	(¹)	(¹)	(¹)	(¹)	(¹)	-
Lead-zinc.....	16,200	900	-	4,100	10,400	46,400	78,000
Copper-lead-zinc	900,000	900,000	900,000	-	4,300	392,100	3,096,400
Copper-zinc.....	342,000	-	-	-	1,800	6,300	350,100
Lead.....	1,700	-	-	-	2,700	111,700	116,100
Zinc.....	-	-	-	1,300	2,200	4,600	8,100
Total.....	1,259,900	900,900	900,000	5,400	21,400	561,100	3,648,700
California:							
Copper.....	-	9,200	18,300	-	900	9,600	38,000
Lead-zinc.....	83,500	83,600	167,300	-	5,400	36,000	375,800
Copper-lead-zinc	-	-	-	-	144,900	218,700	363,600
Copper-zinc.....	-	38,900	40,400	-	-	-	79,300
Total.....	83,500	131,700	226,000	-	151,200	264,300	856,700
Colorado:							
Copper.....	-	-	11,400	-	1,700	13,400	26,500
Lead-zinc.....	10,700	52,200	381,800	9,000	113,000	505,300	1,072,000
Copper-lead-zinc	405,800	424,300	472,200	24,600	47,000	334,500	1,708,400
Copper-lead.....	4,300	2,900	41,800	600	2,100	49,400	101,100
Copper-zinc.....	-	-	2,600	-	18,300	39,200	60,100
Lead.....	-	-	8,000	100	-	21,600	29,700
Total.....	420,800	479,400	917,800	34,300	182,100	963,400	2,997,800
Idaho:							
Copper.....	21,400	9,000	15,200	-	1,500	43,200	90,300
Lead-zinc.....	53,900	15,500	215,200	18,600	31,600	1,656,100	1,990,900
Copper-lead-zinc	22,800	11,600	6,900	-	-	-	41,300
Copper-lead.....	9,000	300	10,800	-	-	-	20,100
Lead.....	-	-	-	-	18,000	18,000	36,000
Zinc.....	-	-	-	-	-	800	800
Total.....	107,100	36,400	248,100	18,600	51,100	1,718,100	2,179,400
Montana:							
Copper.....	3,024,000	3,700,800	6,580,800	-	-	-	13,305,600
Lead-zinc.....	11,600	4,000	600	-	500	4,300	21,000
Lead.....	-	100	300	-	-	-	400
Zinc.....	43,600	52,800	4,000	-	96,200	3,700	200,300
Total.....	3,079,200	3,757,700	6,585,700	-	96,700	8,000	13,527,300
Nevada:							
Copper.....	-	28,800	55,800	-	2,569,500	2,342,200	4,996,300
Lead-zinc.....	-	26,600	53,200	100	125,800	103,400	309,100
Lead-silver.....	3,400	8,800	18,000	-	-	-	30,200
Total.....	3,400	64,200	127,000	100	2,695,300	2,445,600	5,335,600
New Mexico:							
Lead-zinc.....	30,900	217,000	19,300	-	2,600	81,100	350,900
Copper-lead-zinc	-	-	-	300	2,300	700	3,300
Lead.....	-	1,800	8,600	34,700	23,600	208,800	277,500
Zinc.....	31,100	57,100	56,900	36,000	143,300	126,000	450,400
Total.....	62,000	275,900	84,800	71,000	171,800	416,600	1,082,100
Utah:							
Copper.....	3,782,300	1,265,300	1,261,900	400	6,600	9,100	6,325,600
Lead-zinc.....	51,800	84,600	52,000	-	100	200	188,700
Copper-lead-zinc	18,000	45,000	30,600	-	-	-	93,600
Lead.....	1,900	4,900	-	100	2,600	100	9,600
Zinc.....	-	2,200	-	9,000	9,700	34,000	54,900
Total.....	3,854,000	1,402,000	1,344,500	9,500	19,000	43,400	6,672,400
Grand total..	8,869,900	7,048,200	10,433,900	138,900	3,388,600	6,420,500	36,300,000

¹Some ore deposits show a trace of bismuth, but none has been recovered.

When the 1964 estimate was made, a ratio of total production costs to value of the recoverable base metals, including silver values, was determined for each base-metal deposit and type of operation. The ratio is defined as

$$\text{Ratio} = \frac{\text{Production cost of copper, and/or lead, and/or zinc}}{\text{Value of the recoverable base metal including silver}}$$

A ratio of less than 1.0 indicated that a profitable situation may exist. Values of byproducts other than silver were not considered in the ratio determinations; therefore, a supply diagram could not be based upon bismuth price or bismuth production costs. Because bismuth is dependent upon copper, lead, and zinc production from deposits containing recoverable bismuth, the ratio determined for these base-metal deposits was used. Figure 3 is the resultant availability diagram.

World Reserves and Potential Resources

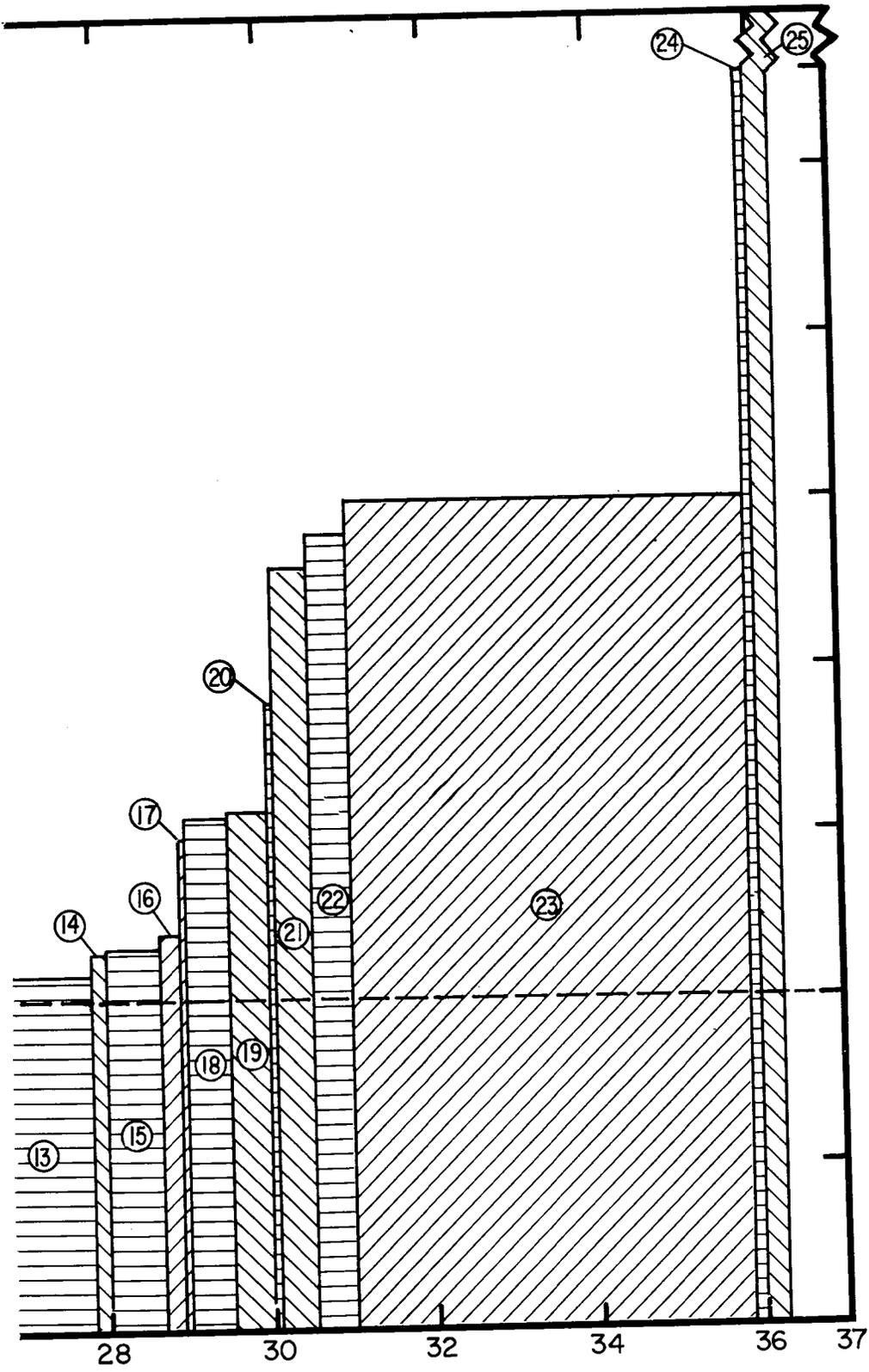
World bismuth reserves and potential resources were conservatively estimated to be 106,030 and 81,560 short tons of bismuth metal, respectively. Reserves and potential resources have been reported from only the United States and 15 other countries (table 2).

TABLE 2. - Estimated world bismuth reserves and potential resources

Country	Reserves, short tons	Potential resources, short tons
Argentina.....	-	80
Bolivia.....	3,000	6,000
Canada.....	2,800	10,000
China.....	10,000	20,000
France.....	1,160	4,600
Japan.....	47,590	-
Korea, Republic of.....	1,200	1,500
Mexico.....	12,500	-
Peru.....	10,000	20,000
South-West Africa.....	20	40
South Africa, Republic of.....	15	30
Sweden.....	515	1,000
Uganda.....	30	60
United States.....	13,850	5,050
U.S.S.R.....	2,750	12,000
Yugoslavia.....	600	1,200
Total.....	106,030	81,560

Possible Supplemental Sources

Although coal ash, municipal refuse, sea water, and most rock contain bismuth, economical recovery methods for these sources have not been developed. Ash from 596 spot samples taken from 16 bituminous coal seams in West Virginia contained between 0.01 and 0.001 percent bismuth, as well as other elements in various concentrations (12). Bismuth has been detected in other coal deposits



A

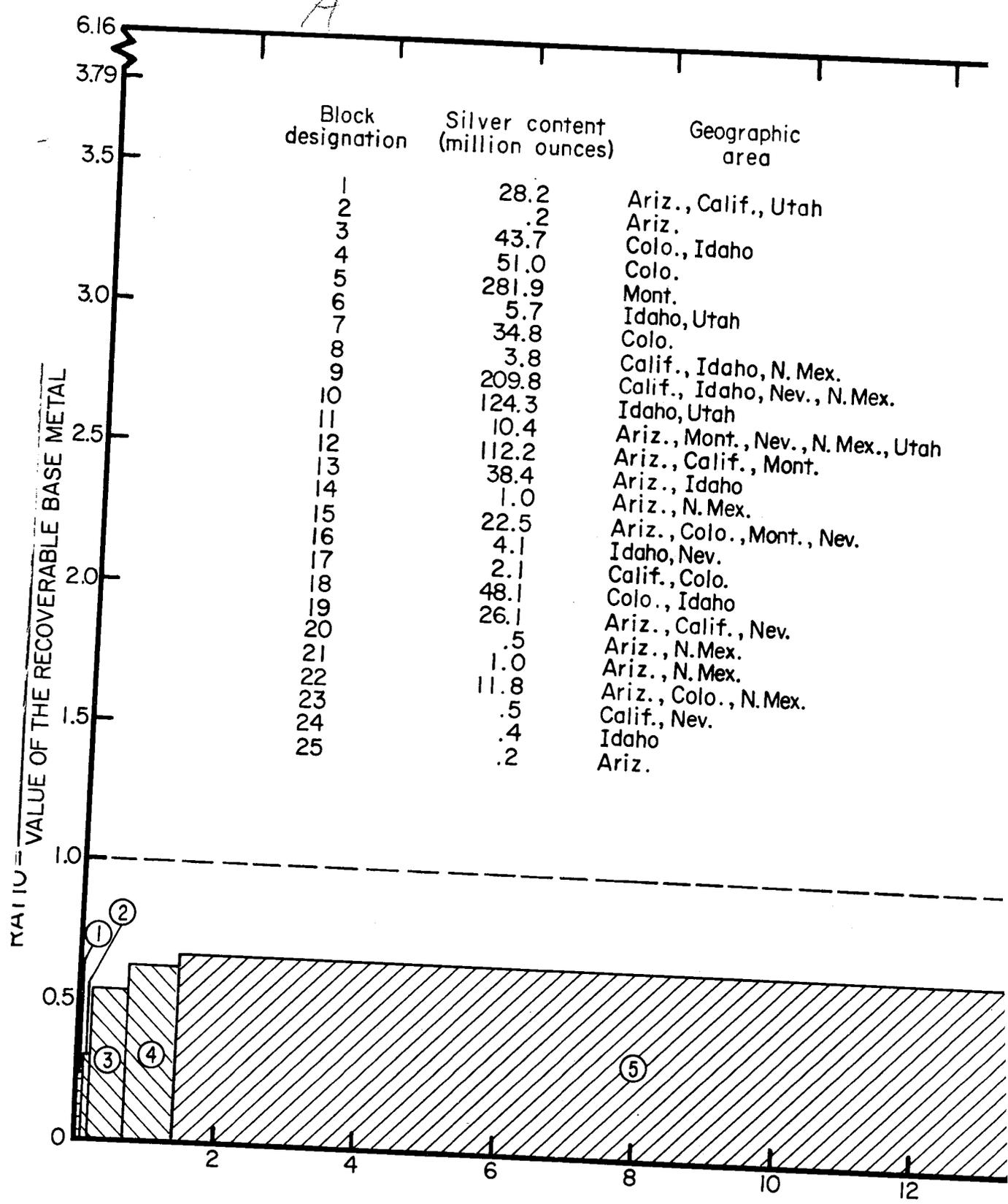


FIGURE 3. - Bismuth Associated With Domestic Copper, Lead Costs to the Value of the Recoverable Base Metal

B



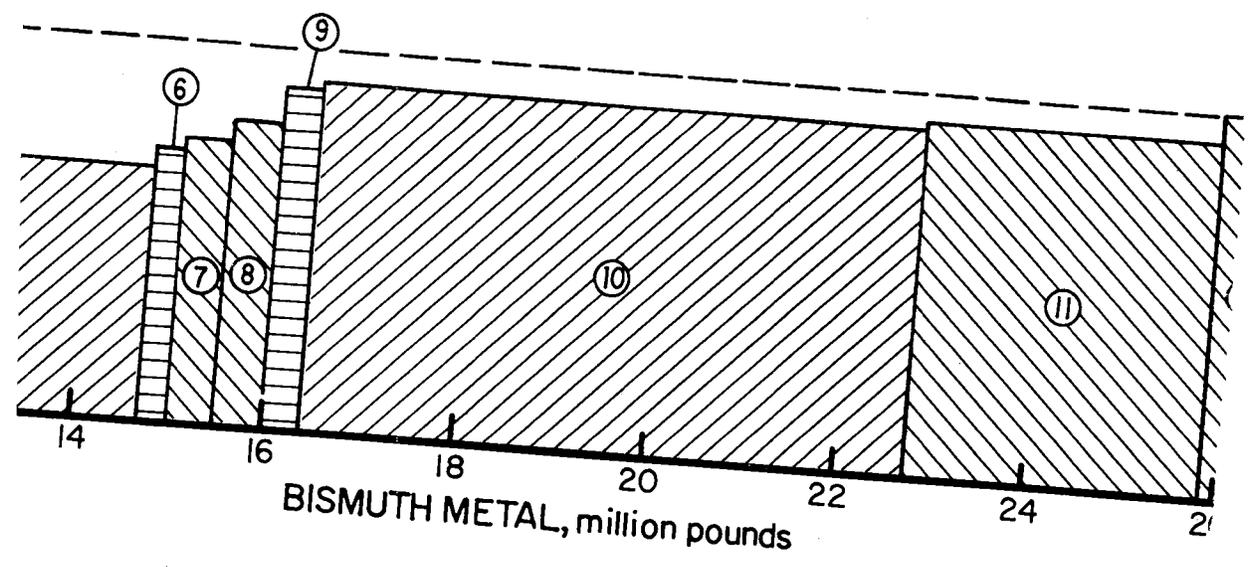
LEGEND

-  Copper
-  Lead
-  Zinc

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d, or Zinc Reserves and Potential Resources in Terms of the Ratio of the Estimated Product
als and Silver. This information was adapted from Bureau of Mines Information Circular 8325(

Future bismuth production estimated for United States mines was based upon the anticipated production of copper, lead, and zinc from ores containing recoverable bismuth. Domestic copper-mine capacity, 1.5 million tons in 1966, is expected to be 2.1 million tons in 1971, a 40-percent increase (7). Increased bismuth output is expected from production increases of copper ore in Montana and Utah (13).

In 1968, lead production was increased approximately 58,000 tons from the new bismuth-free Missouri lead deposit. Normally an increase in Missouri lead production would be expected to reduce output from some high-cost operations in the Rocky Mountain States. However, the rise in the price of silver, which began in 1967, has stimulated exploration and development of silver-bearing lead ores in the Rocky Mountain area; production is expected to follow. Because most of these ores contain recoverable bismuth, an increase in bismuth output is also expected.

The impact of the future zinc production from a recently discovered bismuth-free zinc deposit in central Tennessee cannot be determined until more information is available. However, future bismuth production from zinc ores is not expected to be reduced appreciably.

With the anticipated increase of copper production in Montana and Utah, and lead-silver production in the Rocky Mountain States, domestic mine output of recoverable bismuth was estimated to reach 1 million pounds annually by 1972. After 1972, the increase was estimated to be at a lesser rate, about one-half percent annually, because of the anticipated copper, lead, and zinc output from bismuth-free sources (fig. 5).

A previous projection, the President's Materials Policy Commission 1952 (20), was that 500,000 pounds of bismuth would be supplied from domestic mines in 1975. This amount has been exceeded--750,000 pounds of bismuth were produced in 1966--mainly because copper production exceeded its estimated production.

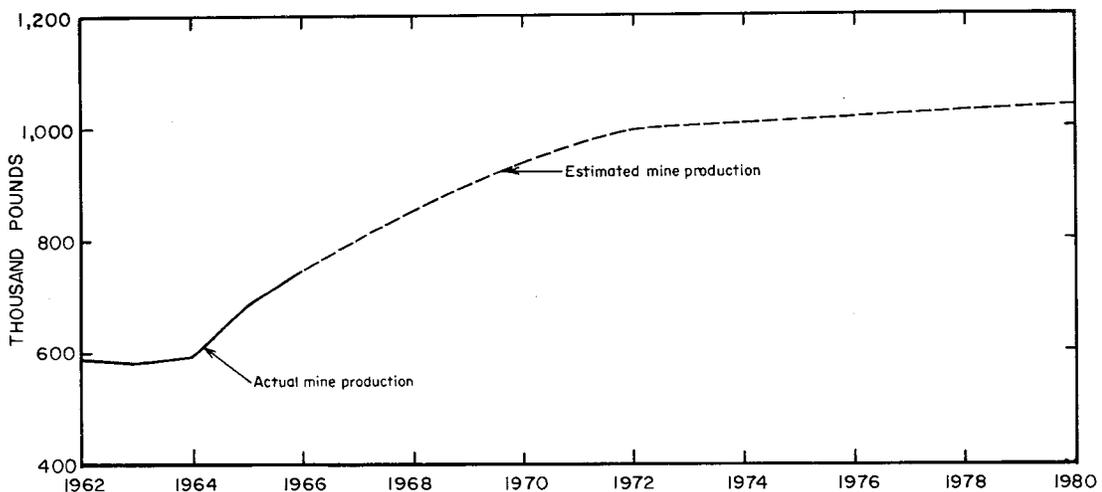


FIGURE 5. - Bismuth Production From Mines in the United States, 1962-66, Estimated to 1980.

Refinery Production

Refinery production of bismuth in the United States has been from two primary refineries and two secondary refineries. The primary refineries are ASARCO, Omaha, Nebr., and U.S.S. Refinery, Inc., a subsidiary of USSR&M Co., East Chicago, Ind. The secondary refineries are United Refining & Smelting Co., Chicago, Ill., and Southern California Chemical Co., Los Nietos, Calif. The sources of the refined bismuth are domestic and foreign ores, concentrates, bullion, and scrap. More than one-half of the annual output of the domestic refineries has been derived from imported material. Estimates and predictions of domestic refinery production were not made because individual company confidential data would be involved.

Bismuth is usually considered an impurity in the host metal and must be removed when established limits are exceeded. Maximum bismuth content allowable for the more common grades of copper and lead is listed in tables 4 and 5.

TABLE 4. - ASTM specifications for bismuth content of copper¹

Grade of fire-refined copper	Copper plus silver, minimum in percent	Bismuth, maximum in percent
Casting:		
Grade A.....	99.75	0.003
Grade B.....	99.50	.003
Copper for wrought products and alloys	99.88	.003

¹Source: Bureau of Mines Bulletin 630 (3).

TABLE 5. - Specifications for bismuth content of commercial pig lead¹

Grade of lead	Lead, minimum in percent	Bismuth, maximum in percent
Corroding.....	99.94	0.05
Chemical.....	99.90	.005
Acid.....	99.90	.025
Copper.....	99.85	.10
Common desilverized A	99.85	.15
Common desilverized B	99.73	.25
Soft undesilverized..	99.93	.005

¹Source: Bureau of Mines Bulletin 630 (3).

Bismuth and other metals such as antimony, arsenic, gold, silver, lead, nickel, selenium, tellurium, and zinc are removed from copper. A partial removal is accomplished by volatilization in the converter, where the dust of these elements is caught in the converter baghouse. The remainder is removed as anode mud by electrolytic refining. In the electrolytic process, several anode impurities, including bismuth, form complex compounds that precipitate (17). The precipitate or anode mud is roasted and leached to further recover copper and any selenium or tellurium present. The leached residue is then

placed in a small reverberatory (doré) furnace where all but the gold, silver, and platinum metals are oxidized and removed with the dross, flue dust, and slag. The dross, flue dust, and slag from the doré furnace, plus the dust from the converter, are sent to a lead smelter.

Bismuth is removed from lead bullion by the Kroll-Betterton debismuthizing process, the final step in lead refining. In this process, molten lead bullion held at 485° C is treated with metallic calcium and magnesium to form insoluble compounds of bismuth. Since these compounds have a lower specific gravity than lead, they form a dross which must be skimmed off the surface. The result is lead with a bismuth-impurity content ranging from 0.007 to 0.01 percent (5). The bismuth dross is treated and re-treated with chlorine or lead chloride to remove the calcium, magnesium, and remaining lead. Final treatments with caustic soda produce a high-purity metal greater than 99.95-percent bismuth.

Bismuth ores when encountered are smelted with an alkaline flux and iron as a desulfurizer and then leached with hydrochloric acid. Bismuth is precipitated from the leach solution by dilution. Dissolution and precipitation are repeated; scrap iron is added for copper removal. When melted under charcoal and lime, the resultant oxychloride will yield a crude metallic bismuth which requires refining. Refining is usually done by the Kroll-Betterton process.

Recent World Production

Excluding the United States, world bismuth production in 1966 and 1967 was estimated to be 6.7 and 6.9 million pounds, respectively. Table 6 lists this production by countries and the host metals from which the bismuth was obtained. Future production of bismuth in the rest of the world is expected to increase as the demand for the host metals increases. However, an increase in bismuth production will not necessarily be proportional to the increase of the host metals, but, as in the past, should be somewhat in accord with world demand for bismuth.

Imports

Table 7 is a list of countries and the quantity of metallic bismuth imported from each into the United States during 1963-68. Bismuth contained in bullion, and base-metal ores, concentrates, and scrap also enter the United States, but since the duty is assessed only on the base metal, the quantity of bismuth is unknown. Most of this bismuth is recovered at domestic refineries.

TABLE 6. - World production of bismuth by countries, pounds¹

Country ²	1966	1967	1968 ^p	Host metal
Australia (in concentrate)	716	^e 132,276	NA	Molybdenum, tin, and tungsten.
Bolivia.....	990,564	1,107,203	1,235,000	Copper, tin, and tungsten.
Canada (metal) ³	525,659	668,468	640,000	Copper, lead-zinc, and molybdenum.
China, mainland (in ore) ^e .	660,000	660,000	550,000	Assumed to be tin and tungsten.
France (in ore).....	129,452	127,867	132,000	Copper and tin.
Italy (metal) ⁴	26,500	33,000	NA	Copper and lead.
Japan (metal).....	1,213,513	1,398,565	^e 1,549,000	Base metals, but refining production was from domestic and imported ores.
Korea, South (metal).....	216,051	242,506	^e 216,000	Tungsten.
Mexico ³	1,036,162	1,111,118	^e 1,146,000	Lead-zinc.
Mozambique.....	3,616	4,180	NA	Pegmatite ores.
Peru ³	1,674,261	1,754,033	^e 1,790,000	Copper, lead, and silver.
South-West Africa (in ore)	4	NA	NA	Tin and tungsten.
Spain (metal).....	NA	97	NA	Cobalt, nickel, and silver.
Sweden ^e	77,200	66,100	NA	Copper and lead.
U.S.S.R. (metal) ^e	77,000	88,000	88,000	Unknown.
United States.....	W	W	W	Copper, lead, zinc, and silver.
Yugoslavia (metal).....	228,546	236,928	243,000	Lead and zinc.
Totals ⁵	6,859,244	7,630,341	7,589,000	

^e Estimate. ^p Preliminary. NA Not available. W Withheld to avoid disclosing individual company confidential data.

¹ Compiled from data available April 1969.

² In addition to countries listed, Argentina, Republic of South Africa, and Uganda also produce bismuth in small quantities, and it is believed to be produced in Brazil, Bulgaria, and East Germany but production data for the latter countries are not available.

³ Bismuth content of refined metal and bullion plus recoverable content of concentrates exported.

⁴ Production of Monteponi-Montevecchio Co., probably including production from purchased and toll materials.

⁵ Total is of listed figures only.

Source: 1968 Minerals Yearbook (4).

TABLE 7. - U.S. general imports of metallic bismuth by countries, 1963-68, pounds

Country	1963	1964	1965	1966	1967	1968
Belgium-Luxembourg..	-	-	-	4,489	-	-
Canada.....	152,408	80,671	50,424	36,386	64,829	121,916
Germany, West.....	-	5	-	-	-	-
Japan.....	-	-	2,211	59,605	67,039	97,693
Korea, South.....	-	-	-	-	29,690	4,435
Mexico.....	166,322	244,709	274,356	348,087	366,211	383,367
Netherlands.....	18,513	4,310	5,048	-	1,877	-
Portugal.....	-	-	4,409	-	-	-
Peru.....	728,909	877,180	1,019,654	1,182,047	850,083	658,260
United Kingdom.....	3	-	-	4,480	-	-
Yugoslavia.....	57,311	31,377	22,045	30,865	-	-
Total.....	1,123,466	1,238,252	1,378,147	1,681,472	1,379,729	1,265,671

Source: 1968 Minerals Yearbook (4).

DEMAND

Recent Demand

Recently, the United States accounted for approximately one-third of the world's bismuth consumption, which is a greater portion than any other single country. The pounds of bismuth consumed in the United States during 1963-68 are as follows (4):

1963.....	2,175,038
1964.....	2,160,100
1965.....	2,931,673
1966.....	3,199,321
1967.....	2,513,652
1968.....	2,347,768

Bismuth consumption data for the rest of the world was not available. Before World War II, although an international cartel was alleged to have restricted bismuth output, there never appeared to be a shortage. Since World War II, inventory buildup during short periods of oversupply has met the demand during labor disputes or other events that interrupted refinery output. With a history such as this, it is believed that world demand has approximated world production and should continue to do so in the foreseeable future.

Projected Demand

Bismuth consumption has been projected for the United States and the rest of the world (19). Domestic consumption in the year 2000 is estimated to range between 3 million and 9.6 million pounds--the median point of the range is 6.4 million pounds. This corresponds to an average annual increase of 3.1 percent for the period 1968-2000. By 1980, annual domestic mine production was estimated to be 1.3 million pounds. This will be only 37 percent of the estimated 3.5-million-pound requirement for that year. The forecast is an assessment of technologic, economic, and other influences because they might affect demands, by end uses of bismuth. Consumption in the rest of the world was estimated to range from 8.8 million to 12.2 million pounds in the year 2000, with a median of 10.5 million pounds. The average annual increase ranges from 0.7 to 1.7 percent, with a median of 1.3 percent.

DEMAND-SUPPLY RELATIONSHIP

World demand for bismuth can be supplied from known bismuth reserves and potential resources to about the end of the 20th century. However, reserves and potential resources of bismuth were reported from only 15 countries, in addition to the United States, and did not include latent deposits. Considering that the rest of the world reserves and potential resources were conservatively reported, and that a reasonable probability exists that bismuth recovered from scrap and waste will increase, apparently world demand for bismuth could be met by world supply well into the 21st century.

The United States annual consumption of bismuth has been about one-third of the world consumption. Currently the United States depends upon imports for about 75 percent of its supply. Unless a domestic source other than as a byproduct of base-metal ores is developed, the United States will depend upon

imports for 80 to 85 percent by the year 2000.

USES

Uses are classified by the Bureau of Mines in five categories: (1) fusible alloys, (2) other alloys, (3) pharmaceuticals, (4) experimental, and (5) other. The first three categories account for most of the bismuth consumption. The amounts consumed annually since 1957 are shown graphically in figure 6; experimental and other uses were consolidated.

Fusible alloys, most of which contain bismuth, melt at a comparatively low temperature (10). The composition of some fusible bismuth alloys are listed in table 8. Bismuth alloy solders are generally used for special applications, such as Wood's metal to "wet" glass. Wood's metal can be applied to glass when sealing metal to glass, and for

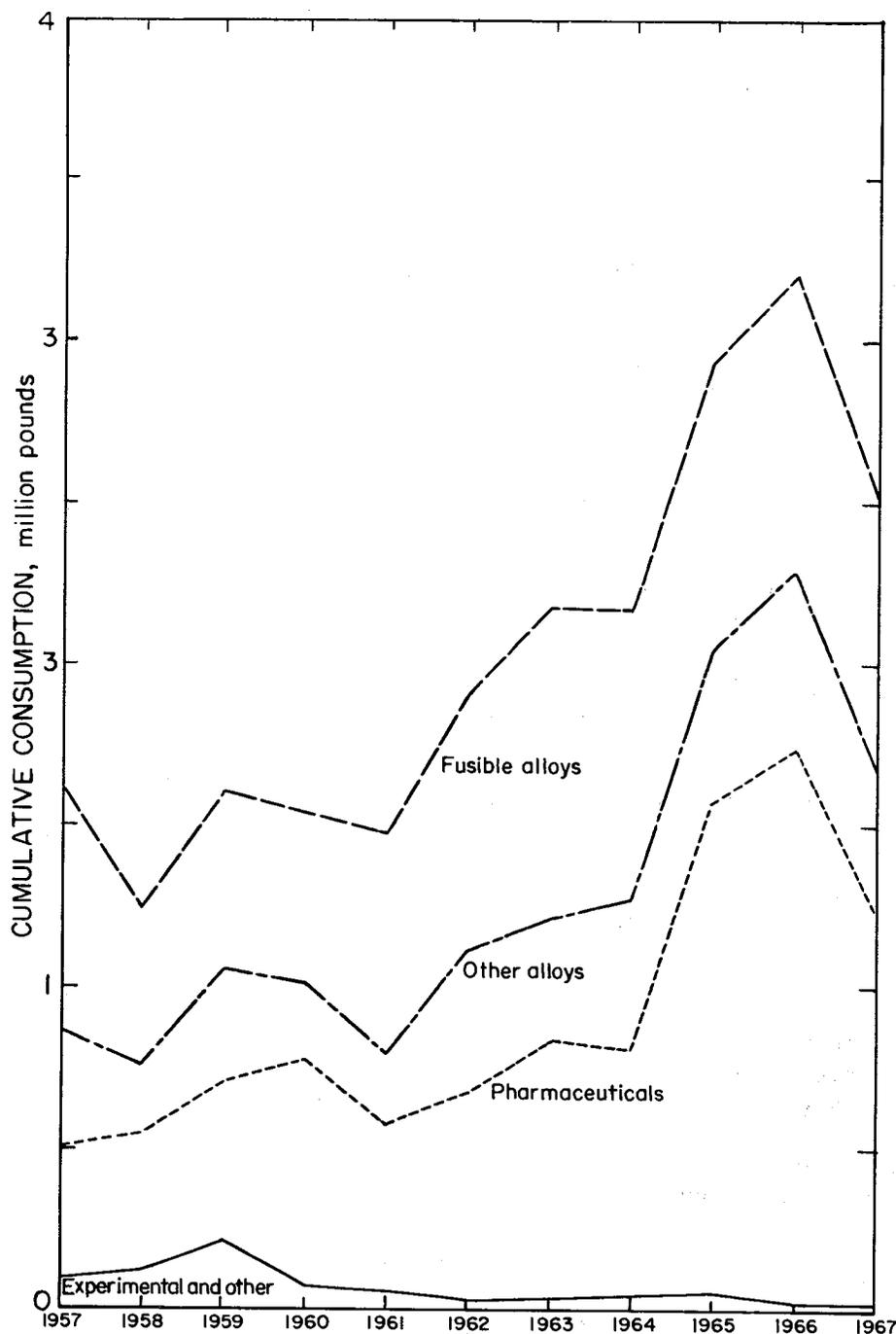


FIGURE 6. - Bismuth Consumption in the United States, by Uses, 1957-67. Adapted from 1967 Minerals Yearbooks (4).

making gastight joints in glass apparatus. A eutectic alloy of 58 percent bismuth and 42 percent lead will not expand or contract when changing from liquid to solid state. This property makes the alloy a useful material for seals, gages, and castings which require close tolerance. The low-melting temperatures of fusible alloys make them desirable for release mechanisms in safety devices. Fusible bismuth alloys are also used in denture molding, hollow silverware casting, tube bending, anchoring devices, tool tempering baths, dye setting baths in the textile industry, amalgams for silvering mirrors, and medium range thermometers.

TABLE 8. - Composition of some fusible bismuth alloys

	Composition, percent					Melting point, ° F
	Bismuth	Lead	Tin	Cadmium	Other	
Cerrolow 105.....	42.9	21.7	8.0	5.0	18.3 antimony 4.0 mercury	100
Cerrolow 147.....	48.0	25.6	12.8	9.6	4.0 indium	142
D'Arcet's metal....	50.0	25.0	25.0	-	-	200
Homborg's alloy....	33.3	33.3	33.3	-	-	251
Lichtenberg's alloy	50.0	30.0	20.0	-	-	198
Lipowitz alloy.....	50.0	26.7	13.3	10	-	158
Malotte's metal....	46.0	20.0	34.0	-	-	203
Matrix alloy.....	47.0	28.5	14.5	-	9.0 antimony	103
Newton's metal.....	50.0	25.0	25.0	-	-	203
Rose's metal.....	35.0	35.0	30.0	-	-	212
Wood's metal.....	50.0	25.0	12.5	12.5	-	158
Eutectic.....	58.0	42.0	-	-	-	257

Source in part: Material Handbook (2) and U.S. National Bureau of Standards (21-22).

Approximately 85 percent of the annual consumption of bismuth classified as other alloys has been used as an additive to increase machinability without greatly reducing corrosion resistance, strength, and toughness in aluminum and malleable iron and steel. Nonferrous alloys requiring small quantities of bismuth account for the remaining 15 percent. These alloys include brasses, bronzes, antifriction metals, and bismuth-copper-manganese alloy for permanent magnets.

The bismuth consumed in manufacturing chemicals, cosmetics, and medicines, is classified as pharmaceutical use. Until 1964, bismuth used in cosmetics and medicine accounted for a greater amount than that used in chemical manufacture. Since then bismuth consumed as the catalyst--bismuth phosphomolybdate developed by The Standard Oil Company of Ohio (Sohio) for manufacturing acrylonitrile--increased chemical consumption to over 80 percent of the pharmaceutical category. A lesser quantity of bismuth is expected to be consumed for this use because a sufficient quantity has been obtained by the acrylonitrile manufacturers for plant operation. Moreover, future consumption will be only for replacement of the catalyst lost in operation.

Chemical uses of bismuth also include bismuth trichloride as an additive to waterproofing materials for reduced flammability; bismuth cerium and

bismuth thorium as refractory ceramics in aerospace; bismuth trioxide as a flux to increase fusibility of coloring compounds for vitreous enamels, porcelain, and glass; and bismuth telluride as a heat transfer agent in refrigeration. Bismuth compounds of acetate, chloride, citrate, fluoride, glycolyl arsenalate, hydroxide, iodate, iodide, nitrate, stannate, subbromide, subcarbonate, subgallate, subsalicylate, titanate, tribromphenate, and zirconate are used in manufacturing various products. Insoluble salts of bismuth are taken by patients before X-raying for intestinal disorders. Many bismuth compounds are contained in burn and wound ointments; stomach-acid, indigestion, and syphilis remedies; and cosmetics.

In 1967, United States consumption of bismuth for cosmetics was on the increase because the pearlescent pigments which produce a "frosted" or "iridescent" look to lipstick, face powder, and nail polish became fashionable. Should this fashion spread to the rest of the world, bismuth consumption by the cosmetic industry could increase considerably (1).

Not classified under the three major categories, a small amount of bismuth consumed each year is reported as "other uses." An example is bismuth wire used as a component for manufacturing measuring instruments and thermocouples.

Experimental uses of bismuth continually change. Currently, that used for aerospace programs and for the Atomic Energy Commission (AEC) liquid-metal fuel-breeder reactor account for a large part of the experimental consumption.

SUBSTITUTES

Substitutes for bismuth in fusible alloys are uncommon. Although gallium could impart similar characteristics to fusible alloys, its cost is approximately 150 times that of bismuth. In the 19th century, bismuth was replaced by antimony in type metal. Other alloys, plastics, and resins have been substituted for fusible bismuth alloys.

In 1967, tellurium replaced some bismuth in alloying malleable iron. With bismuth priced at \$4 per pound, major alloyers discovered that by using a bismuth-tellurium combination, production costs per pound of iron could be reduced by as much as one-half the cost of using bismuth alone (16).

Substitutes for bismuth have been greatest in pharmaceuticals. Kaolin has often been interchanged with bismuth in medical preparations for relief of intestinal disorders. Sulfa drugs and antibiotics have replaced a large amount of bismuth in medicines for both internal and external use.

A catalyst, believed to be spent uranium and referred to as "catalyst 21," is expected to be used in place of bismuth phosphomolybdate in all acrylonitrile manufacturing plants constructed in the future. Acrylonitrile is a chemical intermediate used in manufacturing acrylic fibers, nitrile rubber, and several plastics. Many plants now using the bismuth phosphomolybdate catalyst have been evaluating the possibility of plant conversion to use the less expensive catalyst 21. Also, it was reported that Sohio is looking for other substitute catalysts for use in manufacturing acrylonitrile (6).

PRICE RELATIONSHIP

The price of most commodities has a direct relationship with supply and demand; however, because bismuth is a byproduct with only limited and specialized uses, its price does not conform to the general pattern. Bismuth prices have not been known to influence mine production of host metals. Supply is therefore regarded as relatively inelastic to price. The price of the host metal has a greater relationship with the supply of bismuth than has the price of bismuth. Production of the host metal increases when its price increases; therefore, bismuth production is increased. Host metal production could possibly increase bismuth output to a point that exceeded bismuth demand and concurrently force the price of bismuth downward. However, bismuth refiners have a limited control over supply, for they may remove either the maximum amount of bismuth from the bullion when demand is favorable or the minimum amount when unfavorable conditions exist.

Since 1936, the price of bismuth has increased in steps from \$1 to \$4 per pound (fig. 7). However, the general price trend has been in reasonable

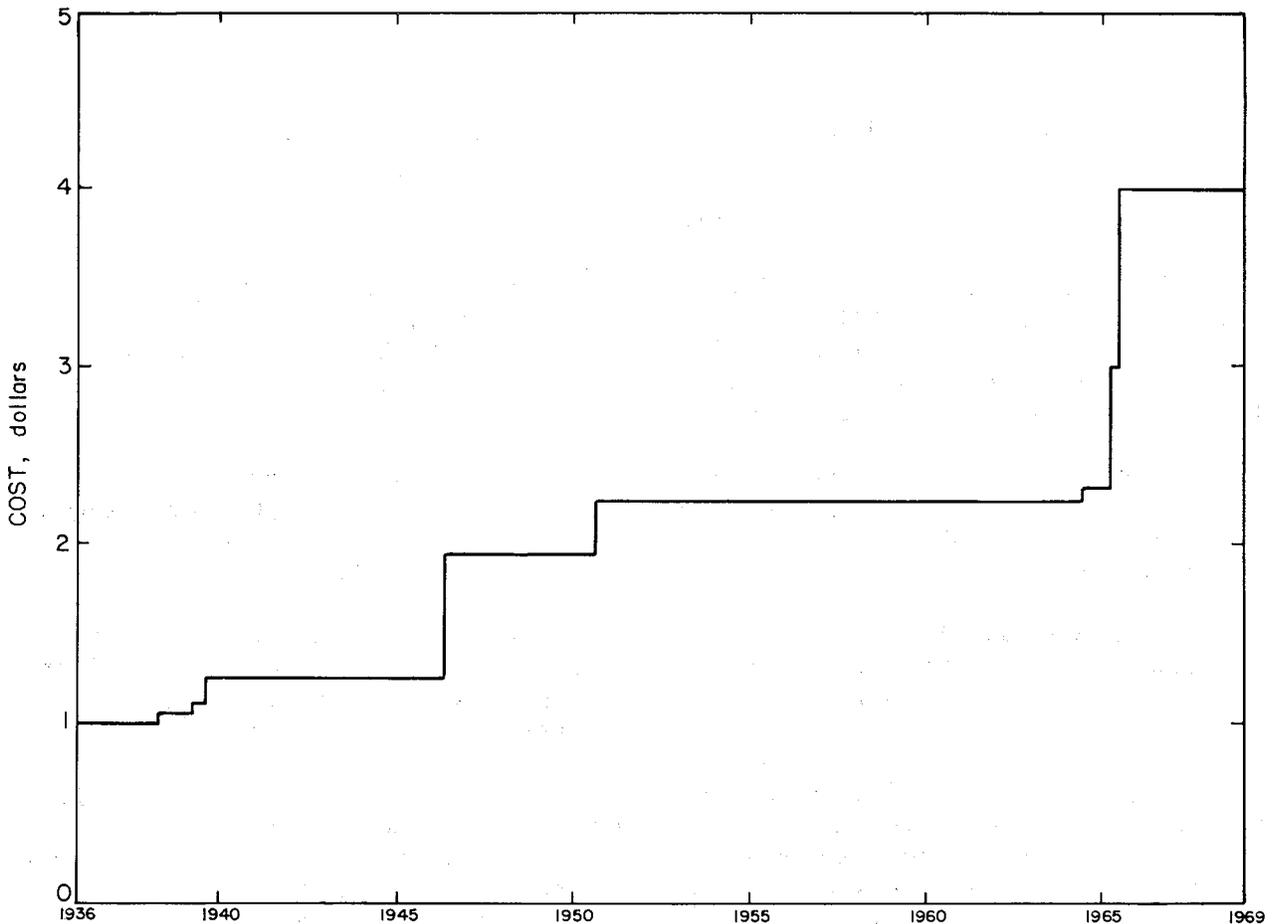


FIGURE 7. - Bismuth Price per Pound in 2,000-Pound Lots, New York, 1936-69.
Adapted from Metals Week (15).

accord with the Industrial Production Index, Total Industrial Production at the time of the increases. A relationship was not evident between the increases.

Before World War II, when, allegedly, a cartel controlled bismuth production, bismuth prices were at a level low enough to encourage its use. Recently, however, it seems that the quantity of bismuth demanded has been slightly sensitive to price changes. Indications of this phenomenon are a June 1965 price increase which contributed to the development of catalyst 21 as a substitute for bismuth phosphomolybdate catalyst and, also, tellurium being substituted for some of the bismuth used in malleable iron.

GOVERNMENT PROGRAMS AND POLICIES

Stockpiles

Since the approval of Public Law 520 on July 23, 1946, 79th Congress, "The Strategic and Critical Materials Stock Piling Act," which superseded the Stock Piling Act of June 7, 1939, three additional acts authorizing stockpiling of bismuth have been passed. Public Law 774, 81st Congress, "Defense Production Act of 1950," was approved September 8, 1950. This law enabled the Government to purchase bismuth for the Defense Production Act Stockpile (DPA). Two acts passed in 1954, Public Law 480 of the 83d Congress entitled "Agriculture Trade Development and Assistance Act of 1954," approved July 10, 1954, and Public Law 690 of the 83d Congress entitled "Agricultural Act of 1954," approved August 28, 1954, authorized materials--including bismuth--produced abroad for the supplemental stockpile.

These acts enabled the Government to build a stockpile of bismuth from domestic and foreign sources for use in time of emergency. Bismuth for the stockpiles was procured when supply exceeded demand, and thus did not cause a price increase. In 1959, a decision was made to reduce the preparedness program from a 5-year to a 3-year plan; thus, stockpile requirements for bismuth were set at 2.5 million pounds. Procurement of bismuth for the National Stockpile and the DPA Stockpile ceased; however, bartering of surplus agricultural commodities continued until 1963, when the surplus was in excess of 1.8 million pounds. Table 9 lists acquisitions and disposals during 1946-68. In 1965, Congress authorized the DPA Stockpile to be transferred to the AEC and the nonstockpile grade in the National Stockpile to be sold to industry.

A labor strike that began in July 1967 and continued into 1968 stopped production at the ASARCO refinery, Omaha, Nebr., and greatly reduced the output at U.S.S. Refinery, Inc., East Chicago, Ind. Thus the supply to fabricators was reduced, resulting in dealers asking prices above the quoted price of \$4 per pound in quantities of 1 ton or more. To prevent a price increase, Public Law 90-153 was approved November 24, 1967, authorizing the General Services Administration (GSA) to sell approximately 1.2 million pounds of bismuth from the Government stockpiles. The law provides that the time and method of disposition shall be fixed with due regard to the protection of the United States against avoidable loss and the protection of producers, processors, and consumers against avoidable disruption of their usual markets. On

November 30, 1967, GSA announced that 300,000 pounds of bismuth was available for domestic purchase and consumption by eligible companies at \$4 per pound in quantities of 1 ton or more and \$4.05 per pound in less than 1-ton quantities. The 300,000 pounds was the maximum quantity available for the first period which ended March 31, 1968. Quantities of 150,000 pounds were available in each calendar quarter thereafter; any unsold metal from one period was to be carried over to the next. Sales were approximately 146,000 pounds each in the first and second periods.

TABLE 9. - Bismuth stockpile inventories, pounds

Year ending inventory	National	Supplemental	Defense Production Act	Nonstockpile grade (National)	Total
1968.....	1,118,245	2,287,937	-	-	3,406,182
1967.....	¹ 1,276,122	¹ 2,471,693	-	-	¹ 3,747,815
1966.....	1,305,822	2,506,493	-	-	3,812,315
1965.....	1,305,822	2,506,493	-	² 36,580	3,848,895
1964.....	1,305,822	2,506,493	³ 22,901	36,580	3,871,796
1963.....	1,305,822	⁴ 2,506,493	22,901	36,580	3,871,796
1962.....	1,305,822	⁵ 2,001,545	22,901	36,580	3,366,848
1961.....	1,305,822	⁶ 1,496,640	22,901	36,580	2,861,943
1960.....	1,305,822	1,146,323	22,901	36,580	2,511,626
1959.....	1,305,822	⁷ 1,146,323	22,901	36,580	2,511,626
1958.....	1,305,822	⁸ 396,638	22,901	36,580	1,761,941
1957.....	⁹ 1,342,402	-	22,900	-	1,365,303
1956.....	⁹ 1,342,402	-	22,900	-	1,365,303
1955.....	⁹ ¹⁰ 1,342,402	-	22,900	-	1,365,303
1954.....	⁹ ¹⁰ 1,342,401	-	8,000	-	1,350,401
1953.....	⁹ 1,342,397	-	-	66,259	1,408,656
1952.....	1,286,093	-	-	¹¹ 66,004	1,352,097
1951.....	1,286,093	-	-	¹² 27,613	1,313,706
1950.....	¹³ 1,286,093	-	-	-	1,286,093
1949.....	1,029,849	-	-	-	1,029,849
1948.....	¹⁴ 655,000	-	-	-	655,000
1947.....	¹⁴ 586,546	-	-	-	586,546
1946.....	¹⁵ 798,052	-	-	-	798,052

¹ Estimated--approximately 64,500 pounds sold to industry in December 1967.

² Sold to industry.

³ Transferred to Atomic Energy Commission.

⁴ 504,948 pounds acquired by barter from Peru.

⁵ 504,905 pounds acquired by barter from Mexico--refined in the United States.

⁶ 300,000 pounds acquired by barter from Peru and 50,317 pounds from the United Kingdom.

⁷ 225,000 pounds acquired by barter from West Germany, 224,685 pounds from Yugoslavia, and 300,000 pounds from Mexico refined in the United States.

⁸ 396,638 pounds acquired by barter from the United Kingdom.

⁹ Includes nonstockpile grade (36,580 pounds).

¹⁰ Adjustment.

¹¹ 38,391 pounds in alloys from Peru.

¹² 27,613 pounds in alloys from Peru.

¹³ 256,244 pounds refined in the United States from domestic and foreign ores.

¹⁴ 443,348 pounds from Korea--refined in the United States.

¹⁵ 211,506 pounds sold to industry.

Source: GSA stockpile inventory reports.

Some commodities have been sold from the Government stockpile at less than the acquisition cost, but the bismuth sold under Public Law 90-153 has been at a profit. Although individual unit purchase prices were not available, the 1966 GSA report listed the total acquisition cost at \$8,138,000 for 3,812,315 pounds, or an average price of \$2.13 per pound and the supplemental price at \$2.21 per pound.

Exploration Incentives

The Office of Minerals Exploration (OME), Geological Survey, U.S. Department of the Interior, offers financial assistance in the form of a loan of up to \$250,000 for 75 percent of bismuth exploration costs. The percentage varies for different metals; for example, copper is 50 percent, gold and silver are 75 percent, and combinations could be 62.5 percent. Repayment of the loan plus interest is made by royalty payments of 5 percent of the gross proceeds when ore is produced from deposits found as a result of the exploration. The present price of bismuth is creating a moderate interest in domestic bismuth exploration.

Depletion Allowances

Federal income tax laws provide a 23-percent depletion allowance to domestic bismuth producers, and a 15-percent allowance to United States producers with foreign sources.

Tariff

The tariff on imported bismuth depends upon the form in which it is received. Ores and concentrates enter duty-free; intermediate smelter products, such as base bullion, are assessed duty on the base-metal content. Presidential Proclamation 3822 authorized reductions in tariffs in accordance with the Kennedy Round trade agreement of 1967. The first stage of reductions applied to the calendar year 1968 became effective January 1, 1968. Bismuth tariffs were established as follows:

	<u>Percent</u> <u>ad valorem</u>
Metal, unwrought....	1
Alloys.....	16
Compounds.....	25

Statutory duty rates remain unchanged and continue to apply to certain Communist countries.

CONCLUSIONS

Although bismuth is a byproduct of copper, lead, zinc, and tungsten ores, not all such ores in the United States contain economically recoverable bismuth. Increased bismuth production probably will result from increased copper output in Montana and Utah and from lead-silver output in the Rocky Mountain region.

Domestic bismuth consumption is about four times the amount recovered from domestic ores; therefore, the United States must rely on imports for approximately 75 percent of its supply. Bismuth in the rest of the world is recovered as a byproduct from molybdenum, tin, and tungsten ores, in addition to copper, lead, and zinc ores. Increased production of these metals in the rest of the world will not be entirely from deposits that contain bismuth.

Indications are that reserves and potential resources of bismuth in the rest of the world were conservatively reported. However, as reported, the potential world supply is apparently sufficient for the world demand to the end of this century. Domestic bismuth output is determined by the rate of production of host ores; therefore, domestic output of bismuth as a byproduct of known base metals should continue to meet about one-fourth to one-third of the United States needs until the year 2000.

Throughout the world, bismuth supply is relatively insensitive to price because the supply is dependent upon production of host metals. However, demand can be affected by price. The price increase in 1965 contributed to a consumption decrease in 1967-68. This price increase is alleged to have caused the development of substitutes for the catalyst, bismuth phosphomolybdate.

Additional sources must be developed if the United States is to become less dependent upon the rest of the world for its supply of bismuth. Supplementary sources could be developed (1) by increased exploration for base-metal ores containing bismuth, and (2) through improved methods for efficient economic recovery from copper, lead, zinc, and tungsten from which not all of the bismuth is recovered, or from sources in which recoverable bismuth does not exceed the impurity limit.³ Another possible source is fly ash from both coal-burning powerplants and municipal incinerators. This source, however, would require research to develop economic recovery methods.

³For example, it is not economically feasible using present methods to remove bismuth from lead if the bismuth-impurity content of the lead is less than 0.02 percent.

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