DEMAND AND SUPPLY OF MOLYBDENUM IN THE UNITED STATES

By Carl L. Bieniewski

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Carl L. Bieniewski[1]

ABSTRACT

U.S. molybdenum production increased fivefold from 18.2 million pounds in 1946 to 90.5 million pounds in 1966, and constituted 87.3 percent of the total free world supply in the 1946-66 period. Mining development in other free world countries in the next few years may reduce the magnitude of the U.S. position, although similar development planned for the United States may counteract some of the relative gains by those countries.

In 1966 two-thirds of the reported molybdenum consumption in the United States by end uses was as an alloying element in steel. Molybdenum also has important use as an alloying element in iron and high-temperature alloys. Consumption of molybdenum metal for making fabricated parts has increased in the past few years, especially in the space and nuclear industries. Molybdenum compounds are used mainly for making pigment, catalysts, and lubricants. Based on producer reports of shipments of primary products to domestic customers, U.S. consumption of molybdenum increased from 16.5 million pounds of molybdenum in 1946 to 65.6 million pounds in 1966.

U.S. molybdenum reserves are now estimated to be 5.9 billion pounds of recoverable molybdenum, an increase of 2.1 billion pounds above previous estimates. Molybdenum ores account for 71.4 percent of the reserves, copper ores for 22.3 percent, and copper-molybdenum, tungsten, and uranium ores for 6.3 percent.

Several methods for predicting future demand are illustrated and estimates of demand using these methods were made for 1975. Based on present capacities and announced company plans for future developments, estimates of annual production were made for 1967 through 1975 for the United States, Canada, Chile, Peru, and the free world. These data indicate that molybdenum production in 1975 for the free world is expected to be 246 million pounds with the United States producing 68.2 percent and Canada, Chile, and Peru 30.3 percent.

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INTRODUCTION

This report examines the economics of molybdenum. Since World War II domestic molybdenum production has experienced a fivefold growth from 18.2 million pounds in 1946 to 90.5 million pounds in 1966; in the same period consumption, as measured by molybdenum contained in primary product shipments to domestic customers, achieved a fourfold growth from 16.5 million pounds in 1946 to 65.6 million pounds in 1966.

The reader is referred to the following publications for a much more comprehensive discussion of some features of the molybdenum industry than this report presents. In 1957 the Bureau of Mines published "Molybdenum, A Materials Survey" (11),[2] which brought together fundamental data and information about molybdenum and discussed nearly every phase of the molybdenum industry, including history, occurrences, mining and milling methods, metallurgical processes, uses, prices, supply, demand, and trade. A similar publication (14), with emphasis on the Canadian molybdenum industry, was released in 1963 by the Department of Mines and Technical Surveys of Canada. In March 1965 a molybdenum market guide (5) was published in the Engineering and Mining Journal Metal and Mineral Markets (now known as Metals Week). One of the most recent reports about the molybdenum industry was an economic analysis prepared by Charles River Associates in 1967 for the General Services Administration (4). The report presents information about the structure of the industry, an analysis of the historical data, and forecasting methods using econometrics. The current "Mineral Facts and Problems, 1965 Edition," (7) and Minerals Yearbooks (2) of the Bureau of Mines provide general information about the molybdenum industry and recent statistical data.

This report is limited to the domestic supply-demand relationship of molybdenum in the United States since World War II. However, the foreign molybdenum situation is discussed in reference to its effect on the U.S. molybdenum industry.

CONSUMPTION

Molybdenum is used primarily as an alloying element in iron and steel. The addition of molybdenum to iron and steel increases their hardness, strength, wear resistance, endurance limits, and erosion resistance and improves stability at high temperature. Molybdenum may be used as the sole alloying element or in combination with chromium, manganese, nickel, tungsten, and vanadium. Molybdic oxide and ferromolybdenum are the chief forms in which molybdenum is added to iron and steel.

Pure molybdenum metal and molybdenum-base alloys are used in electrical and electronic equipment and for heating elements in electric furnaces or other high-temperature requirements. The metal and alloys are finding important uses in space and nuclear equipment exposed to high temperatures.

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

Molybdenum chemical compounds are used as colorants, paint pigments, catalysts, lubricant additives, and soil nutrients. Figure 1 shows the principal molybdenum products and their main end uses.

The Bureau of Mines publishes various types of consumption figures: One is the quantity of molybdenum contained in concentrate used for making molybdenum products in the United States; these products may be either consumed in the United States or exported. Another type of consumption figure is the quantity of molybdenum in primary products shipped to domestic customers. Still another type is the quantity of molybdenum in molybdenum products consumed by end uses.

Only since 1956 has the Bureau of Mines collected and published data on the consumption of molybdenum in the United States by end uses. This information is obtained by an annual canvass of the consumers. Figures 2 and 3 showing total consumption of molybdenum by end uses for the 1956-66 period are graphical illustrations of the data contained in the appendix (table A-1). Because some reporting firms in the steel industry do not give detailed breakdowns, the "other alloy" category under steel contains some quantities of molybdenum that should be distributed to tool steel and stainless steel. However, detailed reports by other consumers are believed adequate for showing the relative trends of the uses in the steel industry.

Between 1964 and 1965 the consumption of molybdenum in catalysts appears to have increased considerably. The increase is more apparent than real

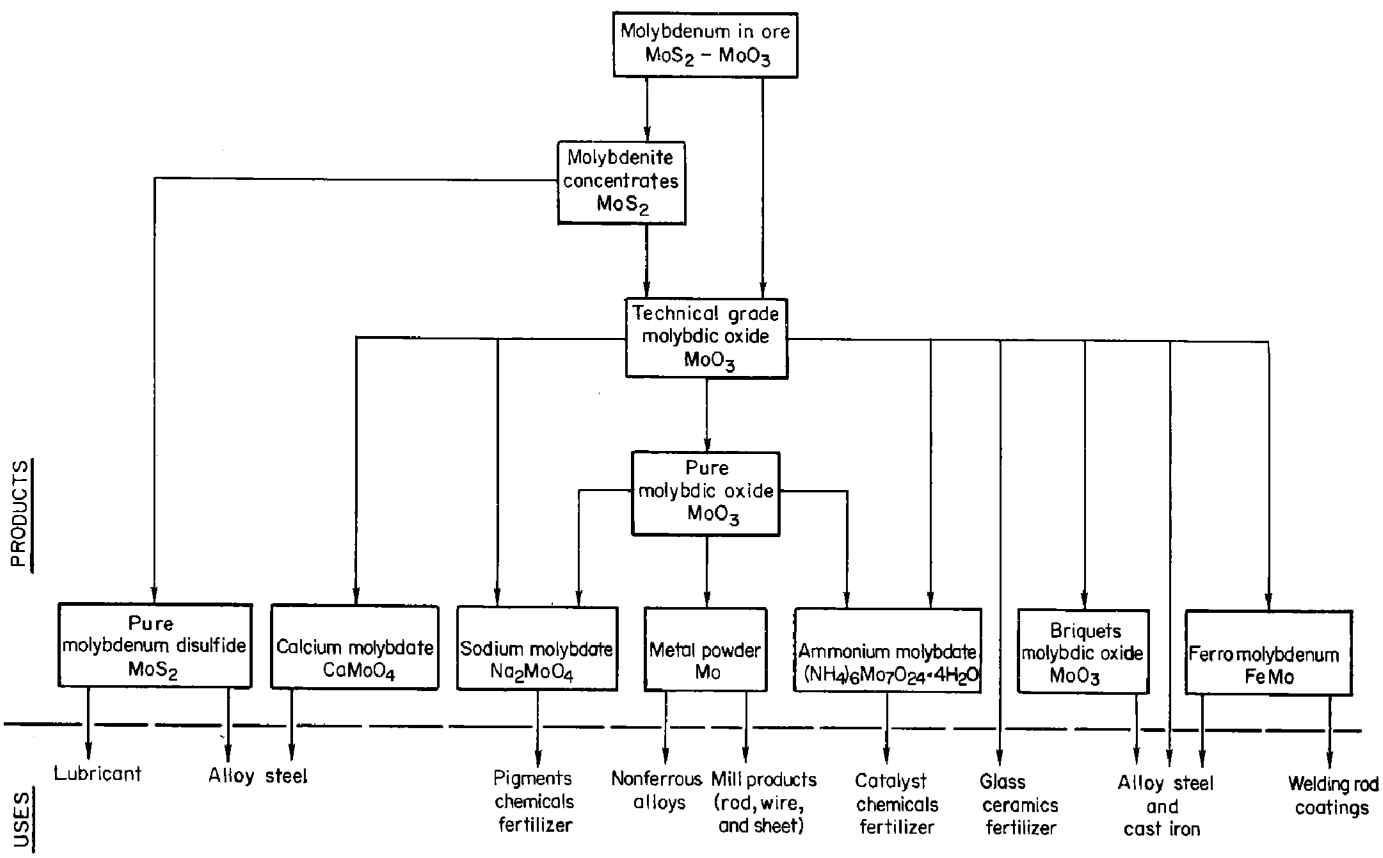

FIGURE 1. - Principal Molybdenum Products and Their Relationships to End Uses.

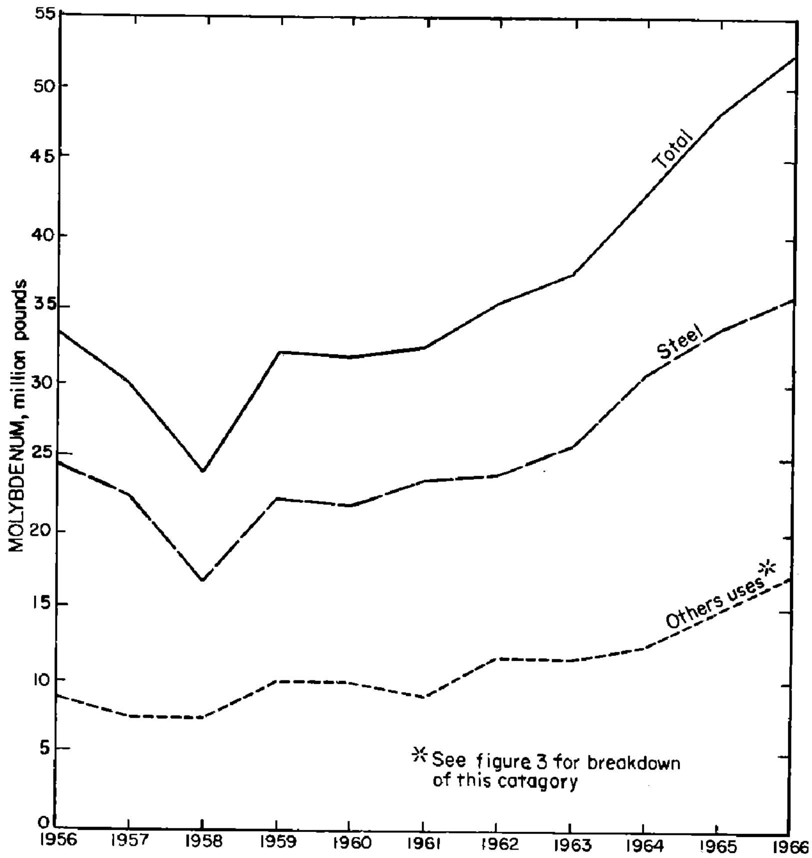

FIGURE 2. - U.S. Consumption of Molybdenum by End Use, 1956-66.

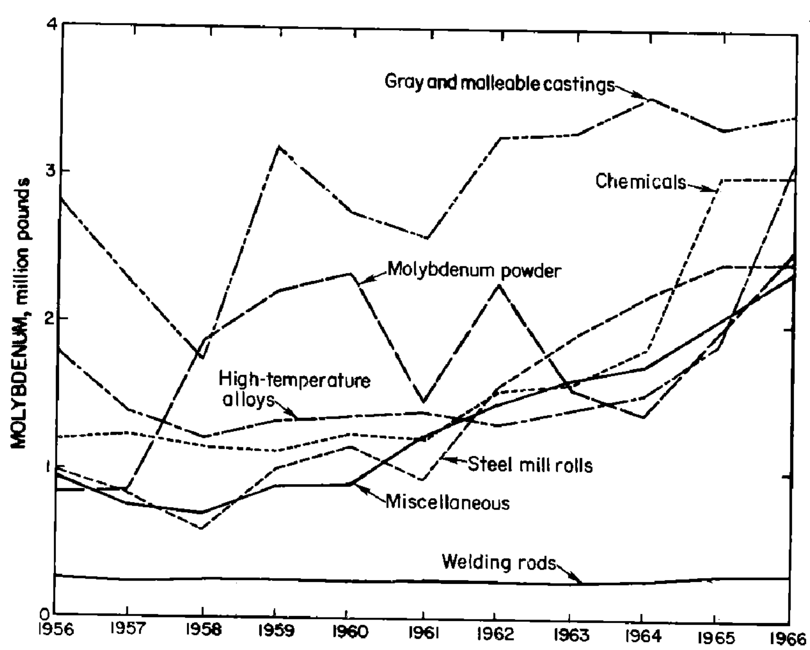

FIGURE 3. - U.S. Consumption of Molybdenum by End Use Other Than Steel, 1956-66.

because the Bureau of Mines expanded its statistical coverage of manufacturers of catalysts during 1965.

The miscellaneous category contains quantities of molybdenum that could not be revealed by end use because of the confidentiality of the data.

Molybdenum for making steel is by far the dominant use. Seventy percent of the total molybdenum consumed annually from 1956 through 1966 was used for this purpose. The second most important use in the 11-year period has been in gray and malleable castings. When including molybdenum used in manufacturing steel mill rolls, iron and steel have accounted for between 78.4 and 85.0 percent of the molybdenum consumed annually.

Consumption of molybdenum in high-temperature alloys and molybdenum powder has increased noticeably in the last 3 years, reflecting a rising demand for high-temperature materials by the aerospace and nuclear industries.

Since 1961 the quantity of molybdenum used for chemical purposes has increased steadily. The large increase from 1964 to 1965 is more apparent than real because for 1965 more manufacturers of catalysts were canvassed than previously.

The quantity of molybdenum used for making welding rods each year has been relatively small compared to the other main uses. Since 1963 this use has experienced an upward growth pattern.

The miscellaneous uses requiring substantial quantities (100,000 pounds or more) of molybdenum in recent years have been lubricants, cutting and wear-resistant material (excluding carbides), soft-magnet alloys, and alloy hard-facing rods and material.

PRICES

The starting point for the price system for molybdenum is the price of molybdenum contained in concentrates, usually the first salable product. The most common concentrate sold is molybdenite concentrate, the first product obtained from most primary and byproduct operations. In addition to molybdenite concentrate, molybdic oxide, calcium molybdate, ammonium tetramolybdate, and ammonium phosphomolybdate concentrates have been sold as the first salable product from mining operations, but the price for the contained molybdenum in these materials is usually higher than that of molybdenum in molybdenite concentrates.

Figure 4 shows a comparison between the quoted price of molybdenum contained in molybdenite concentrate and the Bureau of Labor Statistics Wholesale Price Index for all commodities and for metal and metal products. The price of contained molybdenum followed the upward trend of the two wholesale price indexes from 1946 until 1951. The rises in prices can be attributed to post-World War II boom that continued until the Korean conflict. During the conflict price controls were placed on most commodities, including molybdenum. After the end of hostilities in 1953, the price control on molybdenum was removed. Thereafter, the price moved steadily upward until the present, reflecting the increase in demand that was taking place at the same time.

Table 1 shows the price history since 1945 of molybdenum contained in the major products. Compared to most other metal commodities, the price history of molybdenum is different in that it does not show any fluctuation; there has been no decrease in the price of molybdenum during that time. The first price increases after World War II came in January 1949 when the price of molybdenum contained in three major products (molybdenite concentrate, molybdic oxide, and ferromolybdenum) was raised 15 cents per pound of contained molybdenum. From then on price changes for these three products usually took place simultaneously.

The price pattern for molybdenum powder, another major product, was somewhat different in that it was not subject to as many increases until the later years. Prior to its wide acceptance for commercial uses in 1958, the powder was mainly used in research.

Although the published prices of molybdenum products are those quoted by the major producers, not all buying is at these prices. Moreover, during some periods, actions of the Government set or influenced prices. Usually about 90 percent of molybdenum products are sold at the published quoted prices, the balance is sold at prices which small producers can negotiate in the open

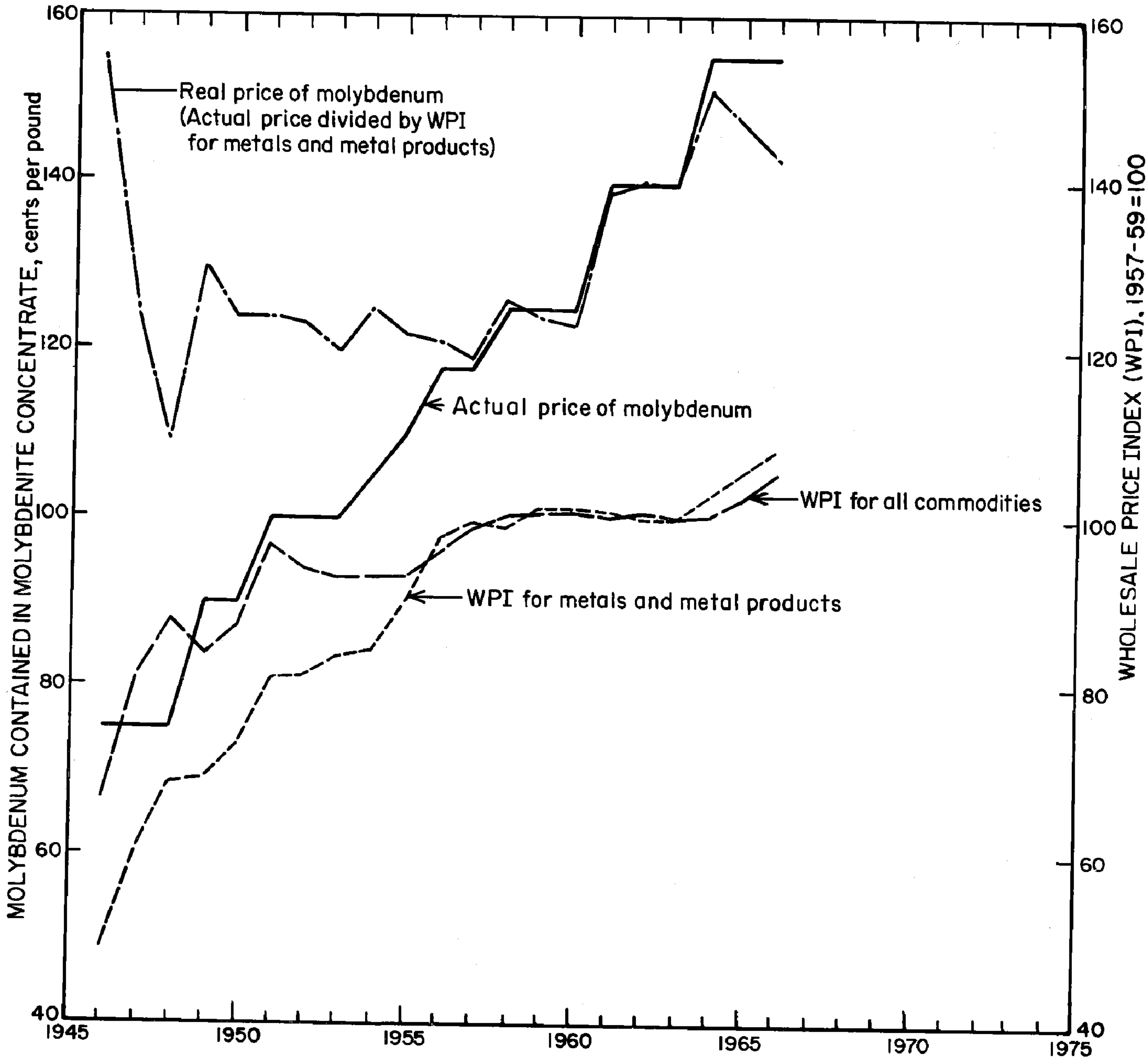

FIGURE 4. - U.S. Prices of Molybdenum Contained in Molybdenite Concentrate and Wholesale Price Indexes, 1946-66.

market. In times of tight supply, such as between 1962 and 1965, some molybdenum producers, usually the byproduct ones, can get premium prices; but in times of oversupply, they may have to sell at a discount.

During the 1963-66 period, the prices of surplus molybdenum in the national stockpile sold by the Government through bids were higher than the quoted prices. The stockpile sales ranged from \$1.595 to \$2.19 per pound of molybdenum in concentrate in 1964 and from \$1.811 to \$2.7125 in 1965; whereas the quoted price was \$1.40 in 1964 and \$1.55 in 1965.

TABLE 1. - *Quoted prices of molybdenum contained in major products, per pound of molybdenum*

Year	Molybdic oxide	Ferro-molybdenum	Molybdenum powder		Molybdenite concentrate
			Hydrogen-reduced	Carbon-reduced	
1946	$0.80	$0.95	$2.60-$3.00	NQ	$0.75
1947	.80	.95	2.60- 3.00	NQ	.75
1948	.80	.95	2.60- 3.00	NQ	.75
1949	.95	1.10	2.60- 3.00	NQ	.90
1950	$0.96- 1.14	$1.13- 1.32	2.60- 3.00	NQ	$0.90- 1.00
1951	1.14	1.32	3.00	NQ	1.00
1952	1.14	1.32	3.00	NQ	1.00
1953	1.14	1.32	3.00	NQ	1.00
1954	1.14- 1.25	1.32- 1.49	3.00	NQ	1.00- 1.05
1955	1.24- 1.30	1.46- 1.54	3.00	NQ	1.05- 1.10
1956	1.30- 1.38	1.54- 1.68	NQ	$3.20-$3.35	1.10- 1.18
1957	1.38	1.68	NQ	3.35	1.18
1958	1.38- 1.46	1.68- 1.76	3.15- 4.10	3.35	1.18- 1.25
1959	1.46	1.76	3.15- 4.10	3.35	1.25
1960	1.46	1.76	3.15- 4.10	3.35	1.25
1961	1.46- 1.59	1.76- 1.89	3.55	3.35	1.25- 1.40
1962	1.59	1.89	3.55	3.35	1.40
1963	1.59	1.89	3.55	3.35	1.40
1964	1.59- 1.74	1.89- 2.04	3.55- 3.75	3.35	1.40- 1.55
1965	1.74	2.04	3.75	3.35	1.55
1966	1.74	2.04	3.75	3.35	1.55
1967	1.81	2.11	3.75	3.35	1.62

NQ--Not quoted.

One of the reasons for increased prices since World War II is because less molybdenum is being recovered per ton of ore due to mining of lower grade ores. Figure 5 shows the relationship of the price of molybdenum and quantity of molybdenum recovered at the Climax mine which was the world's largest producer during the period shown.

The price controls by the Government on molybdenum products set by the Office of Price Administration during World War II were revoked June 12, 1946. During the Korean conflict the Economic Stabilization Agency, through the General Price Regulations issued January 26, 1951, froze the prices of virtually all commodities, including molybdenum, at the highest price received during the period December 19, 1950, to January 25, 1951. Molybdenum, as well as most metals and minerals, was released from price control on February 12, 1953. Since then, there have been no formal Government price regulations for molybdenum; however, informal actions of the Government influenced prices in 1966.

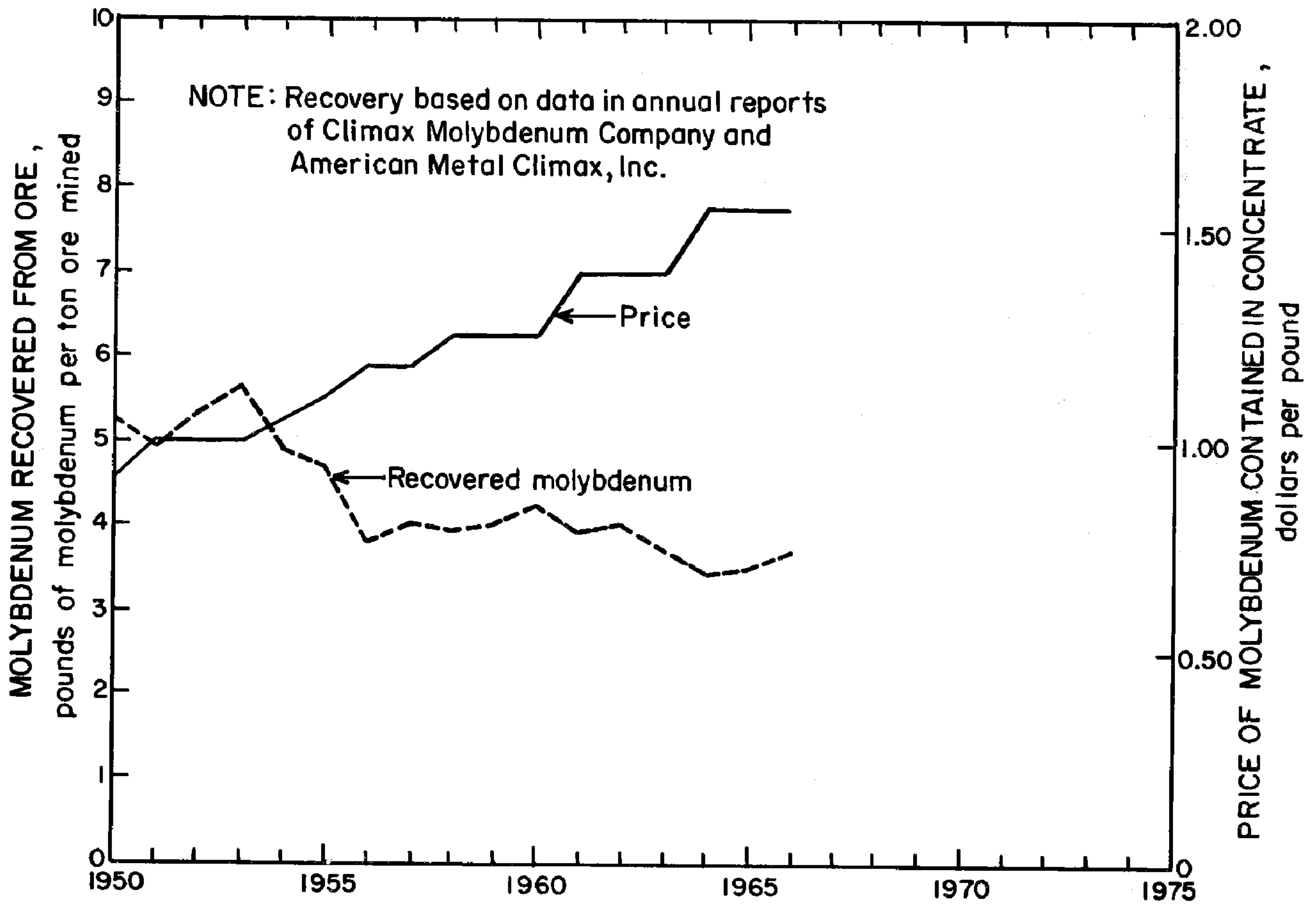

FIGURE 5. - Quoted Price of Molybdenum Contained in Molybdenite Concentrate and Recovered Molybdenum From Ore Mined at the Climax Mine.

SUBSTITUTES AND ALTERNATE MATERIALS

Since the end of World War II, molybdenum has established a sound position in the metal industry because of its availability and versatility as an alloying material. Tungsten and vanadium have some properties similar to those of molybdenum, and substitutions in some alloy steels are feasible. However, even in times of tight supply, companies are reluctant to substitute these metals for molybdenum, or vice versa, because the steels would not have all the standard characteristics and manufacturing techniques would be different. Boron has replaced molybdenum in some steels where hardenability is the only alloying effect. Chromium and manganese could also be substituted to impart hardenability.

Plastic technology has made some outstanding advances in recent years and some plastics are now competing with metals, such as stainless steels containing molybdenum, where corrosion resistance is important. Fluorocarbons, such as Teflon, may compete with molybdenum as a surface coating because they have great heat resistance and impart a nonstick property to the surface.

Industrial ceramics, such as alumina and beryllia, are also becoming competitive for some metal uses. These materials are very hard, stable at elevated temperatures, and virtually inert. However, currently the prices of products made of these materials are usually higher than those made of metal, although in some cases the cost may be of secondary consideration if the ceramic product has a distinct advantage over a metal product. For instance, alumina grinding balls cost more than steel grinding balls containing molybdenum, but the alumina has greater wearability and does not contaminate the ground material with iron.

For certain chemical uses other materials can be substituted for molybdenum. In making orange-colored paint, molybdate orange can be replaced as a pigment by chrome orange, cadmium red, or organic orange pigments; however, each of these pigments has its own desirable properties. Cost considerations may be the deciding factor in determining what pigment to use. Lubricants containing molybdenum can be replaced with other lubricants; however, for some applications the molybdenum lubricants are superior in reducing wear and sustaining high loads.

PRODUCTION

United States

During the 1941-45 period of World War II, stimulated in part by actions of the Government, the U.S. production of molybdenum contained in concentrate was 228 million pounds, or only 150,000 pounds less than the total world production prior to 1941. The first year after World War II, U.S. production slumped badly and molybdenum appeared ready to revert to its old status of being mainly a war metal.

In 1946 U.S. production of molybdenum in concentrate dropped to 18.2 million pounds from 30.8 million pounds in 1945, but when the postwar boom got underway production started to climb. Details of the supply of molybdenum for the 1946-66 period are shown in the appendix (table A-2). Some of molybdenum-type high-speed and low-alloy steels developed during the war were accepted by industry for peacetime use. With the start of the Korean conflict in June 1950, demand for molybdenum increased considerably and the supply became critical. Late in that year, molybdenum was included on the national (strategic) stockpile list of critical and strategic materials.

In 1955 U.S. production hit 61.8 million pounds: a record output surpassing the previous high of 61.7 million pounds in 1943. Production fell off slightly in the next 2 years. In 1958 while the U.S. economy was experiencing a recession and the Climax mine was on strike for 87 days, molybdenum production was only 41 million pounds. With the general recovery of the economy, including the molybdenum industry, in 1959, output rose to 50.9 million pounds. Production increased substantially in 1960 and then dropped slightly in 1961. Starting in July 1962 a strike at the Climax mine that lasted nearly 6 months caused a critical shortage that was to last for almost 3 years. The shortage and resulting price increases did have one good effect--it spurred exploration, development, and expansion of the molybdenum industry not only in the United States but also in other parts of the free world with the result that production increased considerably in 1965 and 1966 and nearly all demands could be met.

The Climax mine has played a prominent role in the supply of molybdenum since it was first developed in 1916. Because of the tremendous demand for molybdenum in World War II, the mine during the war years was "gutted" (taking only high-grade ore and leaving the lower grade ore). At the end of World War II the mine was in poor operational condition. In 1946 ore production at the mine was reduced to 1.7 million tons and only 8.5 million pounds of molybdenum contained in concentrates was shipped. Twenty years later, ore production was 15.2 million tons, a record output, and the amount of the molybdenum contained in concentrates shipped during 1966 was 57.3 million pounds, also a record.

From 1946 through 1952, 47 to 59 percent of the yearly domestic shipments of molybdenum contained in concentrates was produced from the Climax mine and after 1952 and until 1967, 62 to 74 percent. From 1946 through 1966, except for 1948 and 1949, this mine has been the principal source of molybdenum in the world. Because of its huge ore reserve the mine should continue to be one of the major molybdenum sources for the next 30 years.

Other primary operations that shipped molybdenum during the 1946-66 period were the Urad mine (Colorado), Questa mine (New Mexico), Nye mine (Colorado), and Childs-Aldwinkle mine (Arizona). Except for the Questa mine, shipments from these mines were made only during 1 or 2 years.

Byproduct molybdenum from tungsten ore has been shipped from the Pine Creek mine (California) during the entire 1946-66 period and from the Getchell mine (Nevada) in 1958. Three uranium companies have shipped molybdenum as a byproduct from uranium ores from 1964 through 1966.

The only copper mines that have shipped molybdenum produced as a byproduct during the entire 1946-66 period were the Utah Copper (Utah), Chino (New Mexico), and Nevada Mines (Nevada) operations of Kennecott Copper Corp. In 1948 and 1949 shipments of molybdenum in concentrates from the Utah Copper operation surpassed those from the Climax mine. In 1946 and 1947 and from 1950 through 1966 the Utah Copper mine was the second principal source of molybdenum in the United States and in the world.

Other copper operations that have shipped molybdenum produced as a byproduct during the 1946-66 period were the Bagdad, Inspiration, Miami, Mission, Morenci, San Manuel, and Silver Bell mines in Arizona.

Coproduct molybdenum has been shipped from the Esperanza mine (Arizona) from 1959 through 1966 and from the Mineral Park mine (Arizona) from 1964 through 1966.

Figure 6 shows the quantity and figure 7 the percentage of molybdenum produced from primary ores and from byproduct and coproduct ores as measured by shipments. During the 1946-66 period there were two significant declines in molybdenum production, one in the recession year 1958 and the other in 1962 when the Climax mine was shut down due to a 6-month strike. As can be seen in figure 7, from 1954 onward, about two-thirds of the shipments of molybdenum contained in concentrate came from primary ores. Salient molybdenum statistics for the 1946-66 period are given in the appendix (table A-2).

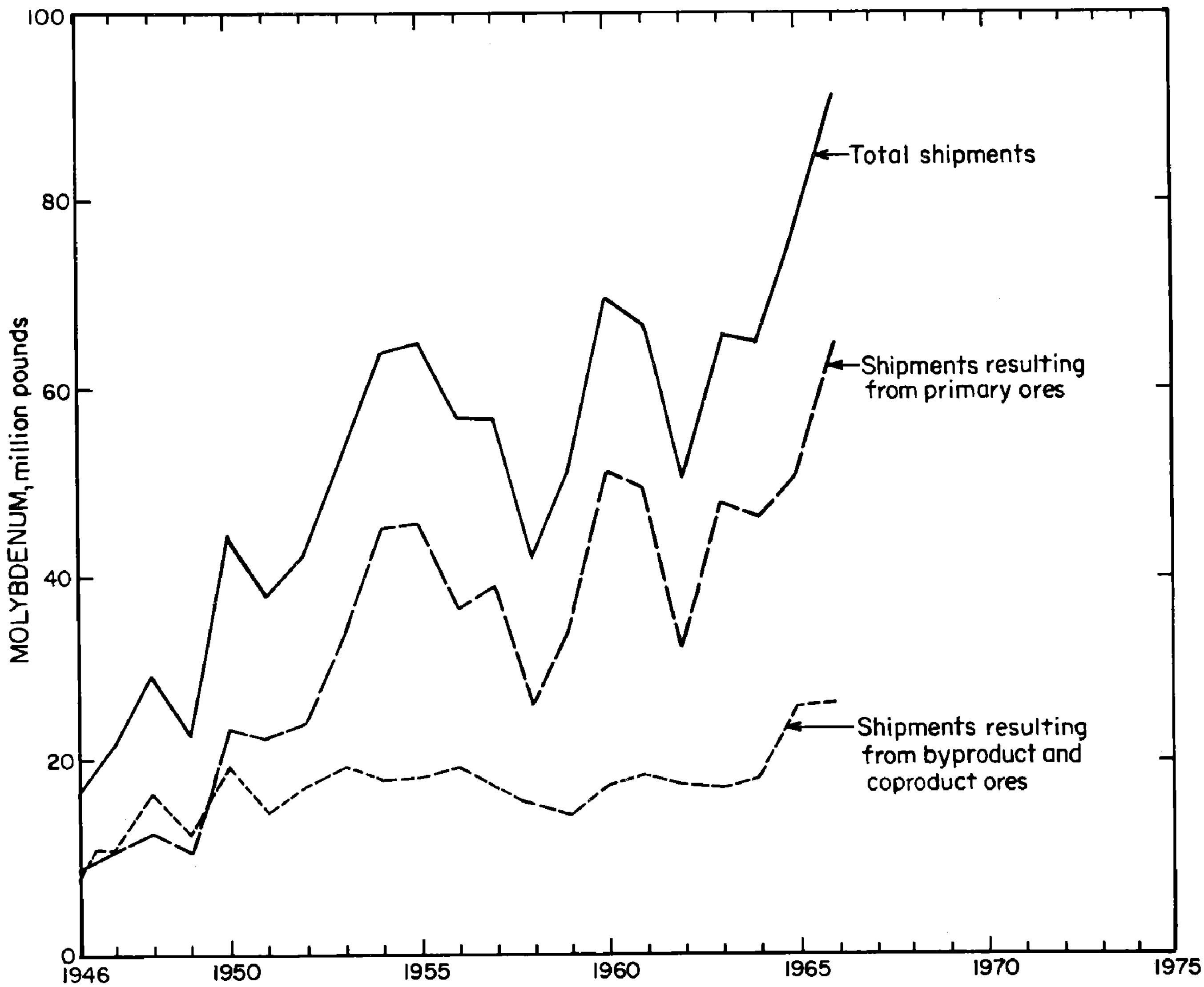

FIGURE 6. - Production As Measured by Shipments of Molybdenum Contained in Concentrates, by Type of Ore.

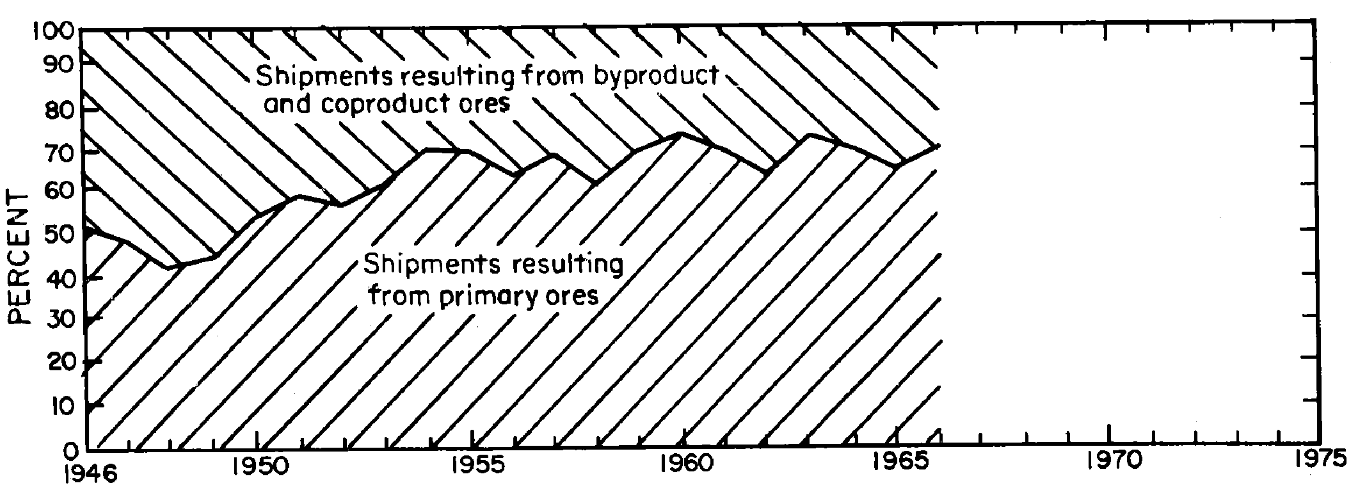

FIGURE 7. - Percent of Production As Measured by Shipments of Molybdenum Contained in Concentrates, by Type of Ore.

World

Figure 8 is a map of the world showing the free world production of molybdenum for 1966, which was 5.7 times that of 1946. The United States has by far been the dominant producer. From 1946 through 1964, the United States was responsible for 82.1 to 94.3 percent of the yearly free world production. In 1965 the percentage decreased for the first time below 80 percent to 78.8 percent and then in 1966 to 71.7 percent. These decreases resulted primarily from substantial increase of production in Canada in those 2 years.

Chile had been the second largest producer until 1965. During 1965 Canada surpassed Chile and since then has maintained its number two position. Although production was relatively small until 1961, Peru has become a major source in the past few years. In 1965 and 1966 the United States, Canada, Chile, and Peru produced 98 percent of the free world output.

Norway and Japan have been consistent producers during the 1946-66 period; however, their individual production for any single year has not reached 900,000 pounds. Most of Norway's production came from the Knaben mine which is considered the earliest molybdenum mining operation in the world.

The Soviet Union, Red China, Yugoslavia, and North Korea also have produced molybdenum. Exact data about the production in these countries is not available; the only information published has been estimates. Starting in 1965 the Bureau of Mines stopped publishing estimates for these countries in the molybdenum chapter of the Minerals Yearbook.

GOVERNMENT STOCKPILING

Table 2 shows the changes of objectives, inventories, and sales for molybdenum in the Government stockpiles of strategic and critical materials. Except for 2.1 million pounds of molybdenum in molybdenite concentrate obtained from foreign sources, the buildup of 84.6 million pounds of molybdenum came from domestic sources. The cost of acquisition for the molybdenum material (molybdenite concentrate and molybdic oxide) in the stockpile as of December 31, 1963, was $89.2 million. Some additional costs were incurred later as more molybdenite concentrate was converted into molybdic oxide or ferromolybdenum to fulfill the subobjectives set for these materials. In addition decreases in quantity resulted as molybdenite concentrate was converted to molybdic oxide or ferromolybdenum or because of losses incurred when some of the material was upgraded to meet new specifications.

Previous to the U.S. Senate investigation of the Government's strategic and critical material stockpiles, information about quantity and costs was cloaked in secrecy. The investigation started in early 1962 and ended a year later. During the investigation the information about the stockpiles was declassified. According to the draft report (16) of the investigating committee, "This was done by executive action at the outset; and if nothing else had been accomplished by the investigation of the national stockpile, the removal of the shroud of secrecy, in itself, fully justified proceeding with the hearings." The data released helped explain some of the wide differences between production and shipments that appear in the Bureau of Mines Minerals Yearbooks.

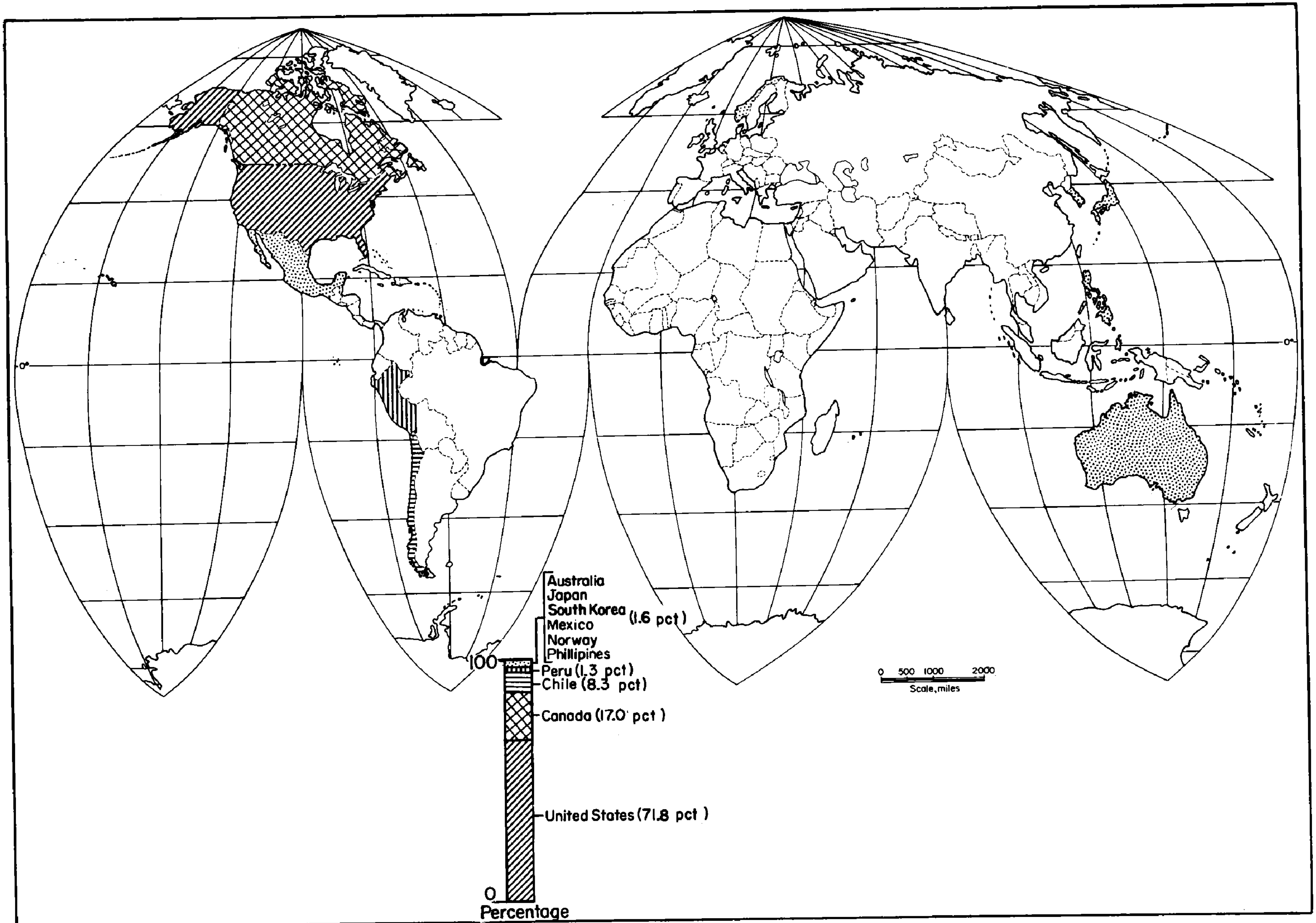

FIGURE 8. - Free World Countries Producing Molybdenum in 1966.

TABLE 2. - *Government stockpiling of molybdenum (million pounds of contained molybdenum)*

Objectives		Inventory			Sales		
Date of establishment of objective	Stockpile objectives	Date of inventory	National stockpile	Defense Production Act stockpile	Year	Quantity	Price, thousand dollars
Aug. 10, 1950	Total: 50.0	Dec. 31, 1950	[1]16.721	-	-	-	-
Dec. 21, 1950	Total: 165.0	Dec. 31, 1952	23.776	-	-	-	-
Feb. 24, 1953	Total: 130.0	June 30, 1954	52.283	[2]1.120			
Sept. 28, 1954	Minimum: 130.0	June 30, 1955	78.094		-	-	-
	Long term: 130.0	-	-	-	-	-	-
July 12, 1955	Minimum: 110.0	-	-	-	-	-	-
	Long term: 110.0	-	-	-	-	-	-
June 30, 1958	Basic: 57.5	June 30, 1958	84.602	-	-	-	-
	Maximum: 57.5	Dec. 31, 1959	84.603	-	-	-	-
Feb. 16, 1960	Basic: 59.0	Dec. 31, 1961	[3] [4]84.305	-	-	-	-
	Maximum: 59.0	Mar. 31, 1963	[5] [6]84.062	-			
		Dec. 31, 1963	79.043		1963	5.019	7,264
Feb. 28, 1964	Total: 68.0[7]	Dec. 31, 1964	70.995	-	1964	8.048	13,048
		Dec. 31, 1965	[8]67.996	-	1965	3.019	6,122
Mar. 17, 1966	Total: 55.0[9]	Dec. 31, 1966	[10]59.136	-	1966	11.940	20,099
Jan. 5, 1967	Conventional warfare: 40.0[11]	-	-	-	-	-	-
	Nuclear warfare: None	-	-	-	-	-	-

[1]Material acquired before 1950 and transferred to the National Stockpile when objectives established.

[2]Acquired under the Defense Production Act and transferred to the National Stockpile between June 30, 1954, and June 30, 1955.

[3]Reduction due to loss in converting part of the molybdenite (MoS_2) concentrate to molybdic oxide (MoO_3); maximum subobjective for molybdenum in molybdic oxide was set at 19.5 million pounds.

[4]Includes 16.954 million pounds of molybdenum in molybdic oxide.

[5]Reduction due to loss in converting some molybdenite concentrate to molybdic oxide and ferromolybdenum; maximum subobjective for molybdenum in molybdic oxide was 19.5 million pounds and in ferromolybdenum 4.0 million pounds.

[6]Includes 19.554 million pounds of molybdenum in molybdic oxide and 4.025 million pounds of molybdenum in ferromolybdenum.

[7]Quantity is equivalent pounds of molybdenum in molybdenite concentrate; the subobjectives are as follows: 39.5 million pounds of molybdenum in molybdenite concentrate, 19.5 million pounds in molybdic oxide, and 7.5 million pounds in ferromolybdenum; the total of the subobjectives is 66.5 million pounds of molybdenum.

[8]Consists of 44.417 million pounds of molybdenum in molybdenite concentrate, 19.554 million pounds in molybdic oxide, and 4.025 million pounds in ferromolybdenum.

[9]Quantity is equivalent pounds of molybdenum in molybdenite concentrate; the subobjectives are as follows: 36.25 million pounds of molybdenum in molybdenite concentrate, 10.0 million pounds in molybdic oxide, and 7.5 million pounds in ferromolybdenum; the total of the subobjectives is 53.750 million pounds of molybdenum.

[10]Consists of 38.435 million pounds of molybdenum in molybdenite concentrate, 14.733 million pounds in molybdic oxide, and 5.968 million pounds in ferromolybdenum.

[11]Quantity is equivalent pounds of molybdenum in molybdenite concentrate; the subobjectives are as follows: 21.25 million pounds of molybdenum in molybdenite concentrate, 10.0 million pounds in molybdic oxide, and 7.5 million pounds in ferromolybdenum; the total of the subobjectives is 38.75 million pounds of molybdenum.

Source: U.S. Department of Commerce and Draft Report, "Inquiry into the Strategic and Critical Material Stockpiles of the United States," of the National Stockpile and Naval Petroleum Reserves Subcommittee of the Committee on Armed Services, U.S. Senate, 88th Congress, 1963.

The objectives of how much material classed as strategic and critical should be stockpiled by the Government since World War II has been subject to review based on world conditions and technological changes. As can be seen in the case of molybdenum, the objectives for this material changed several times.

A total of 28.0 million pounds of molybdenum has been sold by the Government from the stockpile since the first sale in 1963 through December 31, 1966; the molybdenum was contained either in molybdenite concentrate or molybdic oxide. The sales of molybdenum from the stockpile helped alleviate the shortage situation between 1962 and 1966. At the end of 1967 Congress passed a stockpile bill authorizing the disposal of 15 million pounds of molybdenum that is in excess to the conventional warfare objective established in January 1967.

WORLD TRADE

For the 1946-66 period, yearly exports of molybdenum from the United States, as reported by the Bureau of the Census, ranged between 1,253,000 pounds in 1946 and 36,348,000 pounds in 1961, representing 6.9 and 54.6 percent, respectively, of the production in the United States for those years, see appendix (table A-3). For 8 years after World War II the quantities exported were small because of the reconstruction of the metal industries in Western Europe and Japan. After 1953 U.S. exports showed marked increases in quantities until 1958 when there was almost a 50-percent decrease over the previous year, caused by a sharp drop in demand by the industrial nations in Western Europe and in Japan. Most of these nations were either experiencing a recessional period similar to that in the United States or a slowup of industrial activity. In 1959 exports increased 50 percent over those of 1958 and then continued to grow considerably until 1961 when exports hit 36.3 million pounds of contained molybdenum. The cutback of production at the Climax mine in 1962 had some effect on exports as they dropped to only 15.8 million pounds in 1962. During the 1963-65 period, exports were between 26 and 28 million pounds; however, exports might have been greater if more molybdenum had been available. In 1966 exports climbed to 31.4 million pounds, an increase of 5.0 million pounds over the 1965 exports.

Specific data are not available on consumption of molybdenum outside the United States. However, U.S. exports of molybdenum and the rest of the free world production shown in figure 9 are a relative measure of that consumption. The phenomenal growth in the use of molybdenum outside the United States, as indicated by figure 9, has been an important factor leading to increased production both here and abroad.

The United States imported molybdenum in 9 of the 21 years from 1946 through 1966; however, the quantities were small. From 1959 through 1966, only 295,000 pounds were imported and that was in 1965 when a shortage situation existed in the United States. One reason for lack of imports in the United States is the tariff on molybdenum ores and concentrates and primary molybdenum products. Import duties on molybdenum date back to 1913 when the Tariff Act of 1913 imposed duties on molybdenum and its products. The import duties, shown in table 3, became effective on August 31, 1961, and are lower

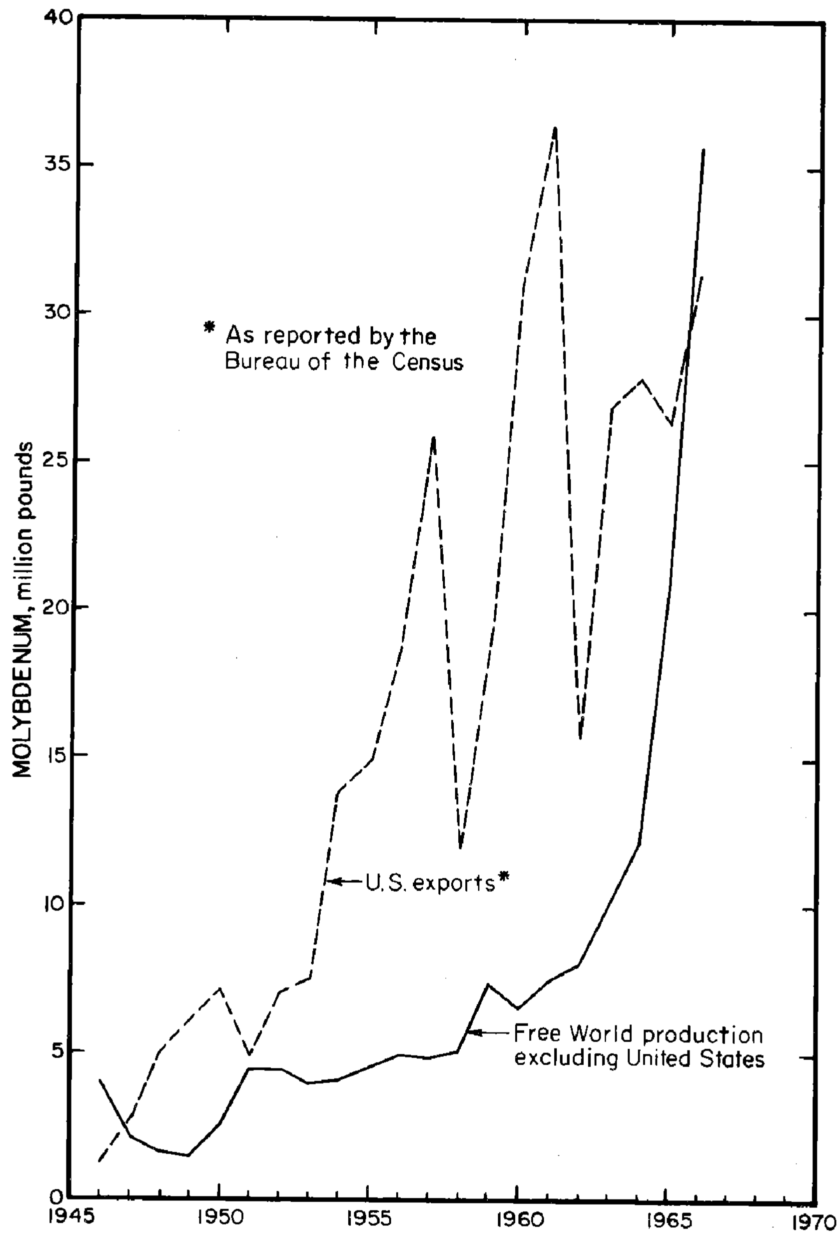

FIGURE 9. - U.S. Exports of Molybdenum and Free World Molybdenum Production Excluding U.S. Production.

than previous duties, except that for wrought molybdenum which remain unchanged from the previous regulations. During the Kennedy Round on international trade in 1967, the United States agreed to reduce tariffs on molybdenum and molybdenum products by 50 percent over a 5-year period tentatively starting in 1968.

During the 1963-65 period of shortage of molybdenum in the United States, some of the domestic consumers again attacked the import duties as unwarranted and objected to not being supplied when producers continued exporting. However, the producers reported that both domestic and foreign customers were being cut by equitable amounts.

The United States is the only major industrial nation in the free world that has a tariff on imports of molybdenum contained in concentrates. The European Economic Community countries (Belgium, France, Italy, Luxembourg, The Netherlands, and West Germany) have an import duty on ferromolybdenum of 7 percent ad valorem and Japan, 15 percent ad valorem. Ferromolybdenum may be imported into Canada duty-free under British preferential treatment and at a duty of 5 percent ad valorem under most-favored-nation treatment; most of the other molybdenum products enter Canada duty-free.

Since the end of World War II there has only been one period when exports of molybdenum from producing nations came under some international control. At the beginning of the Korean conflict the demand for molybdenum and other materials in the world greatly exceeded the supply. In early 1951 the International Materials Conference--sponsored by the United States, France, and the United Kingdom--was formed to assure equitable distribution of these materials to member nations. Allotments for distribution of molybdenum contained in concentrates were first issued in the third quarter of 1951 and afterwards allotments were also made for primary molybdenum products. On June 11, 1953, molybdenum was released from the allocation program.

TABLE 3. - *U.S. import duties on molybdenum and molybdenum products*

TSUS[1] Item No.	Article	Rates of duty[2]
Schedule 4:	Chemicals and related products:	
417.28	Ammonium molybdate..........	20 cents per lb on molybdenum content plus 6 percent ad valorem.
418.26	Calcium molybdate...........	Do.
419.60	Molybdenum compounds.........	Do.
420.22	Potassium molybdate..........	Do.
421.10	Sodium molybdate.............	Do.
473.18	Molybdate orange.............	10 percent ad valorem.
Schedule 6:	Metal and metal products:	
601.33	Molybdenum ore...............	24 cents per lb on molybdenum content.
603.40	Materials chief in value of molybdenum.[3]	20 cents per lb on molybdenum content plus 6 percent ad valorem.
607.40	Ferromolybdenum..............	Do.
628.70	Molybdenum, waste and scrap..	21 percent ad valorem.
628.72	Molybdenum, unwrought........	20 cents per lb on molybdenum content plus 6 percent ad valorem.
628.74	Molybdenum, wrought..........	25.5 percent ad valorem.

[1]Tariff Schedule of the United States.
[2]Not applicable to Communist countries.
[3]Other metal-bearing materials of a type commonly used for the extraction of metal or as a basis for the manufacture of chemical compounds.

Source: Tariff Schedule of the United States annotated (1963). Tariff Commission Publication 103, 1963, 620 pp.

The principal molybdenum consuming nations in the free world are those having a sizable steel industry. In the past 3 years (1964-66) the leading consumers, besides the United States, were Japan, West Germany, the United Kingdom, and France. Except for Japan, these nations must completely rely on imports to satisfy their needs.

Japan is one of the few consuming nations that produces some molybdenum from its natural resources; however, the Japanese annual production since World War II has never exceeded 842,000 pounds (1959). Because of the big demand, most of the molybdenum consumed in the country must be imported, with the United States supplying the largest quantity. Japan is the second largest free world consumer of molybdenum because of its steel industry; in 1964 Japan surpassed West Germany to become the second biggest steel producer in the free world and has continued in this role through 1966. Japanese production of special hot-rolled steel products, most of which require molybdenum as an alloying element, has had considerable growth. Output of these products in

1958 was 558,950 tons and 6 years later was 2.8 million tons (8). In 1964 U.S. production of alloy steel (including stainless steel) was 12.6 million tons. Japanese companies in recent years have invested heavily in some new Canadian mining operations that have been responsible for the tremendous increase in molybdenum production in Canada. In 1964 Japan imported from Canada 258 tons of molybdenum ore and concentrate and in 1965, 1,175 tons.

Japan is one of the few free world countries trading in molybdenum with Communist nations. It occasionally has imported molybdenum ores and concentrates from Red China and has exported molybdenum products to Red China and the Soviet Union.

Because of its spectacular growth in molybdenum production since 1964, Canada has become the second most important source of molybdenum for the free world. In 1965 production was 9.6 million pounds and in 1966, 21.5 million pounds. Exploration and development work currently being done on molybdenum deposits not in production should assure Canada of this position in the future, barring a discovery of huge unknown primary molybdenum deposits in any of the free world countries besides the United States. Although Canada consumes a significant quantity, 1.7 million pounds of molybdenum in 1965, most of the production is exported. From 1964 Canada has been importing a large part of the molybdenum products (molybdic oxide and ferromolybdenum) consumed.

Other free world nations important as sources of molybdenum are Chile and Peru. Except for very small quantities retained and consumed, the production from these countries is exported.

So far the Communist bloc countries have not played very important roles in the molybdenum world trade picture. At times Russia has exported molybdenum to some European countries; both Russia and Red China have exported to Japan. However, quantities involved in these trades were usually small.

RESERVES

For the following discussion, molybdenum reserves are considered to be mineral-bearing material containing molybdenum that can be extracted profitably with present technology. This definition not only can include ores which are mineral-bearing material in its natural place in the earth's crust but also mineral-bearing material contained in mine dumps, tailings piles, and slag dumps that can be reworked at a profit.

United States

The reserves of the major molybdenum ore deposits in the United States are now estimated at 5.9 billion pounds of recoverable molybdenum. The importance of recent exploration, development, and technology is indicated by the fact that this is nearly 2 billion pounds more than that estimated in 1959 by the Raw Materials Group on Molybdenum in the Material Advisory Board Report of the Committee on Refractory Metals (12) or twice as much as that reported for the free world in the Bureau of Mines materials survey on molybdenum (11).

Previous to this study, the latest Bureau of Mines estimate, published "Mineral Facts and Problems, 1965 Edition," (7) was 3.7 billion pounds.

In making the reserve estimate, only deposits known to contain at least 1 million pounds of recoverable molybdenum were considered. Of the 23 deposits shown in figure 10, only six (Henderson, Twin Buttes, Tyrone, Glacier Peak, Sierrita, and Mike Horse) are not in production; however, each of these six deposits is either under development or tentative plans have been announced for their development. There are a few ore deposits presently being explored that probably contain more than a million pounds of recoverable molybdenum; however, because they are still in the exploration stage and no information about their reserves has been released, the molybdenum in these deposits was not included in the reserve estimate.

Molybdenum reserves were greatly enhanced by the discovery in 1965 of a new deposit, Henderson, by the American Metal Climax, Inc., near its Urad mine in Colorado. According to the company's 1966 annual report, evaluation of the deposit by the company placed the reserves at 236,000,000 tons of a grade of 0.45 percent MoS_2.[3] The company stated further in the report that continued drilling was expected to increase this reserve estimate. On September 14, 1967, the company released new reserve figures of 303,000,000 tons of 0.49 percent MoS_2.

The domestic reserves are shown in table 4 under three categories: (1) primary, (2) byproduct of copper ores, and (3) others, consisting of coproduct of copper-molybdenum ores, byproduct of tungsten ores, and byproduct of uranium ores. Figure 10 shows the location of the major deposits of each category. The deposits shown in figure 10 account for 99.5 percent of the total reserves.

Primary reserves are those that could be mined principally for the molybdenum contained in the ore. This classification constitutes 71.4 percent of the total reserve. In some cases, molybdenum could be the only valuable metal recovered from the ore; for example, the ore of the Questa deposit in New Mexico is mined only for the molybdenum content. In other deposits molybdenum may be the principal product recovered together with one or more byproducts. In these deposits the molybdenum content alone would allow for a profitable operation. The ore at the Climax mine in Colorado is of this type. Currently, monazite (a combination of rare-earth phosphates), pyrite, tin, and tungsten are recovered from the ore; however, none of these byproducts exists singly nor together in sufficient quantity so that the ore could be mined profitably merely for the extraction of one or all of these byproducts.

Byproduct reserves of copper ores are those contained in ores that are or would be mined principally for the copper content. The molybdenum is recovered as a byproduct or secondary product during processing of the ore for the recovery of copper. Of the total reserve, 22.3 percent is in this classification.

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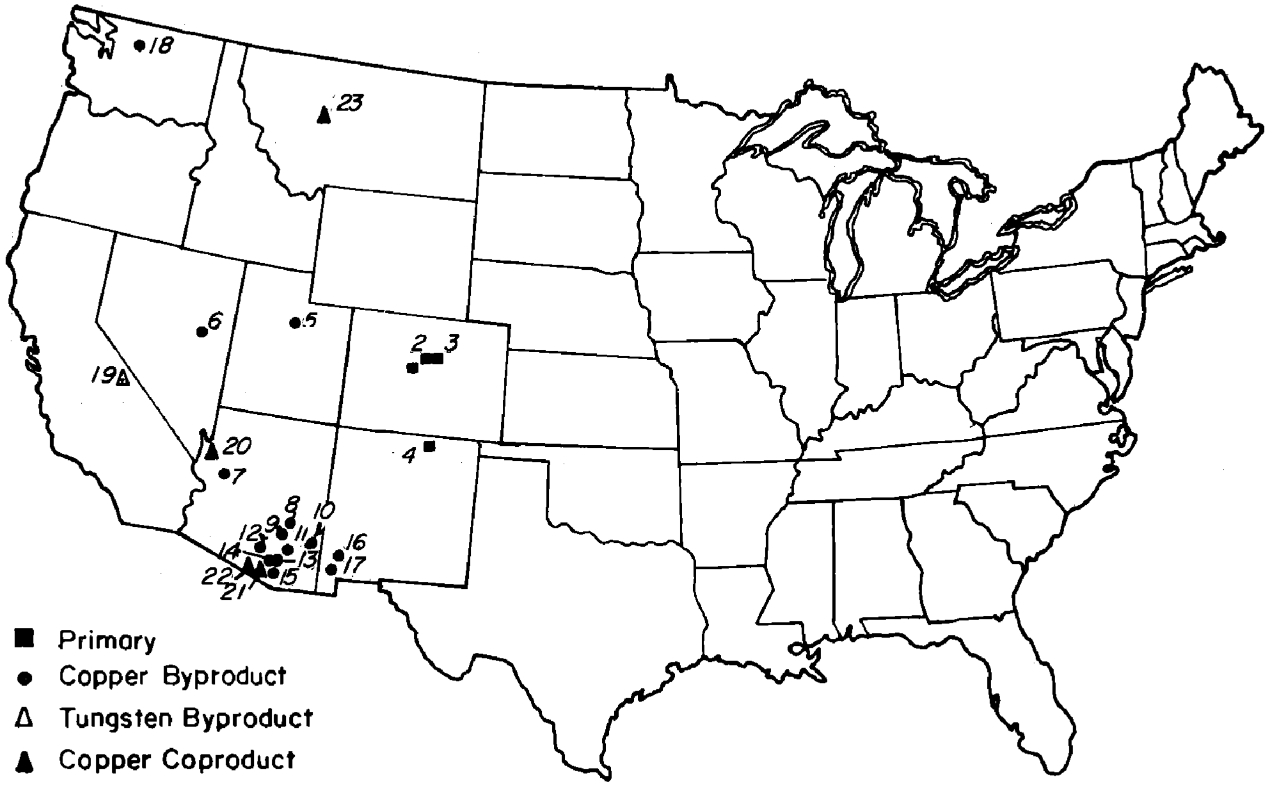
[3] MoS_2, molybdenum disulfide, contains 60 percent molybdenum (Mo).



	DEPOSIT	LOCATION	OWNER
	Primary		
1	Climax	Lake County, Colo.	American Metal Climax, Inc.
2	Urad	Clear Creek County, Colo.	Do.
3	Henderson	Do.	Do.
4	Questa	Taos County, N. Mex.	Molybdenum Corporation of America
	Copper Byproduct		
5	Utah Copper	Tooele County, Utah	Kennecott Copper Corp.
6	Nevada Mines	White Pine County, Ariz.	Do.
7	Bagdad	Yavapai County, Ariz.	Bagdad Copper Corp.
8	Inspiration	Gila County, Ariz.	Inspiration Consolidated Copper Co.
9	Ray	Pinal County, Ariz.	Kennecott Copper Corp.
10	Morenci	Greenlee County, Ariz.	Phelps Dodge Corp.
11	San Manuel	Pinal County, Ariz.	Magma Copper Co.
12	Silver Bell	Pima County, Ariz.	American Smelting and Refining Co.
13	Mission	Do.	Do.
14	Pima	Do.	Pima Mining Co.
15	Twin Buttes	Do.	The Anaconda Company
16	Chino	Grant County, N. Mex.	Kennecott Copper Corp.
17	Tyrone	Do.	Phelps Dodge Corp.
18	Glacier Peak	Snohomish County, Wash.	Kennecott Copper Corp.
	Tungsten Byproduct		
19	Pine Creek	Inyo County, Calif.	Union Carbide Corp.
	Copper Coproduct		
20	Mineral Park	Mohave County, Ariz.	Duval Corp.
21	Esperanza	Pima County, Ariz.	Do.
22	Sierrita	Do.	Do.
23	Mike Horse	Lewis and Clark County, Mont.	The Anaconda Company

FIGURE 10. - Principal Molybdenum Deposits in the United States.

TABLE 4. - *Reserves of molybdenum in the United States*

Type of reserve	Recoverable molybdenum, million pounds	Percent of total reserves
Primary....................	4,220	71.4
Byproduct of copper ores...	1,320	22.3
Others[1]....................	370	6.3
Total.................	5,910	100.0

[1]Includes molybdenum recovered as a coproduct of copper-molybdenum ores, byproduct from tungsten ores, and byproduct of uranium ores.

During 1966 molybdenum was recovered as a byproduct at nine of the 25 leading copper-producing mines including the two largest operations, Utah Copper in Utah and Morenci in Arizona. The Utah Copper mine was surpassed in molybdenum output only by the Climax mine. At two of the 25 leading mines, Ray and Pima in Arizona, equipment was being installed in 1966 to recover molybdenum as a byproduct.

The remaining 6.3 percent of the total reserve consists of three categories classed together as "Others." The most important category of this classification is coproduct reserves of copper-molybdenum ores. In such ores neither copper nor molybdenum exists in large enough quantity for the ore to be mined profitably for the extraction of just one. They do exist in sufficient quantities for the operation to be profitable when both are recovered. For classifying ore containing both copper and molybdenum in the proper reserve classification, a cutoff grade of 0.6 percent copper was used. Ores containing 0.6 percent copper or more were classed as byproduct reserves of copper ores, whereas those containing less than 0.6 percent copper were classed as coproduct reserves of copper-molybdenum ores.

Currently Duval Corp. is mining two such ore deposits with coproduct reserves, Esperanza and Mineral Park in Arizona. Each of these operations was one of the 25 leading copper-producing mines in 1966. At the end of 1967 Duval announced plans for developing the Sierrita copper-molybdenum deposit adjacent to the Esperanza deposit. Tentative plans are for developing this deposit into a 60,000 ton-per-day operation with about 12 million pounds of molybdenum recovered annually.

Another category is byproduct reserves of tungsten ores. The Pine Creek mine in California is the only operation that has such reserves known to contain at least a million pounds of recoverable molybdenum. However, the mine actually contains two types of ore--one, a high-grade tungsten ore containing a small amount of molybdenum that is recovered as a byproduct; and the other, a tungsten-molybdenum ore wherein the tungsten and molybdenum exist in such quantities that both have to be recovered to be profitable. Most of the reserves of molybdenum are in the high-grade tungsten ores. The reserves of the tungsten-molybdenum ore were added to those of the high-grade tungsten ores and the total classed as byproduct reserves of tungsten ores.

The third category is the byproduct reserve of uranium ores consisting mostly of the uraniferous lignites in North and South Dakota. Although the reserves of this category exceed a million pounds they are not considered significant at this time. No single deposit is currently known to contain a million pounds. The two principal producers, Union Carbide Corp. and Kerr-McGee Oil Corp., ceased mining uraniferous lignite in 1967.

In addition to reserves there are other resources of molybdenum in the United States. These consist of mineral-bearing material in known occurrences from which the molybdenum cannot be extracted profitably under present technology. There are numerous such occurrences, mostly in the western part of the United States. Very little is known as to the actual quantity of molybdenum contained in many of these occurrences because exploration work was usually terminated as soon as the occurrence appeared to contain molybdenum that could not be recovered economically. In this report no attempt was made to estimate the quantity of molybdenum in these known occurrences. The latest information, published in 1965 by the Bureau of Mines (7), placed the resources at 10 billion pounds of contained molybdenum.

Two types of resources that may have good possibilities of eventually being developed are (1) those containing oxide minerals of molybdenum in large quantities and (2) the vanadiferous shale deposits in three Western States. Until 1966 molybdenum contained in oxide minerals was not considered economically recoverable, except for that contained in powellite (an oxide mineral containing molybdenum and tungsten) at the Pine Creek mine. In 1965 the Climax Molybdenum Co., a division of American Metal Climax, Inc., constructed a special facility at its Climax mine for recovery of molybdenum in oxide minerals occurring in ore from certain parts of the mine. The hydrometallurgical process developed by the company may open the door for the recovery of molybdenum in oxide minerals at other deposits. Furthermore, under a favorable price the method may possibly be used for the recovery of molybdenum contained in oxide minerals in tailings ponds. At the Climax mine there are about 200 million tons of tailings material that contain some molybdenum in that form. Also, the capping material of the Climax ore body is rich in such oxide minerals and therefore, may eventually be mined.

Molybdenum in small quantities is contained in the vanadiferous shale deposits of Montana, Idaho, and Wyoming. Because of their high vanadium content, these deposits may be eventually mined when an economic process is developed to recover the vanadium. At such time, molybdenum may be recovered as a byproduct.

Foreign

Most of the free world reserves outside the United States are in three countries: Canada, Chile, and Peru. Deposits of commercial significance are known to exist in Australia, Greenland, Japan, Mexico, Norway, Philippines, South Korea, and Turkey; however, these deposits contain relatively small quantities of molybdenum compared to those in Canada, Chile, Peru, and the United States. Although molybdenum mineralization has been noted in some of the African nations, no important deposits have been discovered in Africa.

According to a Canadian Government report (17) on molybdenum deposits in Canada, there are at least 700 known occurrences of molybdenum in Canada. In 1961 molybdenum was recovered from only one deposit, whereas in 1966 it was recovered from eight deposits. Since 1962 exploration for molybdenum has been conducted on a large scale in Canada. This work and that previously done probably resulted in the discovery of about 750 million pounds of recoverable molybdenum. Exploration currently being done can be expected to find another 250 million pounds of recoverable molybdenum, providing the same success ratio is achieved.

Chile ranks second to the United States as having the largest free world reserves. Nearly all the known reserves are tied to the three largest copper mines--Chiquicamata, El Teniente, and El Salvador. Based on copper ore reserves stated in a 1966 mining magazine article (15) on Chilean copper and the current recovery of molybdenum at these mines, the deposits should contain at least 1.7 billion pounds of recoverable molybdenum. The reserve figure only includes molybdenum recoverable from the sulfide mineral, molybdenite (MoS_2). The copper ores also contain some molybdenum oxide minerals; and, according to a statement in the chapter on Chile in the Bureau of Mines 1964 Minerals Yearbook, these minerals may contain about the same quantity of molybdenum in the ore as that of the sulfide mineral. The molybdenum in the oxide minerals therefore represents a significant resource, and possibly some day the molybdenum may be recovered from them with new technology.

In Peru molybdenum is recovered as a byproduct only at the largest copper operation, Toquepala. Another low-grade copper deposit, Cuajone, near Toquepala is in the planning stage for development. These two deposits, controlled by the same company, have an estimated combined total of about 1 billion tons of ore reserves. Based on current molybdenum recovery at Toquepala, these deposits contain at least 125 million pounds of recoverable molybdenum.

Very little reliable information is available about the molybdenum reserves and resources in the Communist countries. Red China, North Korea, U.S.S.R., and Yugoslavia have deposits containing molybdenum, but reserves of these deposits are unknown. Reserves of deposits of Yugoslavia and North Korea are considered minor. Information about Russian deposits indicates reserves are substantial. Most of the molybdenum obtained in Russia is believed to come from copper ores. Some of the copper ores supposedly contain as much as 0.2 percent MoS_2--about three times greater than that contained in the highest grade copper-molybdenum ores in the United States. Prior to the takeover of the mainland by the Red Chinese, China reserves were principally in one deposit. However, the Red Chinese are reported to have found some large primary molybdenum deposits according to a 1958 Russian publication (1) about China's natural resources. The publication also claimed that explored reserves of molybdenum placed Red China second to the United States in world reserves.

ORE EXTRACTION PRACTICES

Mining

Primary Operations

Because of the low grade of most primary molybdenum deposits, the high tonnage producing mining methods--block-caving or open-pit--are necessary to extract the ore profitably. Three primary deposits were mined in 1967--Questa of Molybdenum Corporation of America in New Mexico and Climax and Urad of Climax Molybdenum Co. in Colorado. In 1966 only Climax and Questa were mined; Urad entered the production stage in mid-1967.

The Climax molybdenum deposit is the largest one in the world presently known. Ore occurs within a porphyry stock, around its fringes, and above its extremities. At depth the stock is a single body but in the upper part of the mine (above the Storke level) it divides into two separate masses. The size of the deposit is reflected in the following statement taken from the 1966 annual report of the American Metals Climax, Inc., of which Climax Molybdenum Co. is a division:

> "While the full extent of the ore body has not been fully defined, the current proven ore reserves of the Climax mine, commercially minable under present economic conditions, are calculated at 420,000,000 tons, sufficient to sustain the present scale of mining for approximately 30 years."

Since the opening of the Climax mine in 1916, slightly more than 200 million tons of ore has been mined to date. The grade of ore mined has slowly decreased over the years. Today the average grade is near 0.30 percent MoS_2; no material under 0.20 percent MoS_2 is taken currently because this is considered the lowest grade that can be extracted profitably under present operational conditions.

The block-caving method is used for mining the ore body; this method lends itself to producing at the highest rate of all underground mining methods devised to date. The Climax mine is one of the largest underground mines in the world, based on ore tonnage produced. In 1966 a record of 15.2 million tons was produced or 850,000 tons more than the previous high set in 1965. The average daily output of ore mined in 1966 was approximately 42,300 tons; the mine was operated on a 7-day-a-week basis. Molybdenum production for 1966 was stated in the company's 1966 annual report as 56.3 million pounds.

Questa was originally considered a vein-type deposit from which only the high-grade ore could be mined by underground mining methods, usually cut-and-fill stoping. Although some ore was extracted a few years prior to 1923, mining on a regular basis started in 1923 and at that time a mill was constructed at the property. Production seldom exceeded 50 tons per day. Some ore contained as much as 40 percent MoS_2; however, the grade of the ore usually varied from 3 to 8 percent MoS_2. High operating costs for the selective mining of the many discontinuous veins caused the operation to shut down in 1956.

After considerable exploration work and evaluation in the late 50's and early 60's by Molybdenum Corporation of America, an open-pit mine was planned and developed. According to the company's 1964 annual report, ore reserves for this operation were estimated to be 20.5 million tons averaging 0.297 percent MoS_2 using a cutoff grade for mining at 0.13 percent MoS_2. Ore production commenced from the open-pit operation in 1965. In the early part of 1967 the mining operation was producing so much ore that slightly more than 11,000 tons per day was milled, or, about 1,000 tons per day more than the designed mill capacity of 10,000 tons. Molybdenum Corporation of America objective for 1967 is to recover 10 million pounds of molybdenum. During the time the Questa deposit was operated as an underground mine (1923 through 1956), approximately 11 million pounds of molybdenum was reportedly recovered or 1.1 times the company's 1967 objective.

The Urad deposit consists of vein systems in altered granite. The deposit was first mined during World War I, but the operation only lasted a short time. The next time the mine attained production was during World War II; most of the output came at that time. During these two periods, the deposit was mined by the shrinkage-stope method with only the higher grade parts of the veins removed. In 1960 American Metal Climax, Inc., obtained a lease and option agreement from the owner, Vanadium Corporation of America. After considerable exploration Climax exercised its option in 1963 and purchased the property for $2 million.[4] Data obtained from the exploration indicated that a low-grade deposit of 13 million tons of 0.35 percent MoS_2 existed and could possibly be mined by the block-caving method. In 1964 the company undertook development of the property. The operation was designed to produce 5,000 tons of ore per day with an annual recovery of 7 million pounds of molybdenum. After nearly 3 years of development, the operation entered the production stage in mid-1967.

Byproduct Copper Operations

The deposits from which molybdenum is recovered as a byproduct in the United States are mostly the large low-grade copper deposits mined either by block-caving or open-pit methods. Of the nine copper mines in 1966 at which molybdenum was recovered as a byproduct, only the San Manuel mine in Arizona used the block-caving method. Ore milled in 1966 at San Manuel was 14.3 million tons and that at the eight open-pit mines varied from 2.1 million tons to 33.5 million tons. Table 5 lists the nine copper mines according to their 1966 molybdenum output and shows the quantity of copper ore milled at each operation; the total quantity of ore milled at the nine operations represents 54 percent of all the copper ore sold or treated in 1966. Because some companies prefer to keep their individual data confidential the amount of molybdenum recovered at each operation is not shown. In 1966, 21.5 million pounds of molybdenum was recovered from the nine copper mines; the quantity represents 23.6 percent of the total molybdenum shipped from mines having molybdenum production.

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[4]American Metal Climax, Inc. 1963 Annual Report, p. 5.

TABLE 5. - *Copper mines in the United States at which molybdenum was recovered as a byproduct during 1966--ranked according to molybdenum production*

Rank	Mine	Location	Operator	Copper ore milled, million tons
1	Utah Copper.	Utah......	Kennecott Copper Corp..............	33.5
2	San Manuel..	Arizona...	Magma Copper Co....................	14.3
3	Chino.......	New Mexico	Kennecott Copper Corp..............	8.1
4	Mission.....	Arizona...	American Smelting and Refining Co..	6.0
5	Nevada Mines	Nevada....	Kennecott Copper Corp..............	7.6
6	Bagdad......	Arizona...	Bagdad Copper Corp.................	2.1
7	Silver Bell.	..do......	American Smelting and Refining Co..	3.6
8	Inspiration.	..do......	Inspiration Consolidated Copper Co.	6.4
9	Morenci.....	..do......	Phelps Dodge Corp..................	19.3
	Total....	....	....	100.9

Of the copper mines shown in table 5, Utah Copper has the earliest history of molybdenum production, dating from 1936. Chino's production dates from 1937; Nevada Mines, 1941; and Bagdad's, 1944. Production from the other mines does not date back past 1951.

Coproduct Copper Operations

Only two operations, Esperanza and Mineral Park of Duval Corporation in Arizona, have produced molybdenum as a coproduct from deposits containing copper-molybdenum ores. Both of these operations are recent developments. Esperanza began operations in 1959 and Mineral Park in 1964. Mining is done by the open-pit method. In 1966 the company stated in its annual report that 3.9 million pounds of molybdenum was recovered from the two operations.

Byproduct Tungsten Operations

In the past few years only one mine, Pine Creek of Union Carbide Corp. in California, has been the principal source of molybdenum recovered as a byproduct from tungsten ores. The Pine Creek ore deposit is a contact zone between an igneous rock and a metamorphic rock. Five ore bodies make up the deposit. All except one have been exploited by open pits at their outcrop; three have been developed by underground methods. Currently the production comes from underground. Most of the ore is mined by sublevel stoping and the balance by shrinkage stoping. Tungsten is the main product but substantial quantities of molybdenum and copper and some gold and silver are also obtained from the ore. The molybdenum content decreases with depth. Some of the ore mined could be classed as coproduct because tungsten and molybdenum are the principal constituents. In the other ore the molybdenum is a byproduct. Mining began about 1917 and continued intermittently until 1936 when the mine was purchased by the U.S. Vanadium Corp. (now part of Union Carbide Corp). After considerable exploration and development work, the mine was placed in operation in 1939 and has been worked ever since. Current production is slightly more than 1,000 tons per day.

Byproduct Uranium Operations

The first quantity of molybdenum recovered from uranium ore was reported in 1964. At that time molybdenum was recovered from uraniferous lignite mined in South Dakota. Since then, molybdenum has been recovered from this type of uranium ore in North and South Dakota. The open-pit method was used. After overburden was removed, the exposed lignite was either burned in place or removed and sent to kilns for burning. The lignite ash in either case is sent to uranium mills where both its contained uranium and molybdenum are extracted. In 1966, 34,000 pounds of molybdenum was recovered from uraniferous lignite by three companies.

Milling

Until 1966 only molybdenum in the sulfide mineral, molybdenite, was recovered from primary deposits. In 1966 Climax Molybdenum Co. started to recover molybdenum in molybdenum oxide minerals contained in the ore of the Climax mine. At the byproduct and coproduct copper operations, only molybdenum in molybdenite is recovered whereas at the byproduct tungsten operation at the Pine Creek mine, molybdenum in molybdenite and in the oxide mineral, powellite, is recovered.

At all operations recovering molybdenum the mined ore is sent to a mill where it usually undergoes crushing, grinding, classification, flotation, filtration, and drying, with the end product being a molybdenite concentrate. However, at the Climax and Pine Creek plants, additional processing steps are used for recovery of the molybdenum in the oxide minerals. At some of the byproduct and coproduct operations the molybdenite concentrate is further processed by roasting, resulting in a molybdic oxide concentrate. In the case of molybdenum contained in lignite ash sent to uranium mills, the ash is usually mixed with other uranium ores for processing. During the recovery of uranium the molybdenum is removed and is usually contained in a calcium molybdate, ammonium tetramolybdate, or ammonium phosphomolybdate concentrate.

Recovery of molybdenum from ores ranges usually from 50 to 90 percent. The primary and coproduct operations usually have the highest recovery; however, some of the byproduct operations have achieved recoveries as high as 85 percent.

COST OF EXTRACTION

The cost of producing the first salable product, which can be either molybdenite or molybdic oxide concentrate, varies according to the mining and milling methods employed. At operations using similar methods, costs may vary because of local physical characteristics (size, shape, and depth) of the ore body and the type of ore (mineralogical composition) in the deposit.

Mining and Milling

Distribution of mining and milling costs is complicated when more than one recoverable product is contained in ore. In evaluating a molybdenum deposit for a new mine-mill venture that will have byproducts recovered, mining and milling costs are not usually broken down for individual recovered products. In the case where a new unit is to be installed to recover a byproduct at a prevailing operation, usually none of the existing mining and milling costs are charged to the recovery of the byproduct. However, if the existing mining and milling operations have to be altered for recovering the byproduct, the cost incurred due to the alteration could be chargeable to the byproduct. For example, additional grinding may be required for the recovery of the byproduct and, therefore, the cost of the additional grinding could be charged to the recovery of the byproduct.

In the case where molybdenum is a coproduct, molybdenum and the other coproduct(s) usually are allotted a proportionate share of the mining and milling costs. As in the case of molybdenum obtained as a byproduct, the normal practice would be to charge only the cost of operating the molybdenum recovery circuit against the molybdenum. Where molybdenum is the only product recovered from an ore, then all costs are charged against the molybdenum.

Table 6 lists the mining methods and shows the variation of the direct mining cost of each method under most conditions. Nearly all of the ores from which molybdenum is recovered are mined by either the block-caving or open-pit method.

TABLE 6. - *Direct mine operating costs for various mining methods, period 1955-59*[1]

Mining method	Amount mined per month, tons[2]	Direct mining costs per ton[3]			Labor, percent of total cost[4]
		High	Low	Average[4]	
Underground:					
Square setting............	439,330	$18.72	$6.22	$10.20	71.2
Cut and fill..............	585,300	14.73	3.07	6.69	56.7
Shrinkage.................	305,820	8.12	1.75	3.92	([5])
Room and pillar (trackless type)...................	733,220	2.41	1.16	2.05	43.7
Sublevel stoping..........	1,547,410	4.71	1.06	2.37	56.9
Sublevel caving...........	118,150	([5])	([5])	4.97	63.3
Block caving..............	1,803,150	2.25	1.15	[6]1.41	54.2
Open pit[7]...................	5,198,060	1.15	.21	.32	36.4

[1]Reference 3.
[2]Total aggregate tonnage of ore mined each month except for open pits (see footnote 7).
[3]Includes exploration and development, stoping, haulage, hoisting, pumping, and general underground and surface costs.
[4]Weighted average on the basis of tons produced from each mine.
[5]Not available.
[6]This average may be on the high side due to lack of information covering a number of efficient operations.
[7]Cost is per ton of "material" and is based on total tons of ore and waste handled.

Direct milling costs for recovering molybdenum are estimated to range from about 5 cents to $1.25 per ton of ore processed, depending on the class of ore treated. In most instances the primary ores have the higher cost and the ores from which molybdenum is recovered as a byproduct, the lower cost. The ores from which molybdenum is recovered as a coproduct usually have a cost somewhere between the high and low costs.

In a hypothetical example set forth in an article (6) in a 1961 Colorado School of Mines publication about the extraction of molybdenum as a byproduct from a copper mine, the indicated profit from molybdenum was 8.9 cents per ton of ore. Daily input to the mill was 20,000 tons of copper ore averaging 0.02 percent MoS_2, of which 50 percent or 2,400 pounds of molybdenum was recovered. The cost of recovering the molybdenum was $1,220 per day including an amortization cost of $200 and an expense of $80 due to copper losses from recovering the molybdenum from the copper concentrate. The total milling cost per pound of recovered molybdenum figured out to be 50.8 cents and the direct milling cost (excluding amortization and the expense for loss of copper) 39.2 cents. The total milling cost per ton of ore for recovering molybdenum was 6.1 cents and the direct cost 4.7 cents.

For primary deposits, either mined by open pit with 3-to-1 or lower stripping ratio or by block caving, the direct mining and milling costs should be between $1.50 to $2.50 per ton of ore. For an operation with 0.25 percent MoS_2 (5 pounds MoS_2 per ton) and with a recovery of 85 percent, the cost per pound of recovered molybdenum would be from 59 cents to 98 cents. However, if the grade had been only 0.20 percent MoS_2, then the cost would be between 73 cents to $1.22 per pound of recovered molybdenum.

The cost of recovery of molybdenum as a coproduct would depend on both the mining methods and products recovered. The producer's chief concern is that the overall operation is profitable. As an example, consider a copper-molybdenum deposit containing 0.4 percent copper and 0.07 percent MoS_2 with 80 percent of the copper and 75 percent of the molybdenum recoverable. Assume the deposit can be mined by the open-pit method with a stripping ratio of 3:1 (waste to ore). Direct mining costs per ton of ore mined, including the cost of mining waste, should be between 90 cents to $1.30 and direct milling costs from $1.00 to $1.50. The direct cost of production (mining and milling) would be between $1.90 to $2.80 per ton of ore mined. Using the 1967 average price for copper of 38 cents per pound and for molybdenum (in concentrate) of $1.62 per pound, the recovered value per ton would be $2.43 for the copper and $1.02 for the molybdenum for a total value of $3.45. The copper value would be less than the highest production cost ($2.80), but greater than the lowest production cost ($1.90). However, if the production cost was $1.90, the total cost would probably exceed the copper value because of other expenses, including smelting and refining, amortization, and taxes.

The molybdenum value from the coproduct operation would be about 30 percent of the total recovered value. This also can be considered as a share of the direct cost for molybdenum. Therefore, the cost of recovery of molybdenum would be between 71 cents and $1.19 per pound.

Where molybdenum occurs with tungsten, much higher costs can be expected. The tungsten deposits found so far that contain molybdenum require expensive underground mining methods to extract the ore. The separation of molybdenum from the tungsten-molybdenum ore is more complex than from the copper-molybdenum ore and, consequently, milling costs are higher.

Capital Investment

Most of the molybdenum output in the world comes from mines at which large tonnages of ore are produced. Preparation of the deposit for production requires considerable capital investment. Table 7 shows information published in company annual reports or as news articles in magazines and newspapers about the capital investment required for some recent molybdenum projects either under construction or in the operational stage.

TABLE 7. - *Capital investment of recent molybdenum projects*

Company	Location	Investment, millions	Type of project	Capacity (recoverable molybdenum), million lb/yr	Status	Remarks
Under construction:						
The Anaconda Co..	Twin Buttes Project, Tucson, Ariz.	$60	Mine-mill.	Unknown...	On stream 1968.	Open pit and between 30,000 to 40,000 tpd mill. Molybdenum to be recovered as a byproduct from copper ore.
Phelps-Dodge Corp.	Tyrone, N. Mex.	100	....do....	...do.....	On stream 1969.	Open pit and initially 25,000 tpd mill. Molybdenum to be recovered as a byproduct from copper ore.
Climax Molybdenum Co.	Henderson Project, Empire, Colo.	5	Shaft and initial drifting.	...do.....	Completed 1970.	23-foot-diameter shaft; 2,350 feet deep. Tentative plans are for developing a 30,000 tpd operation capable of producing 50 million pounds of molybdenum annually in the mid-1970's.
Duval Corp.......	Sierrita Project, Tucson, Ariz.	151	Mine-mill.	12........	On stream 1969.	Open pit and 60,000 tpd mill. Molybdenum to be recovered as a coproduct from copper-molybdenum ore.
Brenda Mines,Ltd.	Peachland, B.C., Canada.	60	....do....	8 to 12...	..do...	Open pit and 24,000 tpd mill. Molybdenum to be recovered as a coproduct from copper-molybdenum ore.

Note: tpd = tons per day.

TABLE 7. - *Capital investment of recent molybdenum projects*--Continued

Company	Location	Investment, millions	Type of project	Capacity (recoverable molybdenum), million lb/yr	Status	Remarks
Operational:						
Endako Mines, Ltd.	Fraser Lake, B.C., Canada.	$5	Expansion.	12........	On stream 1968.	Increase mill feed from 15,000 tpd to 22,000 tpd to allow lowered cutoff grade to maintain minimum production of 12 million lb of molybdenum per year.
British Columbia Molybdenum, Ltd.	Alice Arm Area, B.C., Canada.	20	Mine-mill.	4.5.......	..do...	Investment includes cost of wharf pit, 6,000 tpd mill, and townsite; additional $0.9 million spent on exploration during 1960-63.
Pima Mining Co...	Pima mine, Tucson, Ariz.	1	Molybdenum recovery circuit.	0.6.......	..do...	Molybdenum recovered as a byproduct from copper ore.
Kennecott Copper Corp.	Ray mine, Hayden, Ariz.	1	....do....	0.9.......	..do...	Do.
Climax Molybdenum Co.	Urad project, Empire, Colo.	25	Mine-mill.	7.........	On stream 1967.	Underground mine and 5,000 tpd mill. Acquisition cost of $2 million not included in investment.
Do.........	Climax, Colo.	20	Moly-oxide recovery plant.	3.........	On stream 1966.	Investment includes $2 million spent on research for developing process for recovery oxide molybdenum in ore. Plant handles 5,700 tpd of select ore.
Molybdenum Corp. of America	Questa, N. Mex.	40	Mine-mill	10........	..do...	Open pit and 10,000 tpd mill. Cost is of a 3-year program of exploration, development, and construction.
Red Mountain Mines, Ltd.	Rossland, B.C., Canada.	2	....do....	0.4.......	..do...	Open pit and 400 tpd mill.

Note: tpd = tons per day.

OUTLOOK FOR DEMAND AND SUPPLY

Previous Predictions

Before making projections of demand and supply of molybdenum, it may be worthwhile to discuss some of the previous forecasts made by authoritative sources and see how they have fared. One of the earliest predictions after World War II was made in 1952 by the President's Material Policy Commission in the Paley Report (13). In 1957 the Bureau of Mines published a comprehensive report about molybdenum (11). An estimate of reserves was stated in the report; this estimate was later the basis for many other predictions. Although consumption was discussed in detail, no prediction of future consumption was mentioned. In 1959 the Materials Advisory Board issued a report on molybdenum with estimates of reserves and a projection of consumption (12). In 1963 a nonprofit organization--Resources for the Future, Inc.--discussed the molybdenum outlook in their book about the future of natural resources in the United States (9). Later the Bureau of Mines in "Mineral Facts and Problems" (7), stated an estimate of reserves and resources and showed projections of production and consumption. Not always evident in non-Bureau reports is what the consumption figures represented. However, because Bureau of Mines data were used, it can be determined whether the consumption figures were quantities of molybdenum contained in concentrate or products by checking the information in the molybdenum chapter of the Bureau of Mines Minerals Yearbooks.

Paley Report (1952)

On January 22, 1951, the President created the Material Policy Commission to study the materials problem of the United States. He later charged the Commission also with the task of studying the Nation's material position as related to other free and friendly countries. On June 2, 1952, the Commission submitted a report of the results of its studies; the report, officially entitled Resources for Freedom but better known as the Paley Report, consisted of five volumes.

In volume 2, Outlook for Key Commodities, the projected 1975 demand of molybdenum for the United States is shown as 70 million pounds and the projected increase over 1950 (consumption) stated as 170 percent (13, table 3, p. 26). This means the yearly growth was expected to be 1.76 million pounds. The consumption of molybdenum in the United States in 1950 is shown as 26 million pounds and the primary production as 28 million (13, table 2, p. 26). These consumption and production figures correspond to the 1950 production and consumption quantities of molybdenum contained in concentrates.

Figure 11 shows the actual consumption of molybdenum contained in concentrates for the 1946-66 period and the projection of consumption from 1950 to 1975 as stated in the Paley Report. For the period 1951-63 the projection can be considered as accurate. The actual consumption for the 13-year period was 488.9 million pounds whereas the consumption predicted by the projection was 498.2 million pounds or only 2 percent above the actual consumption. After 1963 the projection is considerably lower than the actual consumption.

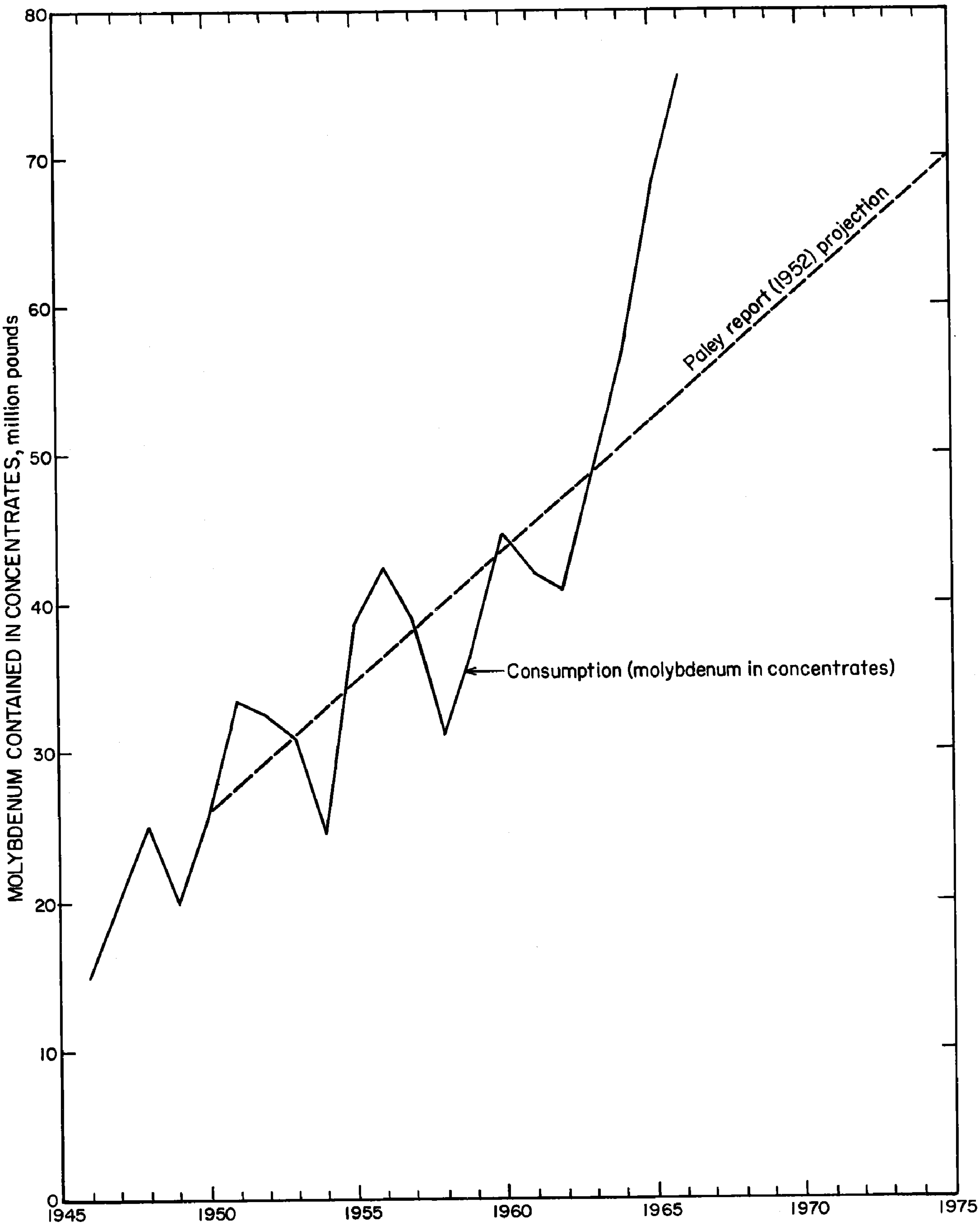

FIGURE 11. - Comparison of the Paley Report Projection of U.S. Consumption of Molybdenum for the 1951-75 Period and the Actual Consumption for the 1946-66 Period.

Materials Advisory Board Report (1959)

The U.S. Department of Defense in October 1957 requested the National Academy of Science to do a study of refractory metals. Two years later, the Committee on Refractory Metals of the Materials Advisory Board, which undertook the study for the Academy, submitted a report of their findings. Volume 2--Panel Reports (12, pp. 111-153) contains a chapter on molybdenum. In the section of the chapter about raw materials, estimates for 1958 through 1968 of annual productive capacity by expected producing countries are shown (12, table 4, p. 124). Notably missing from the list of countries is the Soviet Union. Predicted quantities are notably different from actual production for Canada, Chile, and Peru; Canada and Peru were underestimated and Chile overestimated. Total predicted production for the 1958-66 period for the major producer, United States, is only 1.7 million pounds greater than total actual production, 576.6 million pounds. Until 1966 yearly predictions are relatively close for total production of the free world nations. For 1966 the estimate for the countries was 88.5 million pounds whereas actual production was 126.0 million pounds. For the other 2 years, 1967 and 1968, differences probably will be even greater.

Consumption of molybdenum (contained in concentrates) in the United States for the 1958-68 period in the form of a projection was also shown in the chapter (12, fig. 5, p. 126). The projection was based on the assumption that average annual rate of increase for the 11-year period will be the same as that of the 11 years prior to 1958. Figure 12 shows the projection and actual consumption. Yearly estimates of consumption for 1958 through 1964, based on the projection, are higher than actual consumption except for 1960 and 1963 when estimates corresponded with the actual figures. After 1964, yearly estimates are much lower than actual consumption. The 1966 estimate is about 19 million pounds less than the actual consumption of 75.5 million pounds. The 1967 and 1968 estimates will probably be off as much or more.

Bureau of Mines Report (1965)

In the molybdenum chapter of the Bureau of Mines "Mineral Facts and Problems, 1965 Edition," the outlook for molybdenum is discussed (7, pp. 605-606) and projected production and consumption of molybdenum in the United States are shown from 1963 to 2000 (7, fig. 2, p. 604). Production is shipments of molybdenum contained in concentrates and consumption is shipments to domestic customers of molybdenum contained in primary products. Figure 13 shows the projections and actual production and consumption from 1950 through 1966.

Production from 1963 to 1970 was estimated on expected developments. From 1970 the projected production was based on a 1.2-percent growth rate. It was stated that at this rate the known commercial reserves of 3.7 billion pounds would be depleted within 30 years.

As can be seen in figure 13, the production of 90 million pounds forecast for 1970 was attained in 1966. This resulted from the expected developments taking place in 3 years instead of 7 years. Expansion at the Climax and Utah

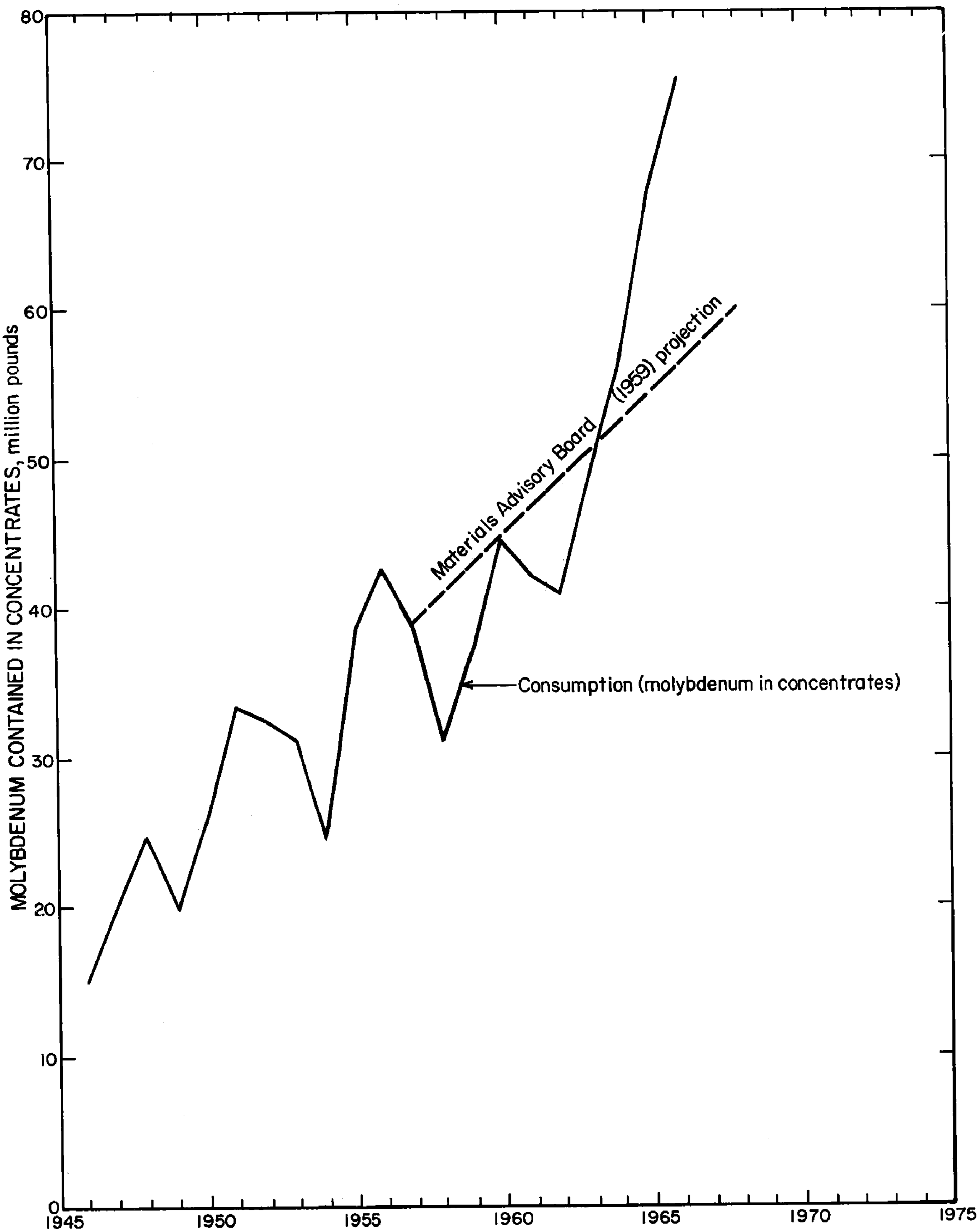

FIGURE 12. - Comparison of the Materials Advisory Board Projection of U.S. Consumption of Molybdenum and the Actual Consumption for the 1946-66 Period.

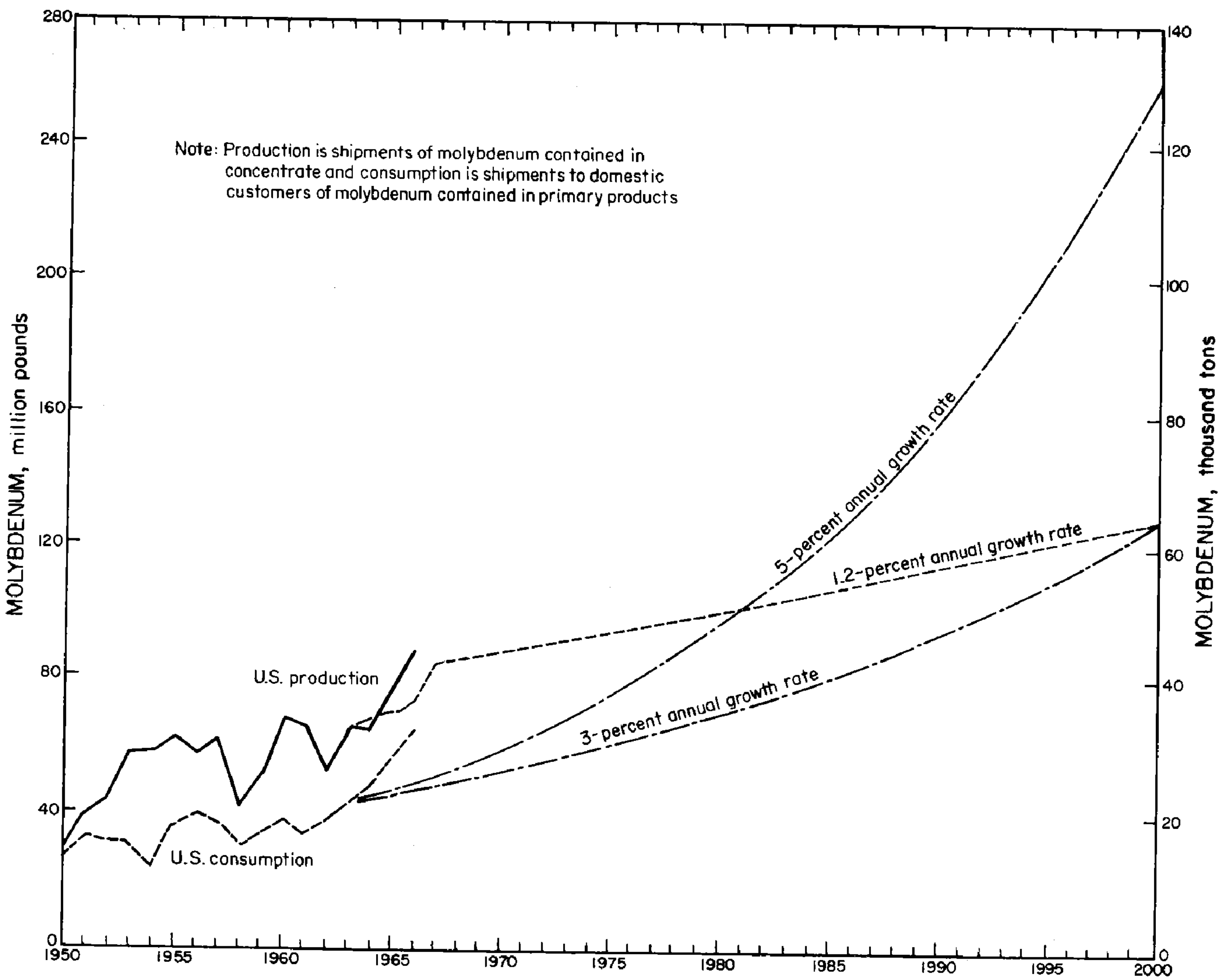

FIGURE 13. - Projected Production and Consumption of Molybdenum in the United States As Shown in Bureau of Mines Bulletin 630 With the Production and Consumption for the 1964-66 Period Added.

Copper mines and the development of the Questa mine into the production stage during the 1963-66 period alone resulted in an increase in production for 1966 of 21 million pounds over the 65.8 million pounds produced in 1963. Increases at the copper operations in Arizona were responsible for nearly all of the balance.

The two projections of consumption, using either a 3-percent or 5-percent growth rate, that are shown were based on a relationship between molybdenum consumption and gross national product (GNP) in 1958 dollars. From the end of World War II to 1964, domestic consumption had averaged a 5-percent growth rate while GNP had averaged slightly more than 3.5 percent. It was assumed that if this relationship held, and a GNP growth rate of about 3.75 percent was anticipated, future growth of molybdenum consumption could be expected to increase by 3 percent and probably by 5 percent annually as long as it was readily available at a real price only slightly higher than in 1964. Instead of 3 percent or 5 percent, the annual growth rate of consumption between 1963 and 1966 was 15 percent and the annual growth rate of GNP was 5.5 percent instead of 3.75 percent.

Resources for the Future, Inc., Report (1962)

Resources for the Future, Inc. (RFF), is a nonprofit corporation for research and education in the development, conservation, and use of natural resources. It was established in 1952 with the cooperation of the Ford Foundation and its activities since have been financed by grants from that foundation. In 1963 RFF published the results of its study of future demands of natural resources for sustaining economic growth to the year 2000 (9). As stated in the preface, "the core of the book is the projection of demand and supply of natural resources--their products and services as well as the basic land, water, and minerals--to the year 2000 for the United States."

In discussing the reserves of molybdenum in the United States, reserve figures published in the molybdenum chapter of the Bureau of Mines 1960 edition of "Mineral Facts and Problems" (10), are quoted. Recoverable molybdenum reserves in the United States, Canada, and Chile were stated to be about 4 billion pounds with the U.S. deposits alone estimated at 3 billion pounds. After discussing the reserves of the Climax mine, deposits in Chile and Canada, and the Questa deposit in New Mexico, RFF states that the 4 billion pounds appears to be a conservative estimate and the reserves of the non-Communist countries would be around 6 billion pounds.

Since 1960 and through 1966, the United States has produced 416 million pounds which would reduce the 3-billion-pound estimate of reserves stated by the Bureau of Mines to 2.6 billion pounds. However, mainly due to the discovery of the Henderson deposit and additional reserves determined at the Climax mine and at some new copper deposits since 1960, the estimate of the U.S. reserves is now about 5.9 billion pounds of recoverable molybdenum and those in Chile, Canada, and Peru near 2.9 billion pounds making the total reserves of these four countries about 8.8 billion pounds.

In a table of projected consumption of molybdenum, U.S. total domestic consumption is shown for 1960 and low, medium, and high estimates are given for the years 1970, 1980, 1990, and 2000 (9, table A16-A26, p. 895). The total estimates for the future years were derived from low, medium, and high estimates made of molybdenum consumption for four end-use categories--alloy steel, ferrous castings, chemical industry, and molybdenum metal and alloys. The 1960 consumption figure is the consumption of molybdenum by end use reported by consumers of primary products. Figure 14 shows the same type of consumption figures from 1956 through 1966 and the low, medium, and high projections to 2000 based on RFF's estimates for 1970, 1980, 1990, and 2000. Actual consumption for 1961, 1962, and 1963 was between the low and medium projections; for 1964 it was the same as that of the medium projection; and for 1965 and 1966 it was between the medium and high projection. Overall it appears that the actual consumption tends to follow the medium projection.

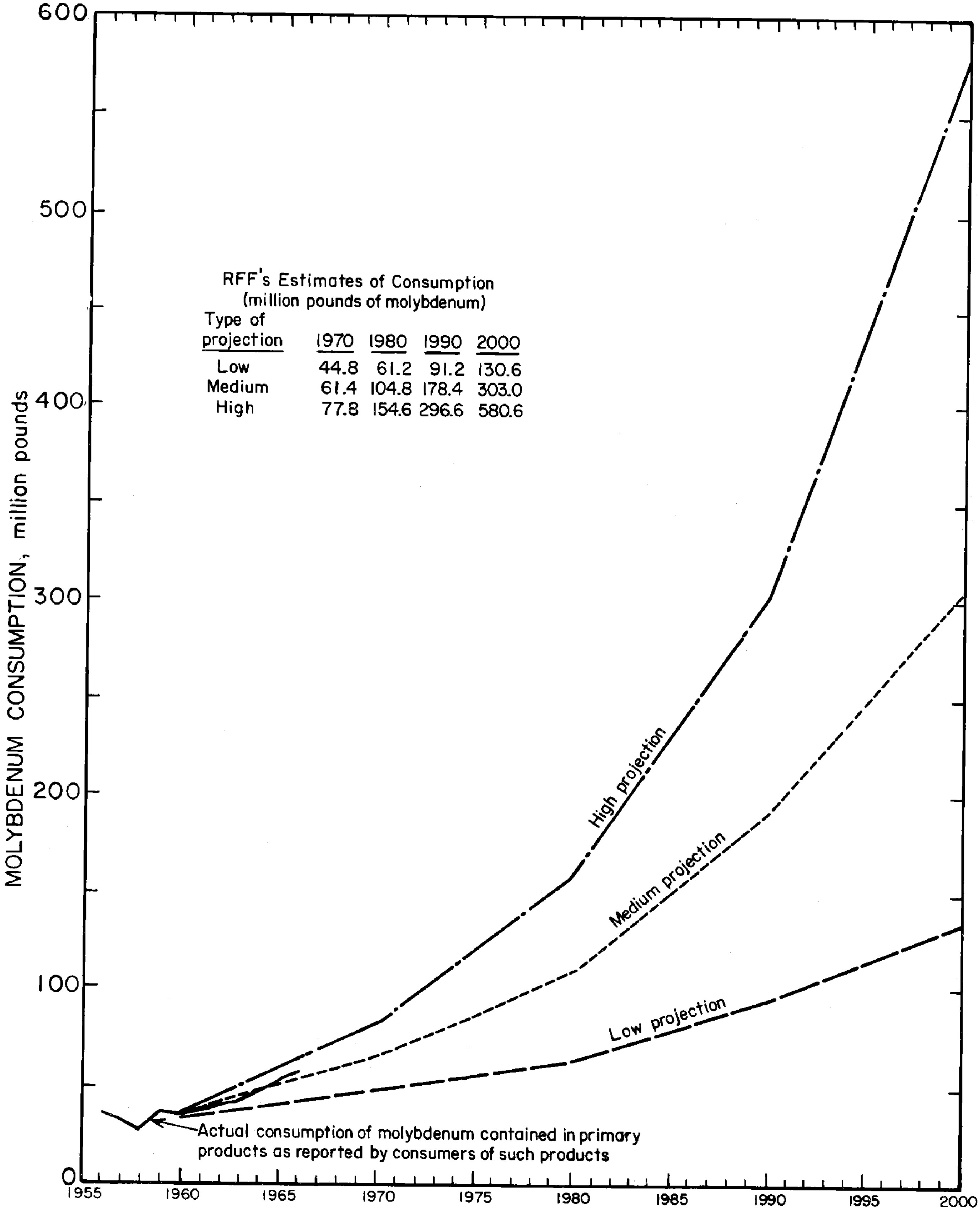

FIGURE 14. - Resources for the Future, Inc. (RFF) Projections of U.S. Consumption of Molybdenum and the Actual Consumption for the 1956-66 Period.

Future Demand

Methods of Determining Future Demand

Future demand of molybdenum in the United States was studied from more than one approach for this report. Because of two possible measurements of consumption, projections were made for each type of consumption. The measurements of consumption are:

SDCMP--shipments to domestic customers of molybdenum in molybdenum products.

CMPEU--molybdenum in molybdenum products consumed by end uses.

The unit of measurement for each type of consumption is million pounds of molybdenum.

The first and simplest approach was to use trend lines based on periods of time. Figure 15 shows two trend lines based on time series for SDCMP and figure 16 shows two for CMPEU. The trend lines were determined as follows:

Based on 1956-66 data; for 1956, X = 0

(1) SDCMP = 29.962 + 2.693X; r^2 = 0.7430[5]
(2) CMPEU = 25.646 + 2.176X; r^2 = 0.7455

Based on 1960-66 data; for 1960, X = 0

(3) SDCMP = 34.530 + 4.475X; r^2 = 0.8959
(4) CMPEU = 29.427 + 3.604X; r^2 = 0.9526

Trend lines for the 1960-66 period probably are more indicative of the near future demands than those developed based on the 1956-66 period because the 1958 recessional period had a significant impact on the consumption of molybdenum. The near-future demands based on the 1960-66 trend line should only be good for 1967 and up until the end of the Vietnam conflict, providing no other conflicts arise. A year or two after the termination of hostilities, a drop or a leveling off in consumption should take place. After this 1- or 2-year period, the consumption until 1975 may be between the two trends which would place it between 81.1 million and 101.7 million pounds for SDCMP and between 67.0 million and 83.5 million pounds for CMPEU.

Table 8 shows the production of various steels and the two categories of consumption of molybdenum. Correlation and regression analyses were made on various combinations of the steel categories and consumptions of molybdenum to find out whether there are some definite relationships and, if so, which are the best relationships that could be used for predicting future domestic

[5] r^2 is the coefficient of determination; it expresses the percentage (in decimal form) of variation in the dependent variable which is explained by the independent variable.

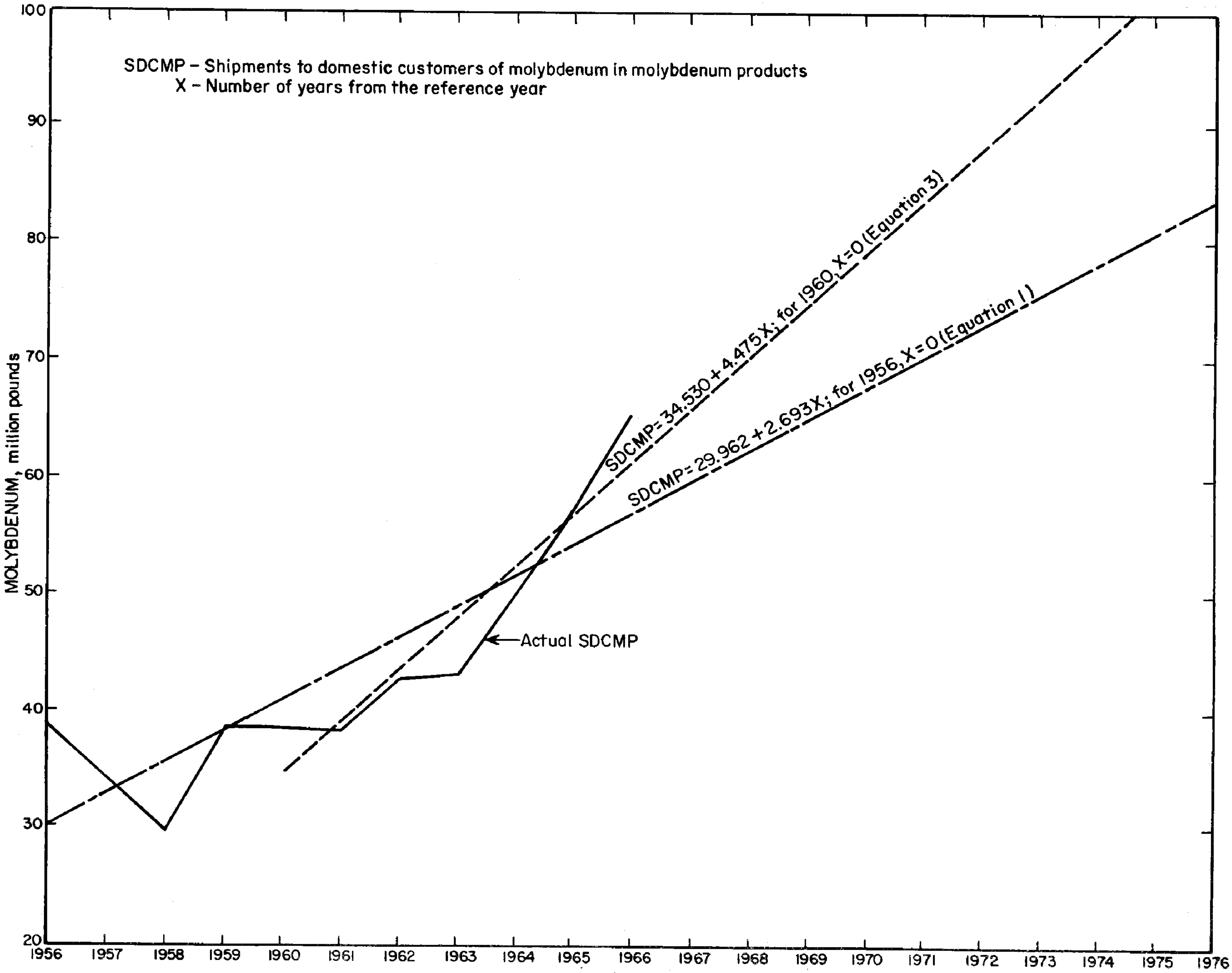

FIGURE 15. - Trend Lines of SDCMP Based on Time.

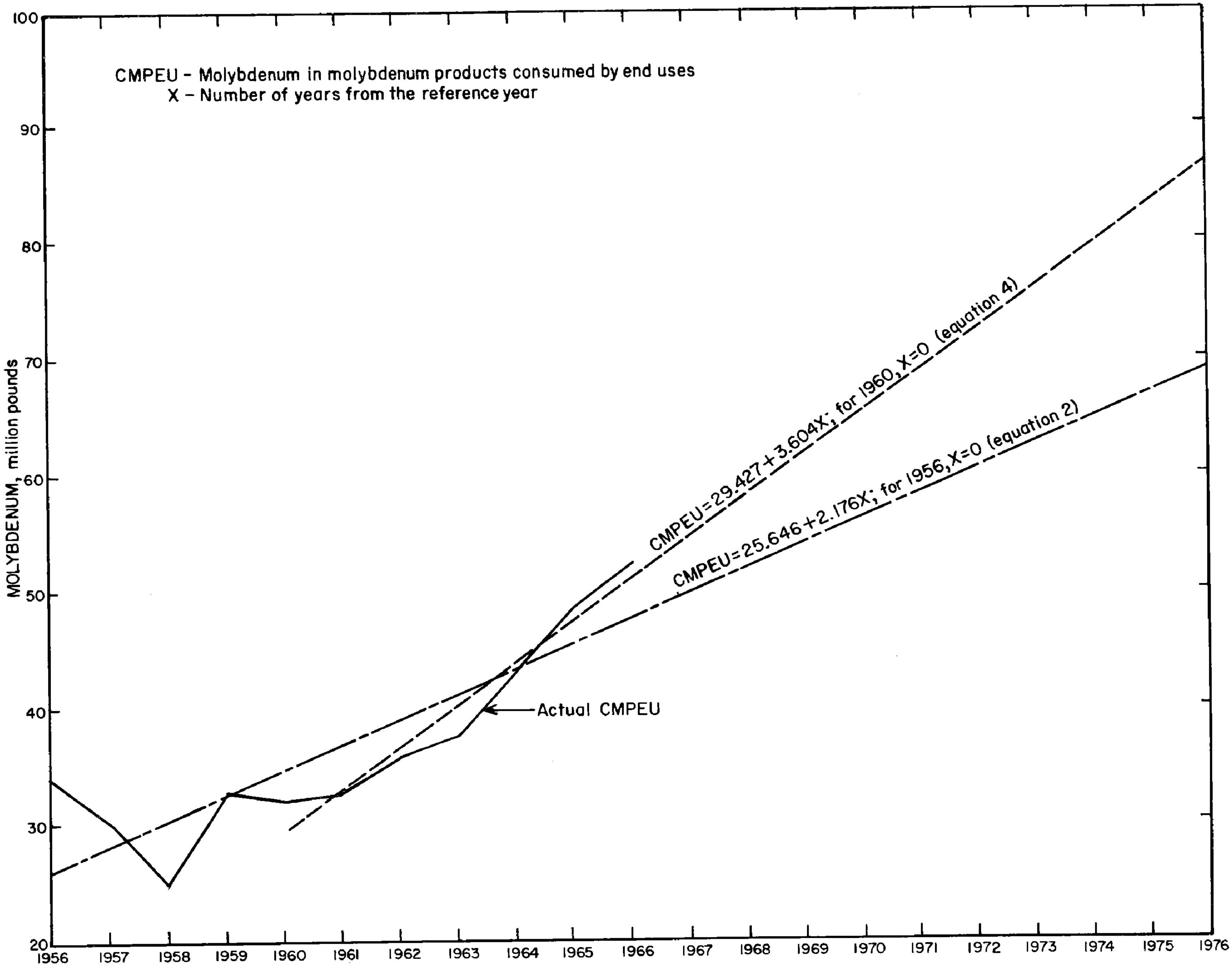

FIGURE 16. - Trend Lines of CMPEU Based on Time.

demand. The data regarding consumption of molybdenum as measured by shipments to domestic customers of molybdenum products (SDCMP) was tested both on a 21-year basis (1946-66) and on an 11-year basis (1956-66), whereas that measured by consumption of molybdenum by end use (CMPEU) was tested on an 11-year basis (1956-66). Most of the combinations of the various steel categories and the molybdenum consumption categories gave good results. The best relationships found to estimate molybdenum consumption were as follows:

Based on 1956-66 data; PASSS is in million tons

(5) SDCMP = 5.728 + 3.624 PASSS; r^2 = 0.9295

(6) CMPEU = 5.606 + 2.972 PASSS; r^2 = 0.9612

Figures 17 and 18 show the comparison of the actual values of SDCMP and CMPEU and the calculated values based on equations 5 and 6.

TABLE 8. - *Production of various steels and SDCMP, 1946-66 period, and CMPEU, 1956-66 period*

Year	PCS		PAS		PSS		PASSS[2]		PTS,[3] million tons	SDCMP, million pounds	CMPEU, million pounds
	Million tons	Percent[1]	Million tons	Percent[1]	Million tons	Percent[1]	Million tons	Percent[1]			
1946	60.526	90.9	5.527	8.3	0.550	0.8	6.077	9.1	66.603	16.502	NA
1947	77.466	91.3	6.908	8.1	.520	.6	7.428	8.7	84.894	19.879	NA
1948	80.159	90.4	7.864	8.9	.617	.7	8.481	9.6	88.640	23.809	NA
1949	72.081	92.4	5.442	7.0	.455	.6	5.897	7.6	77.978	15.019	NA
1950	88.266	91.1	7.735	8.0	.835	.9	8.570	8.9	96.836	32.736	NA
1951	95.075	90.4	9.186	8.7	.939	.9	10.125	9.6	105.200	29.845	NA
1952	84.033	90.2	8.200	8.8	.935	1.0	9.135	9.8	93.168	30.211	NA
1953	101.282	90.7	9.274	8.3	1.054	.9	10.328	9.2	111.610	29.595	NA
1954	81.119	91.9	6.341	7.2	.852	1.0	7.193	8.2	88.312	23.717	NA
1955	106.376	90.9	9.438	8.1	1.222	1.0	10.660	9.1	117.036	35.935	NA
1956	104.888	91.0	9.072	7.9	1.256	1.1	10.328	9.0	115.216	39.082	33.497
1957	103.803	92.1	7.865	7.0	1.047	.9	8.912	7.9	112.715	34.621	30.016
1958	78.591	92.2	5.768	6.8	.896	1.0	6.664	7.8	85.255	29.918	24.231
1959	84.539	90.5	7.776	8.3	1.131	1.2	8.907	9.5	93.446	38.393	32.350
1960	90.864	91.5	7.414	7.5	1.004	1.0	8.418	8.5	99.282	38.761	31.837
1961	89.340	91.2	7.537	7.7	1.137	1.2	8.674	7.9	98.014	38.359	32.621
1962	89.162	90.7	8.080	8.2	1.085	1.1	9.165	9.3	98.327	42.666	35.674
1963	98.714	90.3	9.343	8.6	1.204	1.1	10.547	9.7	109.261	43.157	37.478
1964	114.442	90.1	11.191	8.8	1.443	1.1	12.634	9.9	127.076	50.116	43.119
1965	116.650	88.7	13.318	10.1	1.493	1.2	14.811	11.3	131.462	57.034	48.621
1966	118.732	88.5	13.718	10.2	1.651	1.3	15.369	11.5	134.101	65.597	52.324

[1]Percent of total steel production (PTS).
[2]PASSS = PAS + PSS.
[3]PTS = PCS + PASSS.

Abbreviations used in table:
SDCMP--Shipments to domestic customers of molybdenum in molybdenum products.
CMPEU--Molybdenum in molybdenum products consumed by end uses.
PCS--Production of carbon steel.
PAS--Production of alloy steel excluding stainless steel.
PSS--Production of stainless steel.
PASSS--Production of alloy steel.
PTS--Total steel production.
NA--Not available.

Source of steel data: American Iron and Steel Institute, 1966 Annual Statistical Report.

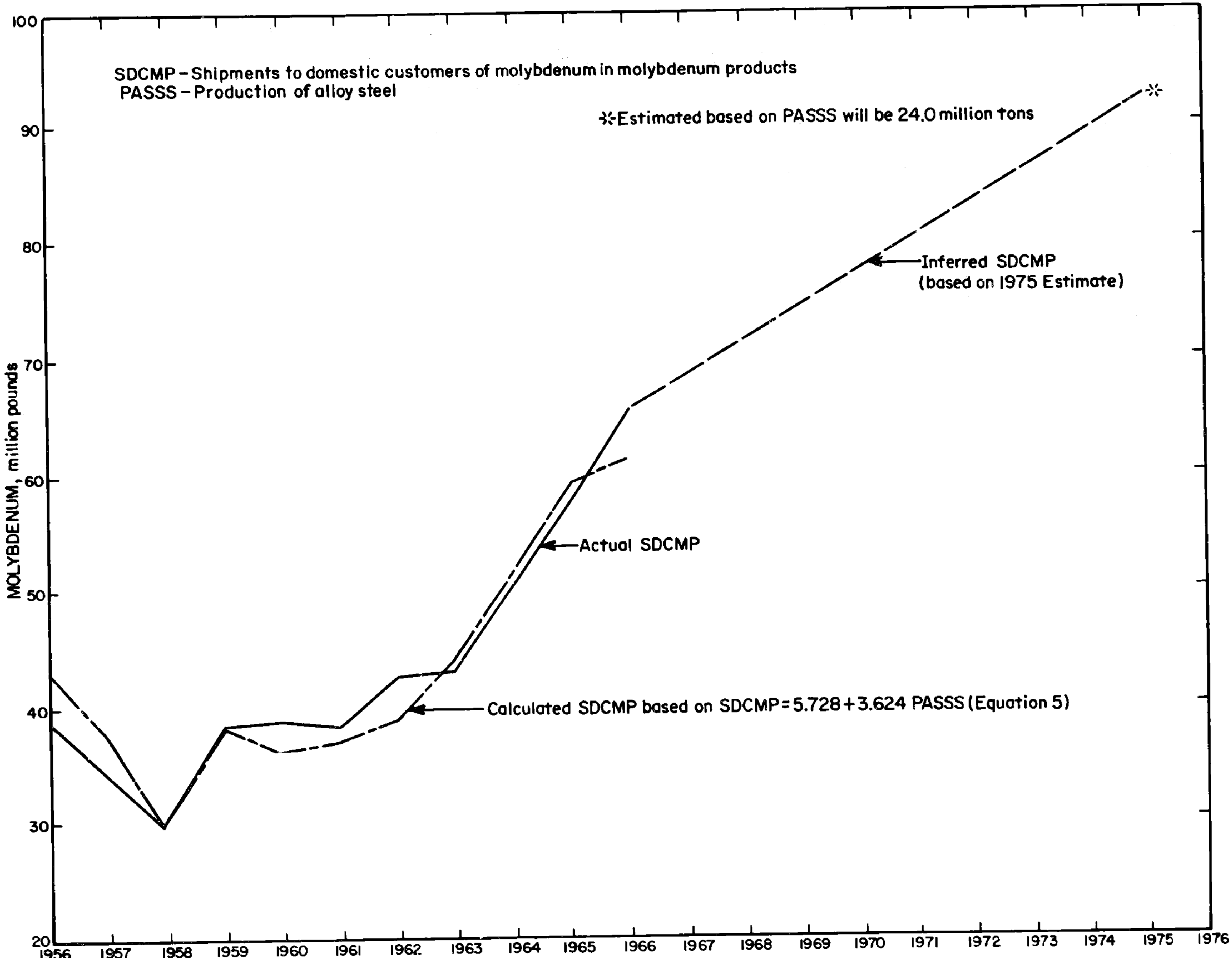

FIGURE 17. - Actual SDCMP and Calculated SDCMP (Based on PASSS), 1956-66; and Projected SDCMP, 1967-75.

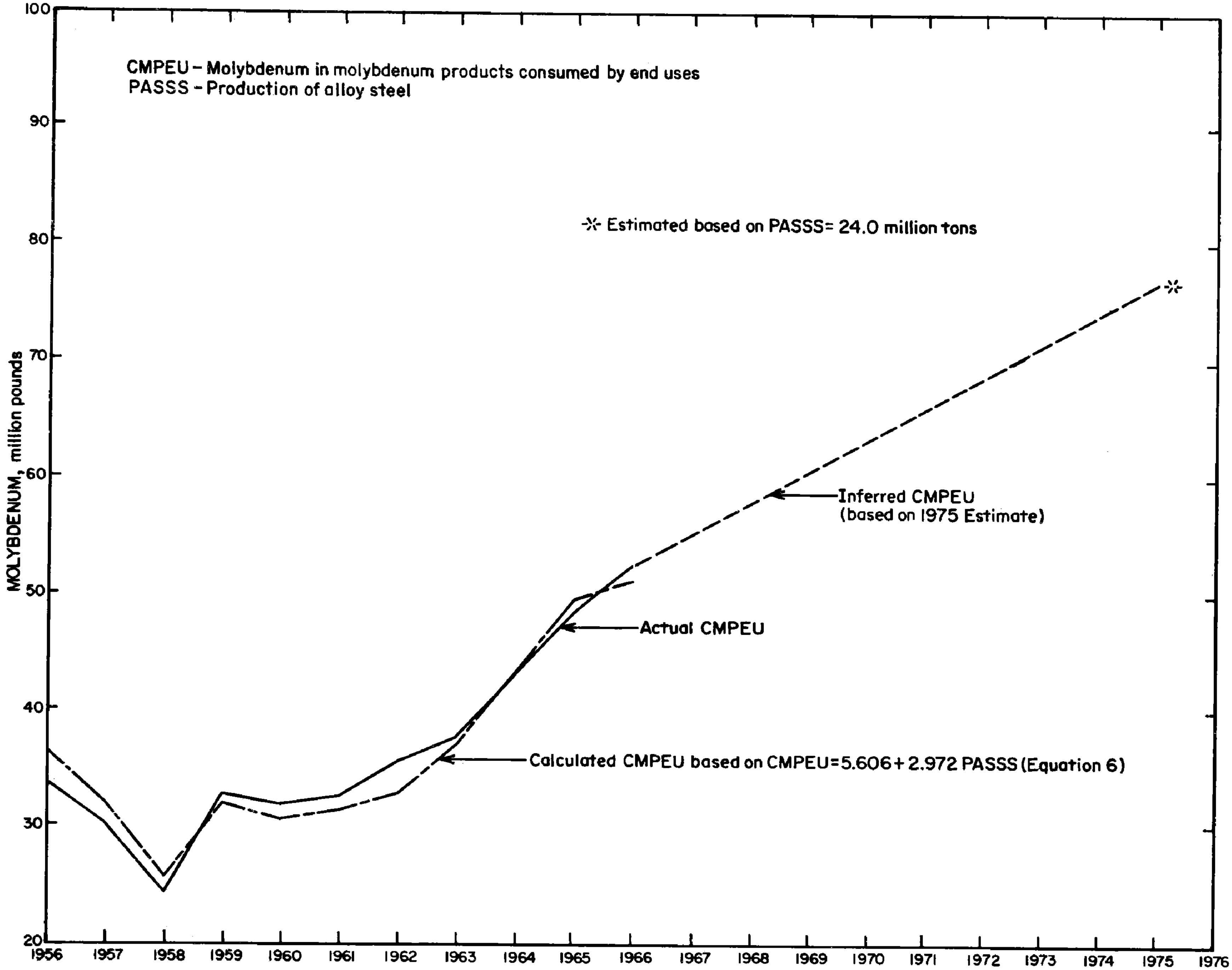

FIGURE 18. - Actual CMPEU and Calculated CMPEU (Based on PASSS), 1956-66; and Projected CMPEU, 1967-75.

For determining PASSS (total alloy steel production), the simplest approach is to estimate total steel production and multiply this quantity by some percentage between 12 and 15, depending on how many years the time of the prediction is from 1966. For the consumption of molybdenum in 1967 and 1968, 12 percent could be used and for that of 1975 and 1976, 15 percent. As can be seen in table 8 total alloy steel production has been rising steadily since 1960.

Another approach for predicting future demands was with the use of economic indicators. Table 9 shows the data of the economic indicators used in this method. Two general indicators, Gross National Product (GNP), 1958 dollars, and Federal Reserve Board Index of Industrial Production (FRBIPI), 1957-59 = 100, were compared with SDCMP for the 1946-66 and 1956-66 periods and with CMPEU for the 1956-66 period. The best relationship for SDCMP was obtained by using data for the 1956-66 period. The following equations, obtained by correlation and regression analysis, gave the best relationships between demand (SDCMP and CMPEU) and the general economic indicators (GNP and FRBIPI):

Based on 1956-66 data; GNP is in billion dollars (1958 prices) and FRBIPI is based on 1957-59 = 100

(7) SDCMP = -30.266 + 0.141 GNP; r^2 = 0.9160
(8) CMPEU = -22.945 + 0.114 GNP; r^2 = 0.9171
(9) SDCMP = -17.016 + 0.514 FRBIPI; r^2 = 0.9545
(10) CMPEU = -12.129 + 0.413 FRBIPI; r^2 = 0.9506

A segment of Gross National Product and a segment of the Federal Reserve Board Index of Industrial Production were also compared with SDCMP and CMPEU to see if they had some close relationships. The segment of GNP used was Gross Private Domestic Investment, Nonresidential, Producers Durable Equipment (GNPPDE) and that of FRBIPI was Manufacturing, Durable Goods (FRBMDG). Good correlations were obtained for those segments with SDCMP and CMPEU for the 1956-66 period and their relationships are expressed by the following equations:

Based on 1956-66 data; GNPPDE is in billion dollars (1958 prices) and FRBMDG is based on 1957-59 = 100

(11) SDCMP = -2.552 + 1.387 GNPPDE; r^2 = 0.9706
(12) CMPEU = -0.348 + 1.112 GNPPDE; r^2 = 0.9598
(13) SDCMP = -11.516 + 0.461 FRBMDG; r^2 = 0.9801
(14) CMPEU = -7.650 + 0.371 FRBMDG; r^2 = 0.9741

Figures 19 through 22 show the comparison of the actual values of SDCMP and CMPEU and the calculated values based on equations 7 through 14.

TABLE 9. - *List of economic indicators*

Year	GNP, 1958 dollars, billions	GNPPDE, 1958 dollars, billions	FRBIPI, 1957-59 = 100	FRBMDG, 1957-59 = 100
1946...........	312.6	17.7	59.5	54.7
1947...........	309.9	24.6	65.7	64.3
1948...........	323.7	25.7	68.4	67.0
1949...........	324.1	22.6	64.7	60.9
1950...........	355.3	24.8	74.9	74.1
1951...........	383.4	25.5	81.3	83.5
1952...........	395.1	24.6	84.3	88.5
1953...........	412.8	25.8	91.3	99.9
1954...........	407.0	24.5	85.8	88.4
1955...........	438.0	27.7	96.6	101.9
1956...........	446.1	28.8	99.9	104.0
1957...........	452.5	29.1	100.7	104.0
1958...........	447.3	25.0	93.7	90.3
1959...........	475.9	27.9	105.6	105.6
1960...........	487.7	29.6	108.7	108.5
1961...........	497.2	28.1	109.7	107.0
1962...........	529.8	31.7	118.3	117.9
1963...........	551.0	34.0	124.3	124.5
1964...........	580.0	38.5	132.3	133.5
1965...........	614.4	43.2	143.4	148.4
1966...........	647.7	48.7	156.3	165.1

Abbreviations used in table:

GNP--Gross National Product.

GNPPDE--Gross National Product, Gross Private Domestic Investment, Fixed Investment, Nonresidential, Producers Durable Equipment.

FRBIPI--Federal Reserve Board Industrial Production Index.

FRBMDG--Federal Reserve Board, Industrial Production Index, Manufacturing, Durable Goods.

Source: Economic Report of the President, January 1967, Tables B-2 and B-32.

Some of the above methods for forecasting future demand of molybdenum in the United States may be adaptable for determining future demand in other principal molybdenum consuming countries, especially those of the European Economic Community and Japan. Statistical data about gross national product and steel production in these countries are readily available. Possibly a plausible estimate of total future world demand may be determined by using world steel production as the predictor (independent variable in the equation).

1975 Predictions

The year 1975 was chosen arbitrarily to show how predictions of SDCMP and CMPEU can be made by using the methods described. Table 10 gives the

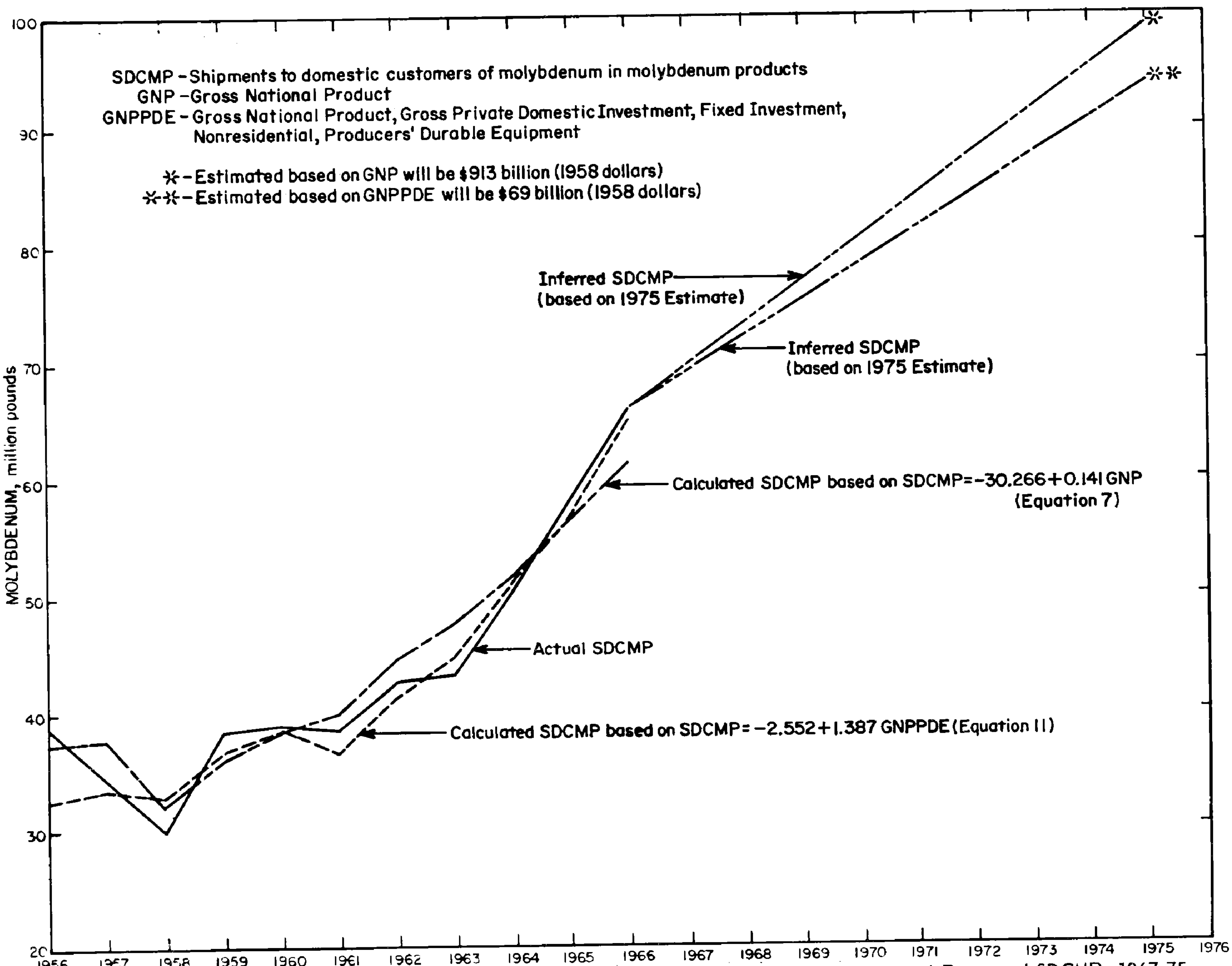

FIGURE 19. - Actual SDCMP and Calculated SDCMP (Based on GNP and GNPPDE), 1956-66; and Projected SDCMP, 1967-75.

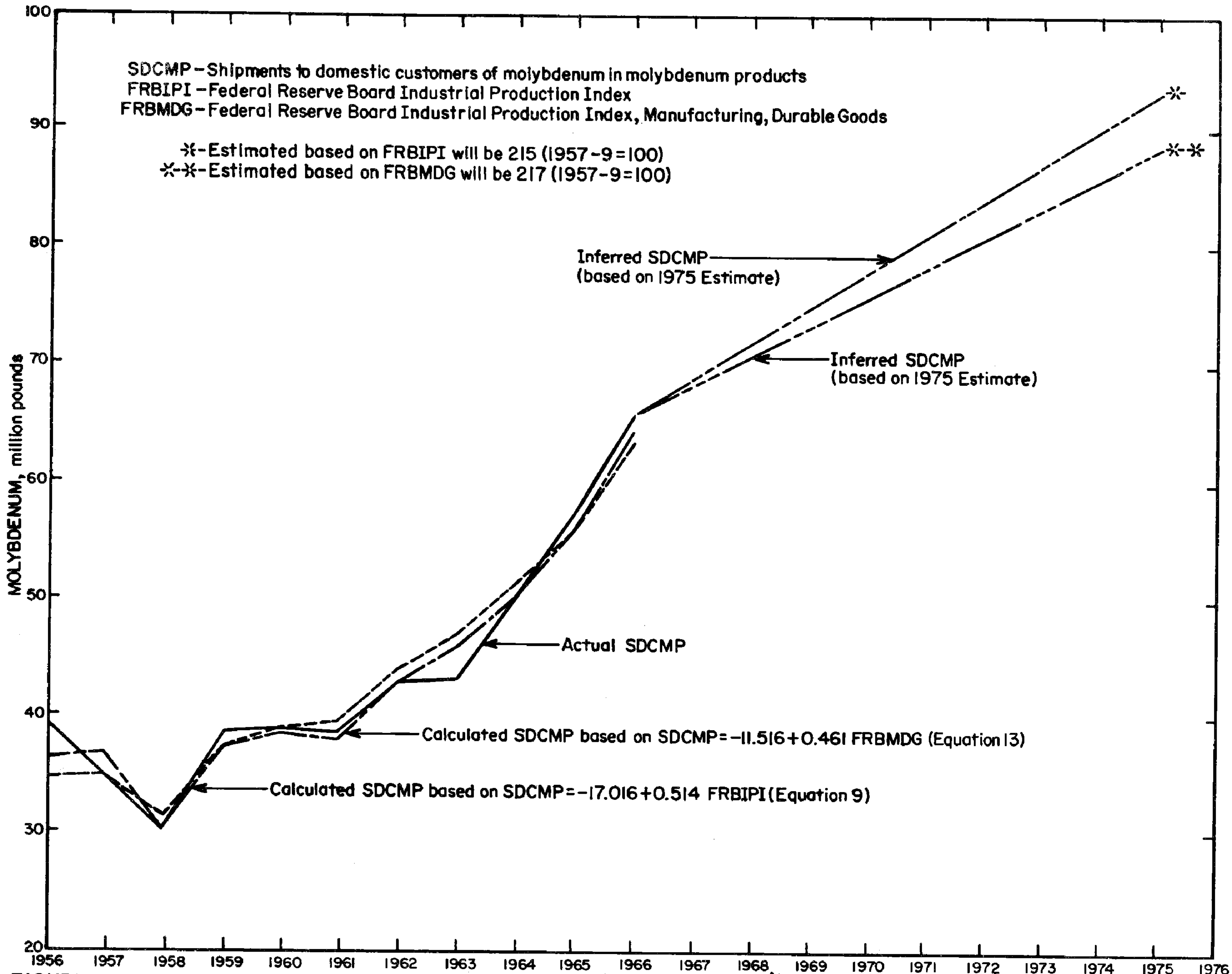

FIGURE 20. - Actual SDCMP and Calculated SDCMP (Based on FRBIPI and FRBMDG), 1956-66; and Projected SDCMP, 1967-75.

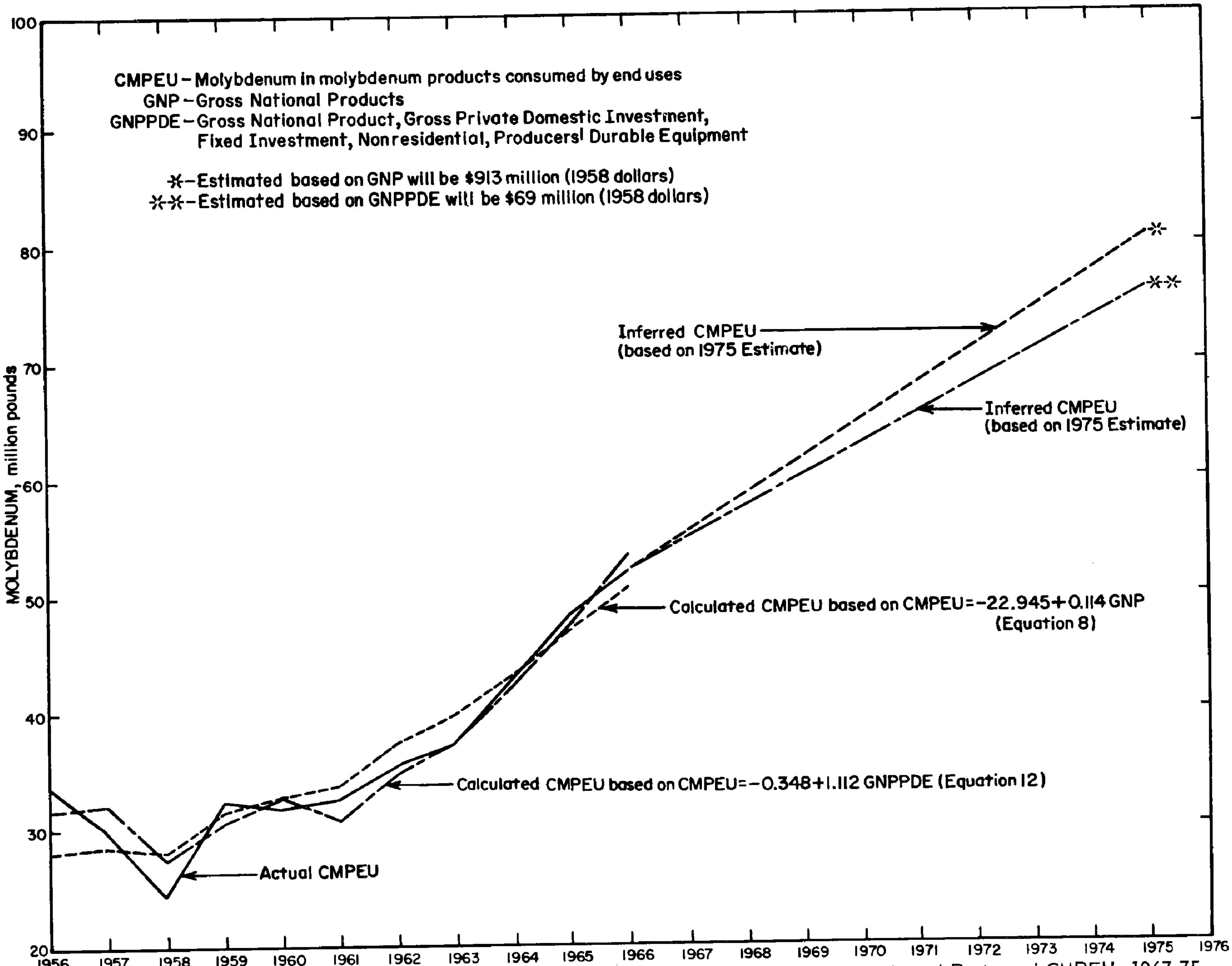

FIGURE 21. - Actual CMPEU and Calculated CMPEU (Based on GNP and GNPPDE), 1956-66; and Projected CMPEU, 1967-75.

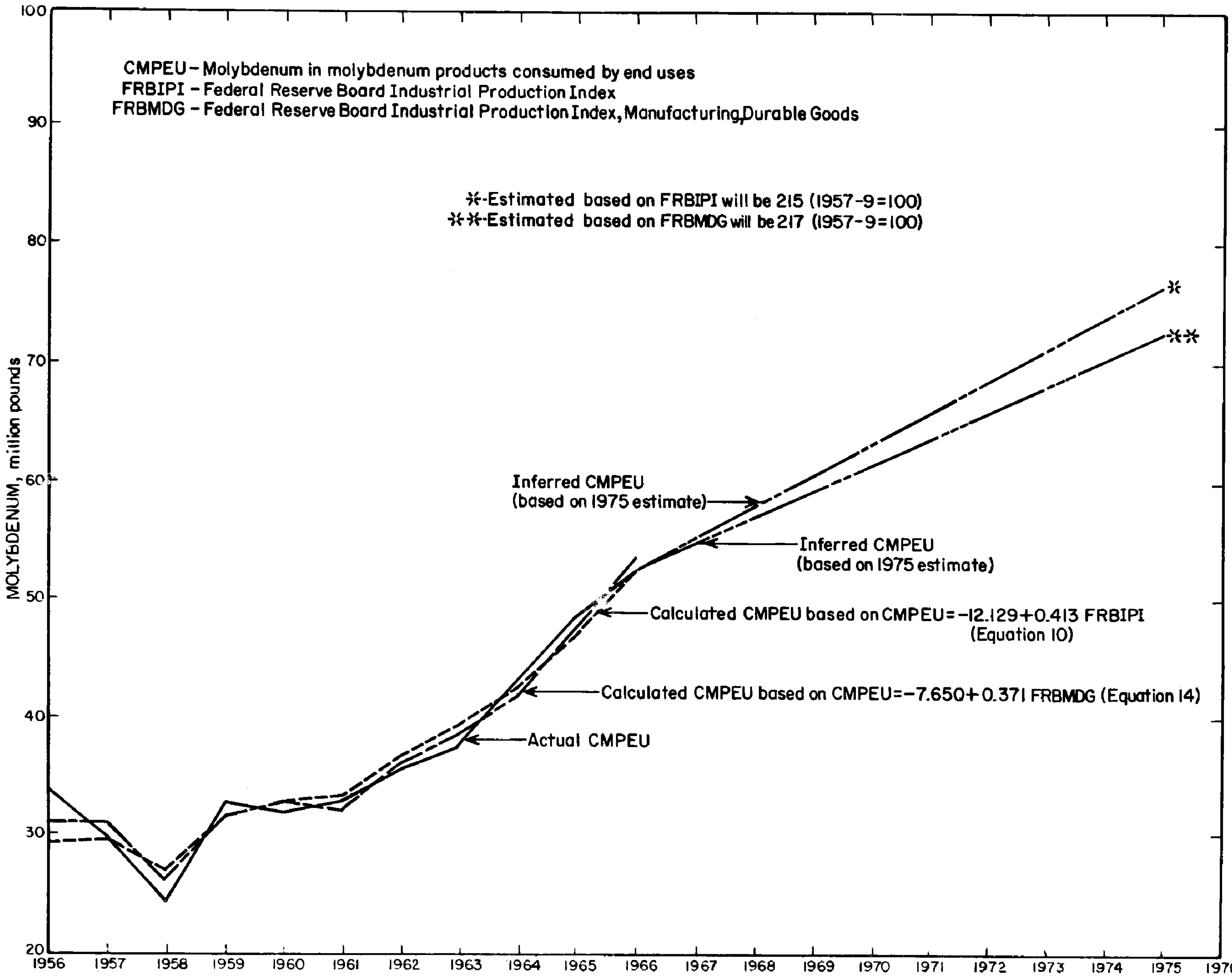

FIGURE 22. - Actual CMPEU and Calculated CMPEU (Based on FRBIPI and FRBMDG), 1956-66; and Projected CMPEU, 1967-75.

predicted values of SDCMP and CMPEU for 1975 and figures 23 and 24 show the actual values for the 1956-66 period, the 1975 estimates, and the inferred projections from 1967 to 1975. Figures 16 through 21 also show the 1975 estimates and inferred projections from 1967 to 1975.

TABLE 10. - *1975 predictions of SDCMP and CMPEU (million pounds of molybdenum)*

	Time[1]	PASSS[2]	GNP[3]	GNPPDE[3]	FRBIPI[3]	FRBMDG[3]
SDCMP..........	81.1-101.7	92.7	98.5	93.2	93.5	88.5
CMPEU..........	67.0- 83.5	76.9	81.1	76.4	76.7	72.9

[1]The first figure is based on the time series for the 1956-66 period and the second figure on the time series for the 1960-66 period.
[2]Based on Bureau of Mines estimate of 160 million tons of steel production for 1975 with 15 percent (24.0 million tons) being alloy steel (PASSS).
[3]Based on the following composite estimates for 1975 by Predicasts, Inc., Issue No. 26, April 15, 1967:

GNP (1958 dollars): $913 billion (converted from $1,048 billion in 1966 dollars)
GNPPDE (1958 dollars): $69 billion (converted from $71 billion in 1966 dollars)
FRBIPI (1957-59 = 100): 215
FRBMDG (1957-59 = 100): 217

Abbreviations used in table:
SDCMP--Shipments to domestic customers of molybdenum in molybdenum products.
CMPEU--Molybdenum in molybdenum products consumed by end uses.
GNP--Gross National Product.
GNPPDE--Gross National Product, Gross Private Domestic Investment, Fixed Investment, Nonresidential, Producers Durable Equipment.
FRBIPI--Federal Reserve Board Industrial Production Index.
FRBMDG--Federal Reserve Board Industrial Production Index, Manufacturing, Durable Goods.
PASSS--Production of alloy steel.

To make the predictions by the methods other than those using time, it was necessary to use estimates of the independent variables in the equations. The estimates used for these variables are shown in table 10.

The two 1975 predictions of SDCMP and CMPEU based on time give the highest and lowest value obtained by the various methods. For SDCMP and CMPEU the high estimate is 25 percent greater than the low estimate. The 1975 predictions of SDCMP and CMPEU made with the use of economic indicators and the production of alloy steel fall within an 11-percent range between the highest and lowest estimates obtained by these methods. The predictions based on economic indicators are between the highest and lowest predictions based on time.

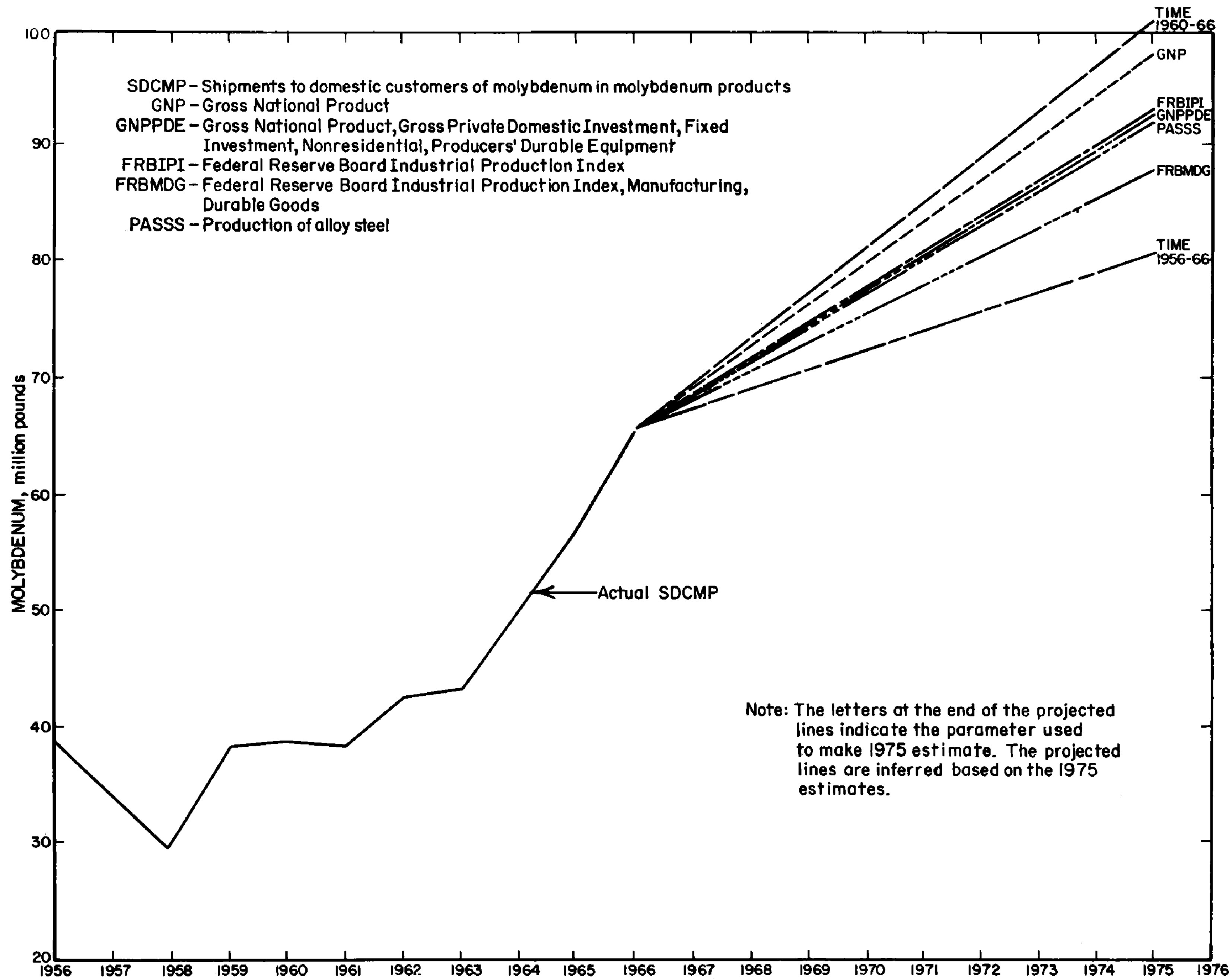

FIGURE 23. - Actual SDCMP, 1956-66; 1975 Estimates; and 1967-75 Projections.

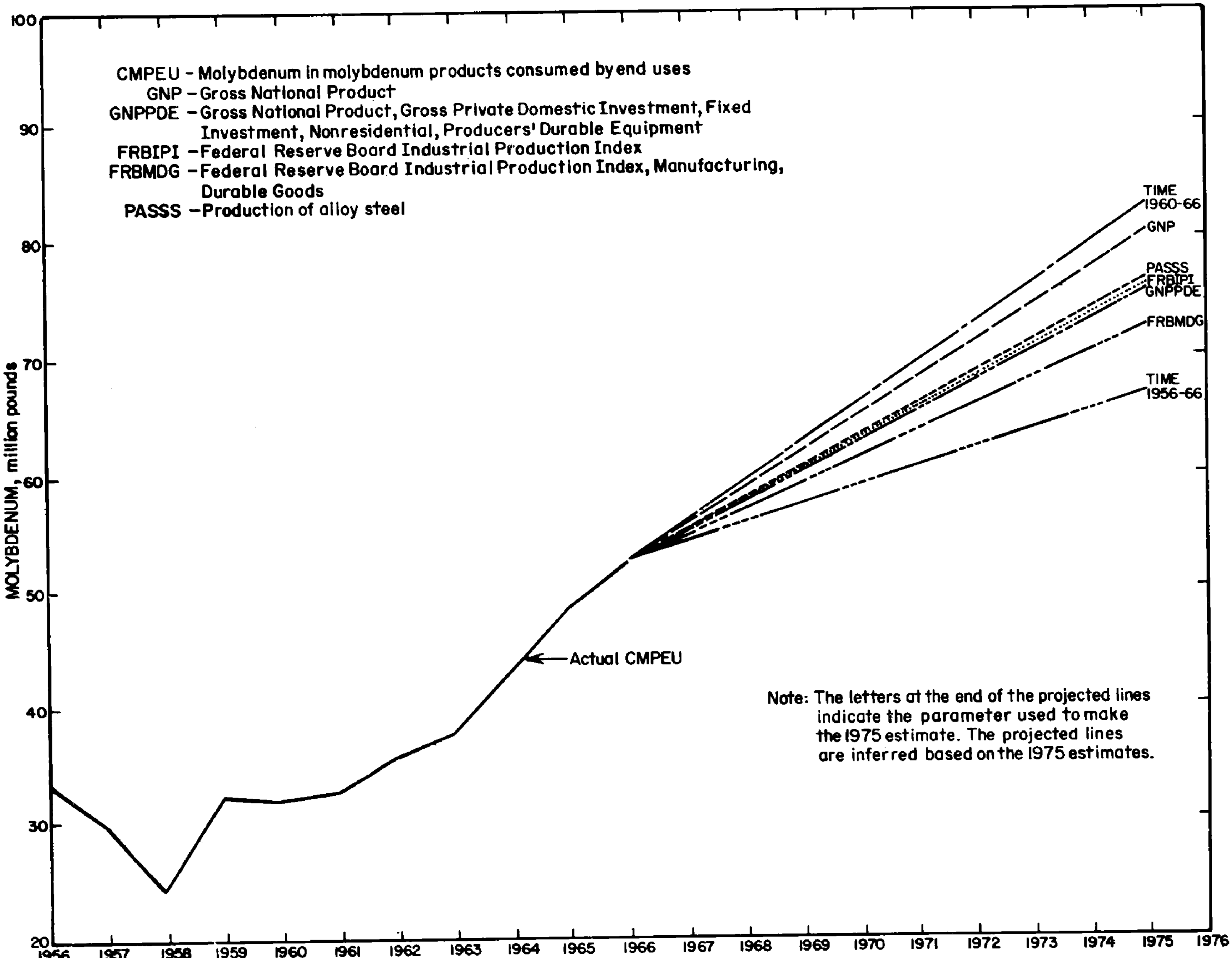

FIGURE 24. - Actual CMPEU, 1956-66; 1975 Estimates; and 1967-75 Projections.

Future Supply

The United States appears to be in a very good position for producing molybdenum. Domestic reserves have been increased considerably in the past few years and are now the highest ever. The reserves at properties now in operation and those at properties expected to be in production within 10 years are adequate to provide enough molybdenum at a rate double the 1966 apparent consumption (shipments of molybdenum contained in primary products to domestic customers) and exports of molybdenite concentrates, molybdic oxide, and other primary products for the next 30 years; the 1966 quantity of consumption and exports was 93.9 million pounds. New deposits can be expected to be found and some resources now considered uneconomical could be developed to further enhance the supply outlook.

The free world supply situation is also good. So far, most of the molybdenum produced in the world has come from North and South America. Known world reserves presently are tied mainly to four countries in those continents--United States, Canada, Chile, and Peru. Table 11 shows production from 1963 through 1966 and the capabilities of these countries and that of the free world for the next 10 years. The United States is expected to produce 65.7 percent of the total free world production in that period; Canada, 22.1 percent; Chile, 9.6 percent; Peru, 1.1 percent; and other free world countries, 1.5 percent.

The estimates for the four countries were mostly based on information announced by companies regarding development and expansion at properties in these countries. The free world production was based on the assumption that the four countries will produce 98.5 percent of the total production. In 1963 these countries accounted for 97.8 percent of the total; in 1964, 97.8 percent; in 1965, 98.1 percent; and in 1966, 98.4 percent. Because of the planned future development in the four countries and barring the discovery and development of a deposit, such as Climax, in other countries, it is expected that these countries will continue to produce 98.5 percent of the total free world production. The table shows a considerable increase around 1974. This should be about the time that the Urad deposit of American Metals Climax, Inc., is depleted and its Henderson deposit brought into the production stage.

In estimating U.S. molybdenum production for 1967, the 1967 copper strike was taken into consideration. The table does not reflect a resulting temporary decrease expected in U.S. production for a year or two after settlement of the current Vietnamese conflict whenever it takes place.

Exploration work for molybdenum is still being continued on a big scale in Canada, with most of the work being done in British Columbia. Canadian production jumped from 834,000 pounds in 1963 to 21.5 million pounds in 1966 because of new properties developed in British Columbia. Possibly a huge deposit similar to a Climax or Henderson deposit may be found in Canada because of the current exploration work.

TABLE 11. - *Free world molybdenum production, 1963-66 period, and estimates, 1967-75 period (thousand pounds of molybdenum contained in concentrate)*

Year	United States	Canada	Chile	Peru	Other free world countries	Total free world production[1]
1963:						
Molybdenum production	65,011	834	6,400	1,186	1,668	75,100
Percent of TFWP......	86.6	1.1	8.5	1.6	2.2	100.0
1964:						
Molybdenum production	65,605	1,225	8,393	871	1,741	77,800
Percent of TFWP......	84.3	1.6	10.8	1.1	2.2	100.0
1965:						
Molybdenum production	77,372	9,557	7,943	1,484	1,861	98,400
Percent of TFWP......	78.8	9.7	8.1	1.5	1.9	100.0
1966:[p]						
Molybdenum production	90,532	21,493	10,439	1,669	2,018	126,200
Percent of TFWP......	71.8	17.0	8.3	1.3	1.6	100.0
1967:						
Molybdenum production	91,500	24,000	11,000	1,800	2,000	130,300
Percent of TFWP......	70.2	18.4	8.5	1.4	1.5	100.0
1968:						
Molybdenum production	103,600	30,500	13,000	1,800	2,300	151,200
Percent of TFWP......	68.5	20.2	8.6	1.2	1.5	100.0
1969:						
Molybdenum production	111,100	35,000	17,000	1,900	2,500	167,500
Percent of TFWP......	66.3	20.9	10.2	1.1	1.5	100.0
1970:						
Molybdenum production	123,600	41,500	18,500	2,000	2,800	188,400
Percent of TFWP......	65.6	22.0	9.8	1.1	1.5	100.0
1971:						
Molybdenum production	124,700	47,000	20,000	2,000	2,900	196,600
Percent of TFWP......	63.4	23.9	10.2	1.0	1.5	100.0
1972:						
Molybdenum production	125,600	47,000	20,000	2,000	3,000	197,600
Percent of TFWP......	63.6	23.8	10.1	1.0	1.5	100.0
1973:						
Molybdenum production	126,000	48,000	20,500	2,100	3,000	199,600
Percent of TFWP......	63.1	24.0	10.3	1.1	1.5	100.0
1974:						
Molybdenum production	137,000	50,000	21,000	2,300	3,200	213,500
Percent of TFWP......	64.2	23.4	9.8	1.1	1.5	100.0
1975:						
Molybdenum production	167,600	50,000	22,000	2,300	3,700	245,600
Percent of TFWP......	68.2	20.4	9.0	.9	1.5	100.0
Total:						
Molybdenum production	1,110,700	373,000	163,000	18,200	25,400	1,690,300
Percent of TFWP......	65.7	22.1	9.6	1.1	1.5	100.0

[p]Preliminary.

[1]Rounded figures to the nearest 100,000 pounds.

In the past 4 years significant developments have taken place in the four countries. No important discoveries or developments have taken place in any of the other countries of the free world except that A/S Knaben Molybdaengruber, which operates the Knaben mine in Norway, announced plans to invest $1.4 million to double the annual production at the mine. The 1966 production from the Knaben mine was 472,000 pounds of molybdenum contained in concentrate. If the plans are carried out within 2 years, Norway then could become the fifth leading producing nation in the free world.

A few marginal primary deposits are known in the free world, especially in the United States, that may be worth developing if the price of molybdenum (contained in concentrate) would rise 10 to 15 percent. Some of the low-grade primary deposits in the free world would require a 25- to 50-percent increase in price before they could be developed and operated profitably.

Low-grade copper-molybdenum marginal deposits are in a favorable position for development because a price increase either for copper or molybdenum may make the deposit profitable. Both the United States and Canada have a few such deposits that appear promising.

At least in the near future, the United States and the other three major producing nations should not face any serious competition from the Communist nations for world markets. The Russians are considered to be self-sufficient for their present molybdenum needs. In case their needs exceed production, they can either enter trade agreements with some of the producing nations or substitute some of their molybdenum needs with vanadium which Russia is considered to have in large reserves. If rumors of discoveries of huge deposits in Red China are true, the country would have the potential of being a serious competitor for world markets.

CONCLUSIONS

Future consumption of molybdenum in the United States will continue to be linked mainly to the production of alloy steels. Recently developed superstrength steels using molybdenum should increase consumption in this use category once they are widely accepted. The greatest growth in consumption, percentagewise, will be in the use of molybdenum as a metal and as an alloying element in nonsteel, high-temperature alloys because of the increasing demand for products made of these materials by the growing nuclear and space industries. Consumption of molybdenum for most other uses will grow, but at a slower rate. Substitution of other materials for molybdenum will have little or no effect on the overall growth in consumption of molybdenum.

The United States has sufficient ore reserves of molybdenum to take care of its needs and a large part of the demand of other free world nations at least until the turn of the century. Short periods of temporary shortages may arise caused by economic conditions and timing of developing new properties. Because of current exploration work being done in the world, especially in Canada and the United States, it is highly probable that new ore deposits containing significant quantities (1 million pounds or more) of recoverable molybdenum will be discovered and thereby extend the supply period. Known low-grade deposits are not expected to be developed using present-day technology even though the price of molybdenum may increase. Paralleling increases in operational costs of labor and material would offset the advantage of the price increase.

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APPENDIX

TABLE A-1. - *Consumption of molybdenum by end use, 1956-66 (thousand pounds)*

End use	1956		1957		1958		1959		1960		1961	
	Quantity	Percent of total	Quantity	Percent of total	Quantity	Percent of total	Quantity	Percent of total	Quantity	Percent of total	Quantity	Percent of total
Steel...........	24,651	73.6	22,422	74.7	16,712	69.0	22,343	69.1	21,849	68.6	23,534	72.1
High-speed tool	(2,637)	-	(2,335)	-	(1,072)	-	(2,488)	-	(1,756)	-	(1,740)	-
Hot-worked tool	NR	-	NR	-	NR	-	(298)	-	(289)	-	(326)	-
Other tool.....	NR	-	NR	-	NR	-	(466)	-	(324)	-	(266)	-
Stainless......	NR	-	NR	-	NR	-	(3,559)	-	(3,759)	-	(4,794)	-
Other alloy....	(22,014)	-	(20,087)	-	(15,640)	-	(15,532)	-	(15,721)	-	(16,408)	-
Steel mill rolls.	980	2.9	832	2.8	601	2.5	1,028	3.2	1,152	3.6	953	2.9
Gray and malleable castings.	2,836	8.5	2,274	7.6	1,738	7.2	3,182	9.8	2,757	8.7	2,578	7.9
Welding rods.....	257	.8	237	.8	249	1.0	233	.7	259	.8	245	.8
High-temperature alloys..........	1,804	5.4	1,401	4.6	1,215	5.0	1,333	4.1	1,346	4.2	1,398	4.3
Molybdenum powder	834	2.5	866	2.9	1,867	7.7	2,206	6.8	2,336	7.3	1,476	4.5
Wire, rod, and sheet.........	NR	-	NR	-	NR	-	(1,046)	-	(829)	-	(859)	-
Other (forging billets, etc.)	NR	-	NR	-	NR	-	(1,160)	-	(1,507)	-	(617)	-
Chemicals........	1,190	3.5	1,227	4.1	1,151	4.7	1,137	3.5	1,228	3.9	1,201	3.7
Inorganic pigments......	NR	-	NR	-	NR	-	(611)	-	(499)	-	(466)	-
Organic pigments......	NR	-	NR	-	NR	-	(290)	-	(357)	-	(365)	-
Catalysts......	(432)	-	(496)	-	(391)	-	(236)	-	(372)	-	(370)	-
Miscellaneous....	945	2.8	757	2.5	698	2.9	888	2.8	910	2.9	1,236	3.8
Total.......	33,497	100.0	30,016	100.0	24,231	100.0	32,350	100.0	31,837	100.0	32,621	100.0
Stocks at the consumers plant as of Dec. 31...	NA	-	NA	-	NA	-	4,587	-	3,980	-	4,234	-

End use	1962		1963		1964		1965		1966		1956-66	
	Quantity	Percent of total	Quantity	Percent of total	Quantity	Percent of total	Quantity	Percent of total	Quantity	Percent of total	Quantity	Percent of total
Steel...........	24,034	67.4	25,889	69.1	30,739	71.3	33,852	69.6	35,238	67.3	281,263	70.0
High-speed tool	(2,273)	-	(2,089)	-	(2,155)	-	(2,814)	-	(3,652)	-	-	-
Hot-worked tool	(435)	-	(504)	-	(541)	-	(689)	-	(436)	-	-	-
Other tool.....	(283)	-	(427)	-	(554)	-	(624)	-	(839)	-	-	-
Stainless......	(4,327)	-	(4,996)	-	(6,840)	-	(7,332)	-	(7,568)	-	-	-
Other alloy....	(16,716)	-	(17,873)	-	(20,649)	-	(22,393)	-	(22,743)	-	-	-
Steel mill rolls.	1,564	4.4	1,907	5.1	2,181	5.1	2,400	4.9	2,420	4.6	16,018	4.0
Gray and malleable castings.	3,248	9.1	3,287	8.8	3,525	8.2	3,335	6.9	3,419	6.5	32,179	8.0
Welding rods.....	239	.7	238	.6	249	.6	292	.6	311	.6	2,809	.7
High-temperature alloys..........	1,314	3.7	1,396	3.7	1,522	3.5	1,846	3.8	3,064	5.9	17,639	4.4
Molybdenum powder	2,250	6.3	1,548	4.1	1,371	3.2	1,904	3.9	2,479	4.7	19,137	4.8
Wire, rod, and sheet.........	(1,079)	-	(822)	-	(1,146)	-	(1,715)	-	NR	-	-	-
Other (forging billets, etc.)	(1,171)	-	(726)	-	(225)	-	(189)	-	NR	-	-	-
Chemicals........	1,549	4.3	1,596	4.3	1,828	4.2	2,976	6.1	3,028	5.9	18,111	4.5
Inorganic pigments......	(471)	-	(554)	-	(540)	-	(623)	-	(606)	-	-	-
Organic pigments......	(388)	-	(354)	-	(325)	-	(378)	-	(454)	-	-	-
Catalysts......	(690)	-	(688)	-	(963)	-	(1,975)	-	(1,968)	-	-	-
Miscellaneous....	1,476	4.1	1,617	4.3	1,704	3.9	2,016	4.2	2,365	4.5	14,612	3.6
Total.......	35,674	100.0	37,478	100.0	43,119	100.0	48,621	100.0	52,324	100.0	401,768	100.0
Stocks at the consumers plant as of Dec. 31...	4,932	-	5,471	-	4,657	-	5,637	-	10,951	-	-	-

( )--Part of category total.
NR--Not reported separately, included in category total.
NA--Not available.

TABLE A-2. - *Salient molybdenum statistics of the United States, 1946-66 (quantities in thousand pounds of molybdenum and value of shipments in thousand dollars)*

Year	Molybdenum contained in concentrates[1] (reported by concentrate producers)							Molybdenum contained in primary products[2] (reported by primary products producers)			
	Production	Shipments	Value of shipments	Consumption	Exports[3]	Imports for consumption	Stocks as of Dec. 31 at mines and plants[4]	Production	Shipments to domestic customers	Shipments for export	Stocks as of Dec. 31 at producer's plants[4]
1946	18,218	16,787	$11,529	14,994	NR	-	19,275	15,039	16,502	442	8,211
1947	27,047	22,190	15,178	20,221	NR	-	23,661	20,660	19,879	866	8,126
1948	26,706	29,669	20,418	25,156	3,525	-	21,206	24,445	23,809	1,215	7,547
1949	22,530	23,280	19,332	19,960	4,287	48	19,159	19,624	15,019	1,314	10,838
1950	28,480	44,544	37,729	[5]26,029	5,386	3	4,326	25,348	32,736	1,955	1,495
1951	38,855	37,955	36,177	[5]33,691	3,270	4	5,058	32,775	29,845	1,388	3,037
1952	43,259	42,717	40,845	[5]32,715	5,290	50	6,856	32,383	30,211	1,843	3,373
1953	57,243	53,823	52,362	[5]31,193	5,893	-	11,326	30,283	29,595	1,107	3,894
1954	58,668	64,021	64,070	[5]24,710	12,974	154	5,317	24,328	23,717	1,640	3,430
1955	61,781	64,079	66,919	[5]38,799	11,805	134	2,730	37,774	35,935	2,671	3,156
1956	57,462	57,126	63,901	42,652	14,736	-	2,920	41,208	39,082	3,738	2,812
1957	60,753	57,143	67,605	38,954	17,543	27	7,093	37,698	34,621	2,244	5,789
1958	41,069	42,328	50,731	31,298	11,649	1	5,643	30,915	29,918	1,441	8,081
1959	50,956	51,603	64,655	37,448	15,294	-	4,074	36,294	38,393	3,265	5,958
1960	68,237	69,941	87,406	44,784	23,341	-	3,481	43,427	38,761	7,016	8,157
1961	66,563	66,753	87,925	42,261	24,165	-	2,815	41,050	38,359	8,747	5,074
1962	51,244	50,506	69,390	40,990	10,112	-	3,490	40,074	42,666	4,007	3,068
1963	65,011	65,839	91,096	49,241	18,825	-	2,436	48,756	43,157	6,442	4,504
1964	65,605	65,097	97,121	56,409	13,791	-	4,303	55,946	50,116	10,287	4,398
1965	77,372	77,310	120,801	68,112	12,513	295	4,208	66,616	57,034	14,584	3,839
1966	90,532	91,670	144,385	75,476	15,140	-	3,433	74,392	65,597	13,214	5,945

NR--Not reported.
[1]Mostly molybdenite concentrate and some molybdic oxide concentrate.
[2]Molybdic oxide, molybdenum metal powder, ammonium molybdate, sodium molybdate, ferromolybdenum, calcium molybdate, phosphomolybdic acid, molybdenum disulfide, molybdenum pellets, molybdenum pentachloride, and molybdenum hexacarbonyl.
[3]Molybdenum only contained in molybdenite concentrates.
[4]Calculated stock figures differ from reported data.
[5]Does include additions to national stockpiles.

TABLE A-3. - *U.S. exports of molybdenum, 1946-66 (molybdenum reported by the Bureau of Census as exports, thousand pounds of contained molybdenum)*

Year	Molybdenum ores and concentrates including roasted concentrates	Ferro-molybdenum[1]	Molybdenum metal and alloys in crude form and scrap[2]	Molyb-denum wire	Molyb-denum powder	Molybdenum in semi-fabricated form not elsewhere classified	Total
1946	565	467	221	-	-	-	1,253
1947	2,989	600	133	-	-	-	3,722
1948	4,132	749	56	-	-	-	4,937
1949	5,320	602	86	-	-	-	6,008
1950	6,235	743	146	-	-	-	7,124
1951	3,729	935	109	-	-	-	4,773
1952	6,172	687	172	15	4	8	7,058
1953	7,037	388	22	16	17	13	7,493
1954	13,547	149	34	11	15	26	13,782
1955	14,580	210	23	11	21	4	14,849
1956	17,981	567	35	11	21	5	18,620
1957	25,466	230	99	14	28	4	25,841
1958	11,966	136	14	11	5	21	12,153
1959	18,853	149	15	12	11	9	19,049
1960	30,244	255	295	10	10	5	30,819
1961	35,661	215	441	12	12	7	36,348
1962	15,555	114	75	12	25	9	15,790
1963	26,545	143	139	31	17	9	26,884
1964	24,940	1,100	1,405	31	311	35	27,822
1965	24,096	1,526	111	23	603	66	26,425
1966	29,768	1,386	59	19	120	72	31,424

[1]Census figures were in quantity of ferromolybdenum; for this table the quantity of contained molybdenum was obtained by multiplying the quantity of ferromolybdenum by 63 percent which is the approximate percentage of molybdenum in ferromolybdenum.

[2]The molybdenum alloys contain other metals beside molybdenum; however, for this table the alloys are considered as all molybdenum because no breakdown was available and the quantity of other metals usually would be a small part of the weight.

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