INVESTIGATION INTO MERCURY PRICE INCREASE OF 1964-1967 AND IMPLICATIONS FOR FUTURE CONDITION OF THE MERCURY MARKET

by

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ABSTRACT

The price of mercury, for several years a stable quantity, increased from $228 per flask at the end of 1963 to $725 by June 25, 1965 and has remained, by previous standards, at a very high level since that time. This thesis proposes to investigate the causes and effects of such a price rise. It is limited generally to a consideration of the mercury industry in the United States.

Mercury mining has been recorded in Europe for over 2300 years and spread to the Western Hemisphere in 1571. Large-scale mining has taken place in the United States since 1850. Deposits are largely limited to the western portion of the nation. Cinnabar is the primary ore of mercury and is genetically of epithermal origin, typical of volcanic or hot spring activity. Erosion is an adverse influence upon preservation of such deposits.

Mining is generally by either open-pit or underground methods. Refining is by mercury vapor condensation through a retort system. Costs are increasing yearly and may vary between $28 and $40 per ton of ore, yielding an average of about seven pounds of mercury.

The price changes since 1963 were caused by an imbalance of supply and demand and their subsequent adjustments. Scarce supply was due to labor difficulties and mine closings brought about by years of low prices and rising costs. Adequate reserves also were not being developed. High demand levels were caused by depleted inventories and large purchases for new caustic soda and chlorine facilities.

To predict a future long-run price, quarterly data compiled by the U. S. Bureau of Mines were subjected to regression analysis. Projected usage data also were analysed. The most reasonable price forecast on this basis is $424.20. Industry sources, on the average, predict a price of $406. The writer concludes that a realistic forecast is $400 per flask. Recommendations for additional research are made.

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CHAPTER I

INTRODUCTION

What causes a commodity market to run wild and in what condition will it be when it settles down? Often asked about the stock markets, this question will now be asked of the mercury market. Mercury miners, brokers, and consumers have all tried to find the solution. Depending upon the answer he receives, the miner may expand his operations or possibly not open his mine at all. The broker may enter or refuse to enter into new contracts at given prices. The consumer will replenish his inventories or deplete them.

In recent years prior to 1963, the mercury market had been one of the more stable of the metal markets. Prices had been slowly declining from 1955, but fluctuations were minimal. The average price for 1963 was $189.45 and a mild upturn had raised the year's final price to $228. By June 25, 1965, however, the market price had soared to $725.

This thesis is an investigation into the causes and possible consequences of this price rise. In search of an answer many facets of the mercury industry must be examined. Chapter II investigates mercury's recent record of price stability and the effect of its dramatic instability upon those involved in the market. It also sets forth the purpose and limitations of this thesis.

Chapter III traces the geographic development of mercury mining from Europe into the United States and shows the physical magnitude and distribution of the mining industry. The geology and mineralogy of mercury deposits are discussed in Chapter IV, which also contrasts some major deposits with some that are marginal. Chapter V examines the mining and milling processes and the costs involved.

Price behavior from the turn of the twentieth century to the present is discussed in Chapter VI. The succeeding chapter looks at recent trends and future prospects for each of the usage categories defined by the U. S. Bureau of Mines.

The heart of this investigation lies in Chapter VIII is which the quantitative analysis is pursued and in Chapter IX where the conclusion of the analysis is presented, along with a criticism of methods and recommendations for further research.

The writer wishes to express his gratitude to his thesis advisor, Dr. William H. Dennen, for his guidance and criticisms; to Mr. George T. Engel of the U. S. Bureau of Mines in Washington for making available quarterly reports which could not be located elsewhere; and to the large number of individuals and firms who made available data, often confidential, from which to draw in writing this thesis. Special appreciation is due the writer's wife, Marcia, for her patience and encouragement.

CHAPTER II

BACKGROUND

Price Stability

Not until 1951 did the current dollar New York price of mercury reach a yearly average of over $200 per flask.[1] In fact, in the twenty years previous, the average price per flask of mercury exceeded $100 only in the war years of 1939-1945.

In the thirteen year period, 1951-1963, the price of mercury has averaged $223.81 per flask. Table I lists the average current dollar New York price for each of these years.

Table I[2]

Price of Mercury, 1951-1963

Year	Average New York Price per Flask (Current Dollars)	Year	Average New York Price per Flask (Current Dollars)
1951	$210.13	1958	$229.06
1952	199.10	1959	227.48
1953	193.03	1960	210.76
1954	264.39	1961	197.61
1955	290.35	1962	191.21
1956	259.92	1963	189.45
1957	246.98		

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[1] The market unit for mercury is the 76-pound "flask." (2.8 quarts)

[2] Engineering and Mining Journal, Feb. 1966, p. 76c.

Thus, it would appear that recent prices through 1963 could be characterized as stable, though slowly decreasing. It may be noted that, from 1956, the year-to-year annual decrease in price never exceeded $20 and averaged only $10.09 per year.

By the standards of other mineral prices in that period, this stability was indeed remarkable. The following table indicates price stability for that period.

Table II

Stability of Mineral Prices, 1956-1963[3]

Mineral	Year of Maximum Change in Price	Change in Price	% Change	Standard Deviation
Mercury	1957-8	$-17.92	-7.26%	22.42
Copper (Domestic Refinery)	1956-7	-12.24	-29.3%	4.30
Copper (Foreign Refinery)	1956-7	-13.27	-32.9%	4.43
Lead	1957-8	-2.55	-17.4%	3.14
Zinc	1956-7	-2.09	-15.5%	.92
Tin	1960-1	+11.87	+11.7%	7.93
Silver	1961-2	+16.07	+17.4%	12.78
Aluminum	1961-2	-1.58	-6.20%	1.01

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3. Calculated from statistics in Engineering and Mining Journal, Feb. 1966, p. 76c.

With the background of recent stable and slowly decreasing prices, why then did the average price of mercury jump from $189.45 in 1963 to $315.79 in 1964 and to $570.75 in 1965,[4] - - a total increase of 201%? Why did the price of mercury rise as high as $725.00 on June 25, 1965?[5] More important from an economic viewpoint, what price level can be expected to prevail in the future? Will the price decline to the 1963 level?

Impact of Price Instability

The answers to the latter questions will affect the mine operator, the metal broker, the industrial consumer, and the government. It is to them that the findings of this thesis could be most beneficially directed.

The mine operator must be able to justify the cost of capital improvements on the basis of anticipated future revenues. In the extreme case, is the mineral deposit which is not economic at $200 but which could yield a respectable profit at, say, $500 worth developing today? In the time required to develop such a property, will the increased production from presently operating mines and from mines which had reopened because of elevated prices lead to so high a level of output that the price of mercury will be forced to a level uneconomic for this property? Where will an equilibrium be reached?

The metal broker, like the stockbroker, must be able to advise his clients on the state of the market. Also, most metal brokers stock trading inventories which are subject to constant revaluation. Their own profits depend upon proper estimation of the market.

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[4] Ibid.

[5] Idem. p. 76d.

Since industrial consumers may buy several months requirements of mercury at one time, the timing of such a purchase can be critical. Inventory policies must be affected by price trends. Furthermore, if an extended period of elevated prices is foreseen, it may be to a company's advantage to "engineer" mercury out of its products and find a substitute. Frequently, however, as will be discussed in a later section, this is practically impossible. Alternatively, the price of the manufactured product may be adjusted, leading possibly to competitive repercussions for that product.

Finally, the prevailing price level of mercury will have an impact on governmental actions. In general, the government will favor price stability. If prices are considered unduly low, a price support program could be initiated, as was in effect from July,1954 through December, 1958. If prices are deemed too high, one alternative action is the sale of mercury from government inventories. This course was taken, when on December 23, 1964, the General Services Administration announced that it would open bids on January 15, 1965 on the sale of 4,000 flasks of mercury.[6]

Other possible governmental actions include restrictions on foreign trade and special tax legislation. The extent to which the government seeks stability in mineral prices is indicated by the great lengths to which it went to obtain the repeal of price increases which had been announced by the copper, steel, and aluminum industries.

Neither the government, the consumer, the broker, nor the miner is independent from one another in the structure of the mercury industry. All are interrelated elements. Thereby, any discussion of the mercury market from the point

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6. Bureau of Mines Mineral Yearbook, 1964, Vol. 1, p. 862.

of view of one element must necessarily incorporate the effect of the market on each of the other elements. It is hoped that by pursueing the discussion from the point of view of the primary source of mercury--the miner--that little loss of generality will result.

The primary problem is that of forecasting a price level that will prevail some years from now. Each element of the interdependent system is related to price. Each influences and is influenced by the price. How much longer must the sale of mercury from government stockpiles continue? Should mercury be replaced by other materials in manufactured products? Will the demand for mercury be such that metal brokers cannot fill all orders? Just as the answers to each of the questions depends on the price of mercury, the price depends on each of the answers. The mine operator must consider all of these when he contemplates, "Shall I develop this mineral deposit which was not economic last year? Will it be economic next year?"

Purpose and Scope of Thesis

This thesis proposes to investigate the long-run price prospects for mercury and their effect on the mine that previously had been marginal.

In order that the scope of the investigation be kept within manageable limits, certain restrictions have been imposed. Most important is that the emphasis is placed heavily on the mercury industry of the United States, although Spain and Italy both produce more mercury than does the United States. Additionally, the U.S.S.R., Communist China, Yugoslovia, and Mexico all produce mercury in major quantities.

Thus sales of foreign mercury to foreign consumers are not considered. Sales of such mercury to American consumers are incorporated as imports. They are one of the three important supply determinants of price. The influence upon price of stimulated foreign production is not explicitly considered. The primary cause for this restriction is the absence of available data on marginal productive capacity in these countries.

Mercury mined in the U.S.S.R. or Communist China is not generally sold outside the Communist bloc. Thus its effect on price is not significant, excepting that it may be "dumped" to bring foreign exchange into the Communist bloc. Indicators are, however, that dumping is, for all practical purposes, non-existent. The Engineering and Mining Journal cites large Eastern European purchases from the Western European producers.[7] Indeed, this is one of the reasons for the current high level of prices.

Production from Spain, Italy, and other major nations do affect the world price. Although some term contracts do exist, nearly all mercury is sold in accordance with either New York or London price quotation. Because of the leveling effects of speculation, the difference between the New York and London quotations is almost never greater than the cost of tariffs and trans-Atlantic shipping. In the thirteen year period, 1951-1963, the New York price exceeded the London price by an average of only $12.66[8] (Range: $21.24 (1956)--$.54 (1954)). The tariff for importing mercury into the United States is $19 per flask.

However, the average difference in 1964 between the New York price and the lower London quotation was $32.52.[9] At one point during that year the difference

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[7] Engineering and Mining Journal, Feb. 1966, p. 118.

[8] Calculated from average prices of Bureau of Mines Mineral Yearbooks.

[9] Ibid.

was nearly $100. By June, 1965, the London price had exceeded New York's quotation by the same amount.[10] These variations are attributable to the instability of a rapidly rising market.

Nevertheless, despite the recent differences, in the long-run the London and New York prices may be expected to generally be no further apart then the costs of tariffs and transportation. Hence, the qualification that all prices in this thesis be New York quotations will not have a harmful effect.

Therefore, the limitations in the scope of this investigation may be summarized as follows. It is assumed that the United States consumption of mercury is satisfied by United States mine production, secondary production, and by imports; that United States supply (including imports) and demand interact, possibly incorporating a time lead or lag, with a United States price which is equivalent to the world price; and that data for the United States industry are capable of analysis for future trends in the United States industry.

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[10] Engineering and Mining Journal, Feb. 1966, p. 116.

CHAPTER III

HISTORY AND DEVELOPMENT OF MERCURY MINING

One of the determinants of priceing is the structure of the industry. In showing the structure, something must be said about the history of the mercury industry.

History of Usage

Mercury is believed to have been known to man since prehistoric times. A vessel containing mercury, found in a grave at Kurna in Mespotamia, was determined to be about 3500 years old. The use of mercury by priests was described by Aristotle nearly 2300 years ago.

Nineteen hundred years ago mercury was known to have been used in the amalgamation and refining of gold and in silvering; and its primary ore, cinnabar, was used for medicine and pigments. At that time, cinnabar was mined at the Almaden mine in Spain under an exclusive license from the Roman Government and was transported from where it was refined by retorting.

Through the Middle Ages mercury was in large demand by alchemists for its characteristic fusibility. Because of their experimentation, the physical properties of mercury were well-known by the sixteenth century.

The Spanish discoveries of large gold and silver deposits in Mexico and South America in that century and the need for mercury as an amalgamating agent created the first large-scale demand for the metal.

In the seventeenth and eighteenth centuries, mercury was in large demand for the manufacture of thermometers and other scientific instruments. In 1799, mercury fulminate was invented and the use of mercury became widespread in the preparation of explosives. In the 1890's, electrolytic mercury cells were first utilized to produce chlorine and caustic soda. This process has become a major consumer of mercury.

Within the twentieth century, mercury has found important new uses in dental preparations, medicines, anti-fouling and mildew-proofing paints, lamps, fungicides, the electronics industry, and so forth. Present-day uses of mercury will be discussed in greater detail in a later chapter.

Political Domination of Mining

The production of mercury has always been characterized by the domination of a very small number of major mines. Thus mercury as a commodity has been frequently subject to cartels and other artificial means of controlling production.

Mercury production began at the Almaden mine, in Cuidad Real Province, Spain, as early as 400 B.C. Operated under Iberian, Roman and Moorish control until 1151 A.D., the mine was transferred to the Knights Templars by Alfonso VII in that year and was later transferred to the military-religious Order of Calatrava.

The government of Spain repossessed the mine and subsequently leased it, for 120 years, to the Fugger brothers of Germany in 1525. Since the expiration of that lease the mine has been operated directly by an agency of the Spanish Government. In 1923, the furnaces built in 1651 were replaced. Production in 1961 was estimated as 50,000 flasks.

Until 1470, Almaden was virtually the only producer of mercury for western civilization. In 1470, the orebody of the Idria mine was discovered in the foothills of the Julian Alps, 25 miles northeast of Trieste. Production began shortly thereafter. Having once been, for many years, the only major source of mercury in Europe outside Spain, Idria has often been a source of political contention, having been variously under Venetian, Italian, Austrian, and Yugoslavian ownership. Control currently rests with the latter nation. Idria's

1961 production was about 15,000 flasks. Cumulative total output has been 2.5 million flasks.

Western Hemisphere Production

Western hemisphere production of mercury was first started in 1571 with the discovery of the Santa Barbara orebody in the Department of Huancavelica, Peru. Between 1571 and 1790, primarily, 1,470,000flasks of mercury were mined. Attempts to discover additional deposits at the mine have repeatedly failed.

California

Within the United States, itself, mercury was first discovered in 1834, by the Spanish explorers and settlers in the New Almaden area of California. The very rich orebodies of New Almaden were not found, however, until 1845. Large-scale mining was started five years later.

The New Idria orebody was reportedly discovered in 1853 by Mexican prospectors. Mining operations were begun the following year and have been essentially continuous since that time.

Gold discoveries in California from 1849 through the 1860's and the gold mining industry which was subsequently developed provided the impetus for the growth of mercury mining in that state. Mercury amalgamation was the principal process for separating native gold from its host rock in most mines.

In addition to the New Almaden district (Santa Clara County, California) and the New Idria district (San Benito and Fresno Counties), the major properties discovered through the 1860's include Guadalupe (Santa Clara County), Abbott (Lake County), Gibraltar (Santa Barbara County), Knoxville and Manhatten (Napa County), Oceanic and Klan (San Luis Obispo County), Manzonita (Colusa County), and St. Johns (Solano County). In the 1870's the Great Western, Helen, and Sulphur Bank mines of Lake County were brought into production, along with other smaller properties.

With one exception, no significant mercury deposits had been discovered in California since 1895. Only the Challenge Mine of the Emerald Lake district, San Mateo County, has been located since that time. It was discovered in 1955. All other discoveries have been in the form of additional orebodies at older mines.

Records show that California's mercury production in 1850 was 7,773 flasks. In the following year production was increased to 27,962 flasks. A peak was reached in 1876 and 1877 with production of 73,194 flasks and 79,917 flasks, respectively.[1] (Records of <u>national</u> mercury production from 1910 show at no time a greater level of production.)[2] The bulk of this output was utilized by the gold mining industry. Production in 1965 from California was 13,404 flasks, 68.5% of the national total.[3]

Oregon

Despite the extensive mercury industry that has been built up in California by 1865, it was not until that year that mercury was found outside the state, with the discovery of the Nonpareil and Bonanza mines in Douglas County, Oregon; and it was not until 1877 and 1879, respectively, that these properties were developed. Mercury mining in Oregon reached a peak in 1940 when twenty-

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[1] U. S. Bureau of Mines, <u>Mercury Potential of the United States, 1965</u>, p. 89, Output adjusted to flasks of 76 pounds.

[2] <u>Ibid</u>. p. 9.

[3] U. S. Bureau of Mines, <u>Mercury in the First Quarter of 1966,</u> p. 4.

three operating mines produced 9,043 flasks.[4] Output in 1965 was 1,364 flasks, 7% of the national total.[5]

Utah

In 1873 an occurrence of cinnabar was reported in the Camp Floyd district of Utah. Production did not begin in Utah until 1881, when a small quantity was extracted from the Lucky Boy mine. Peak production occurred in 1905 when 1,118 flasks were obtained, all as a by-product from the Sacramento Gold mine.[6] No mercury has been mined in Utah since 1942.

Nevada

Two years after its discovery in Utah, Mercury was found in Nevada. There was no significant production, however, until deposits near Ione were developed in 1909. Peak production did not occur until 1960 when 7,821 flasks were retorted.[7] Output in 1965 was 3,333 flasks, 17% of the nation's total.[8]

Arizona

The first discovery of cinnabar in Arizona was in 1878 in the Dome Rock Mountains. Mining in that area was begun twenty years later. Production has never been great, amounting to less than 7,500 flasks in sixty-eight years.[9] Only 158 flasks, less than 1% of the total United State's output, were produced in 1965.[10]

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[4] U. S. Bureau of Mines, Mercury Potential of the U. S., 1965, p. 301.

[5] U. S. Bureau of Mines, Mercury in the First Quarter of 1966, p. 4.

[6] U. S. Bureau of Mines, Mercury Potential of the U. S., 1965, p. 353.

[7] U. S. Bureau of Mines, Mercury Potential of the U. S., 1965, p. 218.

[8] U. S. Bureau of Mines, Mercury in the First Quarter of 1966, p. 4.

[9] U. S. Bureau of Mines, Mercury Potential of the U. S., 1965, p. 61.

[10] U. S. Bureau of Mines, Mercury in the First Quarter of 1966, p. 4.

Alaska

The presence of mercury in Alaska was noted in literature as early as 1884. Development was minimal, however, until the Red Devil and De Coursey Mountain mines were opened during World War II. The year of maximum production was 1951, with 5,461 flasks.[11] Output in 1964 was 303 flasks, and 1965 figures are withheld by the Bureau of Mines to avoid disclosure of individual company confidential data.[12]

Texas

Although the Indians of the Big Bend region had used cinnabar for making red war paint, mercury ore was not found in Texas by prospectors until the discovery on California Mountain. Mining began in 1897 and was continuous through 1945. After that time, the level of prices supported mining only in the years 1951, 1953, 1955-1960, and 1965. Peak production was 10,640 flasks in 1917.[13] Recent figures are withheld by the Bureau of Mines to protect individual company confidential data.

Idaho

The Hermes mine, in Valley County, was the site of the first discovery of cinnabar in Idaho, in 1902. The earliest recorded production was 1917, when five flasks of mercury were extracted from that mine.[14] 1943 was probably

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[11] U. S. Bureau of Mines, Mercury Potential of the U. S., 1965, p. 33.

[12] U. S. Bureau of Mines, Mercury in the First Quarter of 1966, p. 4.

[13] U. S. Bureau of Mines, Mineral Yearbook, 1960, Vol. 1, p. 787.

[14] U. S. Bureau of Mines, Mercury Potential of the U. S., 1965, p. 208, 212.

the year of Idaho's greatest production with 4,261 flasks.[15] In 1965, 1,119 flasks were produced, 5.7% of the country's total.[16]

Washington

In the state of Washington, mercury was not found until 1913 when Edward Barnum noticed cinnabar in a coal seam, southeast of Morton in Lewis County. In 1916 a retort furnace was erected there and the first flasks of mercury were produced. Maximum production probably occurred in 1929 with 1,397 flasks.[17] Production, since World War II, has been limited to the years 1957, 1958, and 1965.[18] Since 1935, production figures have been withheld to protect individual company confidential data.

Arkansas and Others

A latecomer to the ranks of mercury states is Arkansas, where mercury was first discovered and produced in 1931. Peak output was 2,392 flasks in 1942.[19] No production has been reported by the Bureau of Mines since 1946.

Occurrence of mercury minerals have, in addition, been reported in the states of Colorado, Montana, New Mexico, South Dakota, and Wyoming. No production has ever been reported in these states, however.

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[15] Ibid. p. 208.

[16] U. S. Bureau of Mines, Mercury in the First Quarter of 1966, p. 4.

[17] U. S. Bureau of Mines, Mercury Potential in the U. S., 1965, p. 354.

[18] U. S. Bureau of Mines, Mercury in the First Quarter of 1966, p. 4.

[19] U. S. Bureau of Mines, Mineral Yearbook, 1960, Vol. 1, p. 787.

For the United States as a whole, mercury production was greatest in the 1870's and was almost entirely from California. This was a period during which the United States was the world leader in the production of gold[20] and in which amalgamation with mercury was the primary method for separating native gold from its host rock. (The cyanide process for recovering gold was not put into use until about 1900.)[21]

Distribution of Production

Production figures for individual years are generally available only for the years after 1910.[22] Periods of high production relative to preceding and following years occurred in 1912, 1916-1918, 1929-1932, 1940-1945, and 1957-1961. Lowest production occurred during the periods 1914, 1921-1927, 1933, 1949-1951, and 1964.[23]

Production in 1965 was from eight states--each of those just reviewed, except Arkansas and Utah. Eight mines located in Alaska, California, Idaho, and Nevada supplied over 84 per cent of the 3,955 flasks of mercury produced in the first quarter of the year.[24]

Of the 14,142 flasks produced in 1964, three mines--the New Idria and the Buena Vista in California and the Cordero in Nevada--produced 75 per cent. Along with eight other mines--five in California, two in Alaska, and one in

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20. Ryan, J. P., "Gold," Mineral Facts and Problems, U. S. Bureau of Mines Bulletin 585, 1960, p. 347.

21. Homestake Mining Co., The Homestake Story, Lead, S.D., 1960, p. 7.

22. 1910 was the founding year of the U. S. Bureau of Mines.

23. U. S. Bureau of Mines, Minerals Yearbook, 1960, Vol. 1, p. 787.

24. U. S. Bureau of Mines, Mercury in the First Quarter of 1965, p. 3.

Nevada--they accounted for 95 per cent of the national total. The remaining 5 per cent was divided among an additional 61 mines--32 of them in California and 19 in Nevada. These two states produced 96 per cent of the nation's mercury in 1964--73 and 23 per cent respectively.[25]

Summary

The structure of the American mercury mining industry emerges as the following: All mines are located in the western portion of the Unites States and cinnabar deposits having any potential commercial value are entirely unknown east of Arkansas. Except for some California mines, the industry is less than a century old. (In contrast, the Almaden mine of Spain, still the world's largest producing mine, has been in operation over 2300 years.)

Structure of Mining Industry

Production is dominated by a few large mines and a moderate number of medium-sized mines. The bulk, however, are mines which produce fewer than 100 flasks yearly and might, therefore, be considered marginal operations which would be profitable only under favorable economic conditions.

The Bureau of Mines statistics clearly show the dominance of the larger mines.[26] (Table III).

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[25] U. S. Bureau of Mines, Minerals Yearbook, 1964, p. 862.

[26] U. S. Bureau of Mines, Mineral Yearbooks, 1960-1964, Vol. 1.

Table III

Distribution of Mercury Production in the United States

Production of 1000 Flasks or More

Year	No. of Mines	% of National Production	States
1964	3	75	Calif., Nev.
1963	3	89	Calif., Nev.
1962	4	90	Calif., Nev.
1961	8	92	Calif., Nev.
1960	6	85	Calif., Nev.

	Production of 100-999 Flasks			Production of less than 100 Flasks		
Year	No. of Mines	% of Nat. Prod.	State	No. of Mines	% of Nat. Prod.	State
1964	8	20	3	61	5	6
1963	5	8	4	39	3	6
1962	4	7	1 (Calif.)	48	3	5
1961	10	6	4	51	2	5
1960	14	13	4	55	2	6

On a world-wide basis, a similar pattern can be noted. There are a small number of nations which account for a large percentage of world production. A few more nations produce only a small percentage and even more have no commercial orebodies whatsoever.

Figures for 1965[27] showed that a mere seven nations--Communist China, Italy, Mexico, Spain, the United States, the U.S.S.R., and Yugoslavia--account for nearly

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[27] U. S. Bureau of Mines, Mercury in the First Quarter of 1966., p. 5.

95 per cent of world production. The remainder is divided among only eleven other nations. Tunisia, for example, is the only producing nation in Africa, yet produced only 174 flasks. Bailey and Smith[28] state that "Of the entire world production...three-fourths (has come) from only six mines or districts."

Statistics such as these would infer that there are a few large orebodies, but that the vast majority are not of this class. Most would be only small deposits or larger deposits that are now nearly exhausted. These would be expected to support marginal operations only under favorable economic conditions.

In appraising these operations one should have a clear understanding of the geologic nature of deposits from which mercury can be extracted.

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28. Bailey, Edgar, H., and Roscoe M. Smith, "Mercury--Its Occurrence and Economic Trends," Geological Survey Circular 496, Washington: U. S. Geological Survey, 1964, p. 2.

CHAPTER IV

GEOLOGY OF MERCURY DEPOSITS

Mercury ores are generally of two mineralogic types: 1) Native mercury (Hg) or 2) Cinnabar (HgS). The latter is, by far, the more important source and contains 86.2 per cent mercury. Although other mercury minerals do occur, these are comparatively quite rare.

Genesis and Its Implications for Exploration

Economic geologists agree that mercury-bearing bodies are generally of an "epithermal" type; that is, they are deposits formed near the surface by ascending thermal waters and in genetic association with igneous rocks.

Lindgren[1] declares that "the uniform character of the quicksilver deposits points to a common genesis for all of them... Their structure indicates deposition near the surface, as does also the physiographic evidence at many places...

"When it is noted that hot springs and volcanic surface flows are present in almost all regions of importance (except at Almaden and Idria,) and that cinnabar in considerable quantities is associated with hot spring deposits, the argument becomes very strong indeed that such solutions have formed the majority of the deposits. For the few deposits that have no such clear connection with volcanic rocks, the characteristic mineral association still holds good, and we are forced to the hypothesis that volcanism and hot-spring action are the causes of these also, though the products of the igneous activity may have

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1. Lindgren, Waldemar, Mineral Deposits, New York: McGraw-Hill Book Company, Inc., 1933, p. 471.

failed to reach the surface and the hot springs may have subsided."

Since, typically, cinnabar bodies are associated with hot springs and volcanism, areas of recent tectonic and volcanic activity, such as the western portion of the United States, provide a very favorable environment for the existence of economic orebodies.

Of major importance is the shallowness characteristic of mercury deposits. Bailey and Smith[2] point out that half of the domestic mines which have yielded over 100 flasks of mercury are less than 200 feet deep and that only six of the larger domestic mines are more than 1000 feet deep. Lindgren[3] also notes that very few deposits have been profitable to a depth of 1,500 feet.

A major effect of such a characteristic is to severely limit the extent of potential ore reserves at mercury mines. The only likelihood of ore at depths greater than, say, 2000 feet would be that it be part of a very large body never exposed to surface erosion. This would seem improbable.

Another effect is the restriction which it places upon exploration. The absence of erosion is a critical factor in the preservation of these near-surface deposits. Consequently, areas where older rocks are exposed through erosion can almost certainly be excluded from consideration.

Bailey and Smith[4] further emphasize these factors by concluding that "it would be useless to look for epithermal mercury deposits in any of the major regions of the United States other than those in which mercury has already been formed."

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[2] Bailey and Smith, Op. cit., p. 1.

[3] Lindgren, Op. cit., p. 465.

[4] Bailey and Smith, Op. cit. p. 1.

Structurally, the most productive deposits are generally typified by major folding and faulting and by numerous shear and facture zones. These would develop permeability for the mercury-bearing solutions. Also characteristic of major mercury orebodies are rock alterations, frequently of a silica-carbonate type. The presence of such alteration is a very favorable indicator in many mercury districts in California.[5]

The massiveness of mineralization is a guide to the richness of the deposit. Widespread areas of mineralization, in zones, veins, or fracture fillings offer, at a minimum, production potential of lower grade material and indicate the possible existence of high-grade deposits. Where mineralization consists only of cinnabar stains and thin fracture coatings and lacks areas of local enrichments, mining can be economic only at elevated prices.

Mineralogy

Mineralogically, the primary ore of mercury is cinnabar (HgS). Except, as noted below, orebodies are mined for mercury along; nor is mercury obtained as a by-product in the mining of other ores. Therefore, mining activity is a function of the price of mercury only, and not of the price of other ores.

The rare exceptions to the isolation of mercury from other ores are in Chile, Czechoslovakia, and Tunisia where very minor amounts are mined as by-products of gold, iron, and lead, respectively. Ores from Huitzuco, Mexico yield both mercury and antimony. The ores of the Red Devil Mine, in Alaska, contain more antimony than mercury. However, the antimony is not recovered from the ore.[6]

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[5] U. S. Bureau of Mines, Mercury Potential of the United States, p. 14.

[6] Bailey and Smith, Op. cit., p. 2.

Geologic Examples

Despite generalities, no two orebodies are exactly alike. Brief sketches of a few individual deposits may serve as examples of the variations encountered.

Spain

The richest mercury mine in the world is the Almaden in Spain. Even though it has been worked for over 2,000 years, it is, according to Bateman,[7] "capable of supplying the world for the next 100 years."

The ore occurs as cinnabar replacement of sandstone grains in three factured beds of steeply dipping Silurian quartzite, separated by bituminous slates. The orebeds may attain a maximum width of 25 meters and in several places average 20 per cent mercury. The richest portions of the deposit occur as massive bands of cinnabar. The low-grade portions occur as stringers and inclusion of mercury minerals in the quartzite.

Diabase dikes are present near the deposit. Van der Veen[8] correlates these with Tertiary diabase dikes common in many parts of Spain and proposes that the cinnabar replacement ores are probably of the same age.

Italy

Other mercury orebodies are formed by the filling of pores and cavities rather than by replacement. Typical of these are the Italian ores. At Idria, the ore is richest in open-textured sandstones, rich in the dolomite breccia, and lean in the bedding planes and small fractures of the bedded dolomite.

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[7] Bateman, Alan M., Economic Mineral Deposits, New York: John Wiley & Sons, 1950, p. 615.

[8] Van der Veen, R. W., "The Almaden mercury ores and their connection with igneous rocks." Economic Geology, Vol. 19, March 1924, pp. 146-156.

Lindgren[9] considers the deposition "certainly post-Cretaceous, probably Tertiary."

At Monte Amiata, the late Pliocene ores are primarily low-temperature, hydrothermal fillings of solution cavities, crushed zones, sandstone pores, and especially of trachyte conglomerate. They lie at intersections of minor fractures with a major fracture that cuts Mesozoic and Tertiary sediments capped by a trachtye flow from the Monte Amiata volcano.

United States

In the United States, mercury deposits are limited almost entirely to the youngest tectonic region of the nation. They are found primarily in Alaska and in a belt west of the Rocky Mountains. Isolated deposits have been located also in Texas and in Arkansas.

In California can be found almost all of the various types of structures associated with mercury deposits. Slightly more than half of the deposits occur in altered serpentine (silica-carbonate rock.) (Minerals formed by alteration of this rock include quartz, chalcedony, calcite, dolomite, and other carbonates.) Another 30 per cent are found in the sedimentary rocks of the Franciscan Group. (Upper Jurassic?) with which the serpentine is associated.[10]

Deposition in the serpentine and in the Franciscan Group has been favored by extensive facturing where the mercury minerals have formed in the interstices of porous or brecciated rocks. Especially rich deposits have been found

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[9] Lindgren, Op. cit., p. 467.

[10] Davis, Fenelon F., "Mercury" from: California Division of Mines, "Mineral Commodities of California," Bullentin 176, Dec., 1957, p. 341,(pp. 341-356).

beneath shales, volcanic flows, fault gouge and other materials which act as an impermeable barrier above the porous zone and thus trap ascending metalliferous solutions.

Mercury bodies in California occur also in the Knoxville (Upper Jurassic) sedimentary rocks, and in younger Lower Cretaceous sedimentary and Tertiary volcanic rocks. Small amounts of cinnabar have been obtained from placer and hot spring deposits.[11]

New Almaden

New Almaden, although no longer a significant producer, is the most prolific mine in the United States in terms of culmulative production. The mercury deposits are in rocks of the Franciscan Group. These include graywacke, arkose, sandstone, shale, conglomerate, chert, limestone, altered volcanics, and some metamorphic rocks.

The area contains a northwest-trending anticline whose southwest limb has been highly sheared. Two major sills of serpentine appear to have intruded the northeast limb, converged near the crest of the anticline, and proceeded down the southwest limb. The margins of the sills were later altered to a silica-carbonate rock and were eventually replaced along a series of northeast-trending fractures by cinnabar, carried in alkaline solution, to form large, rich orebodies.

The richness of the bodies was without question largely due to the presence of the overlying "alta", a slickensided clay, forming a barrier

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[11] Ibid.

impermeable to the rising alkaline solutions. The largest orebody mined was 200 feet wide, 15 feet thick, and 1500 feet in down-dip length. Over its productive life, the New Almaden ores have averaged barely under 4 per cent mercury.[12]

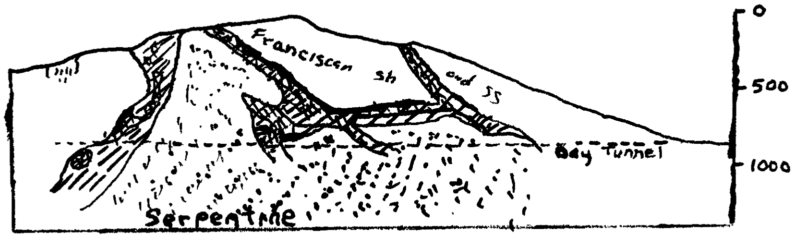

Fig. 1. -- Generalized section through New Almaden mine. California, along the Day tunnel. Shaded areas indicate the fractured zone; cross-hatched areas indicate ore; "alta" shown in black. (After C. N. Schuette.)

New Idria

The New Idria mine of California ranks second in total production and for the last several years has been the American leader in annual production. The structure of the district is that of a northwest-trending, eroded, assymmetric, anticlinal dome, believed formed by the intrusion of a serpentine core into the Franciscan sandstone. Above the sandstone are the Panoche (Upper Cretaceous) shale and sandstone and Tertiary sedimentary rocks. Steep faults cut the serpentine-Franciscan and Franciscan-Panoche contacts.

At the New Idria mine, on the northeast flank of the dome, the serpentine and Franciscan sandstone override crumpled Panoche shales along the New Idria thrust fault. Irregularities in the fault plane determine the shape of the

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[12] Bailey, E. H. "The New Almaden Quicksilver Mines", California Division of Mines Bulletin 154, 1951, pp. 263-270.

underlying zone of altered and indurated shales and the configuration of the orebodies which they contain. Veins and stockworks of fractures filled with cinnabar comprise most of the ore. Where fracturing has been most intensive, rich orebodies have been formed. The richest orebody was 300 feet long, 800 feet wide, and 25-150 feet thick. It occupied a steep inverted trough at the intersection of a tear fault with the New Idria thrust fault.[13]

Texas and Arkansas

The mercury deposits of Texas and Arkansas are not related geologically to those west of the Rocky Mountains. The Texan deposits are located primarily in Brewster County, near the Rio Grande and the Mexican border. They occur in folded and shattered Cretaceous limestone. The principal producer had been the Chisos mine where ore was found, along with boulders and clay, in cavities and caves which occur along fault planes and near the crests of intensively jointed anticlines. The overlying Del Rio clay acted as an impermeable barrier to the ascending hydrothermal solutions carrying the cinnabar. Surface alterations have yielded native mercury, terlinguaite, eglestonite, montroydite, and calomel. The ores have contained an average of only 0.5 per cent mercury, although the richest ores can reach 2 per cent.[14]

Arkansas deposits are very small mineral bodies, the largest being 100 feet long, 30 feet wide, and 120 feet high. They are usually either pipe-like or tabular in shape. The former occur at structural intersections and the latter

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[13] Eckel, E. B., and Myers, W. B., "Quicksilver Deposits of the New Idria District, San Benito and Fresno Counties, California," California Division of Mines, Report 42, 1946, pp. 81-124.

[14] Bateman, Op. cit., pp. 617-8.

essentially parallel sedimentary bedding. Mineralization is attributed to solutions ascending major fault planes and spreading out along subordinate faults and into folds. The host rock is typically a sandstone. Localization of the mineral bodies was controlled apparently by the increased permeability of the sandstone as a result of folding and faulting and by a relatively impermeable shale cap acting as a trap.[15]

Marginal Deposits

It is obviously beyond the scope of this investigation to discuss the geology of each known mercury deposit in the country. A brief description has been given above of a few mining districts and mines. The staff of the U. S. Bureau of Mines in Mercury Potential of the United States (1965) has itemized, by state, 452 mines and prospects and 556 occurrences[16] (deposits with no recorded production) and briefly discusses each of them, giving the geology, productive history, and conditions of mine workings and equipment, if any. The reader is referred to that publication for information on specific deposits and districts.

Since, however, this investigation is concerned largely with marginal mines, descriptions of two marginal deposits will be cited from that report. These are not, however, intended to be representative of all marginal mercury deposits.

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[15] U. S. Bureau of Mines, Mercury Potential of the United States, 1965, p. 79.

[16] U. S. Bureau of Mines, Mercury Potential of the United States, 1965, p. 16.

The Helen Mine, California, "is a wide fault zone between serpentine and Franciscan sandstone which strikes northwest and dips southwest. An irregular, discontinous ledge of silica-carbonate rock occurs along the footwall of the fault zone, which ranges in width from a few feet to over 150 feet. Highly altered basalt dikes occur in the serpentine and the main fault. Principal orebodies are in silica-carbonate rock, although some ore occurs in dikes and in the sandstone hanging wall. Ore in the silica-carbonate rock consists of veinlets and disseminations of cinnabar. Native mercury occurs to a lesser extent and metacinnabarite and tiemannite have been reported. Disseminations of cinnabar also occur in the basalt dikes. Grade of the ore ranges from 5 to 15 pounds mercury per ton.

"Mine workings include over 5,000 feet of adits, drifts, and crosscuts on three main levels, several intermediate adits, and numerous raises, winzes, and stopes covering a strike length of about 16,000 feet over a vertical range of 300 feet. Older workings are caved; recent openings on the 70- and 300-levels are accessible."[17]

The mine has produced over 7,000 flasks of mercury in intermittent operations since 1900.[18] The California Division of Mines and Geology reported that, in 1964, it was under development by the Stauffer Chemical Corporation.[19]

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[17] Ibid, p. 108.

[18] Idem.

[19] Davis, Fenelon F., "Mercury-Volatile in 1964!", Mineral Information Service, California Division of Mines and Geology, Vol. 18, No. 2, February, 1965, p. 25.

The War Eagle Mine, Oregon, has a total production of over 600 flasks.[20] "Two forms of mineralization are present on the property. In the western part, the Rainier vein is in a fault zone in which cinnabar associated with marcasite occurs in silicified fault breccia. The ore contains considerable arsenic which caused some difficulty in the reduction plant. The fault is in the May Creek schist and strikes N 70° W, dipping steeply toward the northeast. On the bank of Rattlesnake Creek, cinnabar was found in a 4-foot coal or lignite seam interbedded in shales and sandstones of the Umpqua Formation. The coal contains variable amounts of cinnabar.

"The Rainier vein was developed by two adit levels which opened two ore-bodies; one was 175 feet and the other 200 feet in length. Workings totaled more than 2,400 feet."[21] Reportedly, the mine was being opened in the early part of 1965.[22]

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[20] U. S. Bureau of Mines, *Op. cit.*, p. 324.

[21] *Ibid.*, pp. 308-9.

[22] *Engineering and Mining Journal*, Vol. 166, No. 4, April, 1965, p. 154.

CHAPTER V

MINERAL PROCESSING AND ITS ECONOMICS

Having considered the geologic environments of mercury deposits let us discuss briefly the actual mining and milling of mercury deposits[1] and the economics thereof.

Mining

Both underground and surface methods are used in mining mercury, the former accounting for about 90 per cent of total domestic production.

Most of the underground mining is by the square-set stoping method or some modification thereof, particularly in the larger mines. Shrinkage or sublevel stoping methods are occasionally used.

Underground mining procedures can yield to 300 tons of ore per day for treatment at the larger mines. The daily yield of a marginal mine might, of course, be much less. Production per man-shift averages less than five tons.

Open pit mining is done by the usual drilling, blasting and loading. Mechanical loaders, or power shovels, usually of less than one-cubic-yard capacity, load the ore onto dump trucks which transport it to the milling plant. Open pit mines generally yield up to 175 tons of ore per day, but productivity ranges as high as 40 tons per man-shift.

Typical of small-scale open pit operations is that of the Crawfoot Lumber and Mining Company in the Antelope mining district of Pershing County, Nevada. There, eight men are employed in round-the-clock ore stripping operations,

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[1] U. S. Bureau of Mines, "Mineral Facts and Problems," Bulletin 630, 1965, pp. 573-581.

recovering an estimated 85 per cent of the mercury. The mill has a capacity of 45 tons per day.[2]

Milling

Compared to the milling of ores of other metals, the treatment of mercury ores is relatively very simple, encouraging the marginal operator with only a minimum amount of capital available for investment.

The initial step in the milling of mercury ore is crushing. Material not crushed finely enough to pass through a sizing screen can be recycled or, if of too low a grade, rejected. The material can also be upgraded by hand sorting. Concentration of material by flotation is efficient and produces a high-grade concentrate. Flotation, if used, necessities fine grinding and an ample water supply.

The primary purpose of crushing is to reduce the raw ore to a size suitable for furnacing. Mercury is extracted from the ore or concentrate by heating in retorts or furnaces to liberate the metal as a vapor. The vapor is then cooled and collected as it condenses. The mercury condensate may contain some soot and dust which can be separated by hoeing the mixture with lime. Mercury from this operation is clean and sufficiently pure for marketing.

Retorts are inexpensive installations for small operators and require only simple firing and condensing apparatus. They are best suited to operations treating 500 tons per day of high-grade sorted ore. One of the most objectionable and costly features of retorts is the manual charging and removal of material.

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2. Engineering and Mining Journal, Vol. 167, No. 1, January, 1966, p. 128.

In larger operations, either rotary or multiple-hearth furnaces with mechanical feeding and discharging devices are used. Standard furnace capacities range from 10 to 100 tons per day or greater.

Mercury can also be extracted for its ore by leaching with a solution of sodium sulfide and sodium hydroxide and recovered as the metal by precipitation with aluminum or by electrolysis.[3] Leaching of mercury ores has not been widely utilized because of reagent-consuming constituents in some ores, irregularities in the compositions of ores, and the cost of fine grinding. Studies have shown, however, that some of these objections may be overcome by concentrating the ore by flotation and leaching the resultant concentrate.

The metallurgical processes by which mercury is extracted from cinnabar ore, as has just been shown, fairly straightforward and uncomplicated. Unlike the miners of copper-lead-zinc ores, for example, the operators of mercury mines can market a refined product of sufficient purity that it may be directly adapted to almost all end uses.

Cost of Mining

Although the extracting apparatus is relatively inexpensive, this should not imply that costs are unimportant. The truly marginal operator can be as easily closed down by rising costs as by falling prices.

The cost of mining one ton of ore sets a lower limit upon the price acceptable for the amount of metal derived from that ton of ore. This limit

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3. Von Bernewitz, M. W., "Occurrences and Treatment of Mercury Ore at Small Mines," Information Circular 6966, U. S. Bureau of Mines, 1937, 40pp.

varies from ton to ton in accordance with the grade, or metal content, of the ore. Grade, therefore, is the measure by which the material which can be mined at a profit under given price and cost conditions is separated from that which can not. Only the former can, by definition, be classified as "ore." It is fallacious to assume should a portion of a cinnabar deposit be classified as ore, that the full mercury content of that deposit is economically minable. In the long-run situation, such material as does not meet at least the variable costs of mining should remain unmined. It is not ore.

All the revenue which the mercury mine operator receives is generated from the sale of metallic mercury. At no domestic mercury mine is a salable by-product extracted which would contribute to revenue and counteract low mercury grades. Mercury, alone, must bear the cost of mining. If the average cost per ton of ore mined exceeds the average revenue per ton, then the mine will soon close. And here, also, the "cost of mining" must have an expanded meaning.

The "cost of mining" encompasses not only the labor, materials, power, and ore haulage actually utilized in the mining operation, but also the fuel, labor, and material costs of milling. It must provide for depreciation of the capital equipment used in mining and milling and for its maintenance. It includes marketing and administrative costs as well as overhead. Mine development expenses also must be covered. Taxes, of several types, must be paid. The mine operator, of course, is entitled to a profit or return on his investment. Finally, since the ore is not in infinite supply, operations must yield enough additional income to pay for successful exploration for a new mineral body of economic value. Without this final item, the company would have to be liquidated within a few years--generally under ten--due to exhaustion of its mineral resources.

Each of these items listed above are expenses which must be paid if the mine is not to go bankrupt. And as previously mentioned, the sole source of revenue is the sale of extracted mercury.

Whereas price information is readily available from a number of published sources, cost data are generally regarded as confidential because of the intense competition faced by most mining concerns.

The cost of mining--in both the broad and the narrow sense--has been continually rising. The cost of mining, in the narrow sense--per ton of <u>unconcentrated</u> ore handled--is expected to be approximately of the same order of magnitude in the case of cinnabar ore as for other ores mined by the same methods. Strict comparisons among metals, however, is complicated by the practice of reporting costs in terms of dollars per pound (or ton) of metallic end-product. Apparent cost differences are created by contrasts in recovery factors, concentration ratios, and in metalic content of ores. Moreover, although methods of mining and concentration may be basically alike, the flow of ore material from unmined ore to final concentrate is generally custom-designed for each mine. Slight equipment and flow differences will result in differing efficiencies and thus in cost differences. The flow capacity of the mine--in tons per day--definitely effects efficiency.

Samuel H. Williston, now president of the American Quicksilver Institute, told a committee of the United States House of Representative that labor costs, in most underground mines, comprise about 50% of the total mining costs. He stated, furthermore, that mining costs had tripled between 1939 and 1953.[4]

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[4] House of Representatives Select Committee on Small Business, <u>Problems in the Metal Mining Industry (Lead, Zinc, and Other Metals)</u>, Washington: United States Government Printing Office, 1953, p. 165.

Little has yet been said about the effects of economics of scale upon mining costs. Compared to orebodies of other metals, those of mercury have to be considered small. Costs are thus expected to be higher than the cost average index for all metals. Relative inefficiency of operation is even more emphasized for the marginal mine. Of 87 mercury mining establishments in 1954, 74 had four or fewer employees.[5]

Brooks gives the following cost data for mercury mines in 1956 and 1957 and further contrasts the cost problems faced by marginal operators:[6] "In 1956, the seven mercury mines producing 74 per cent of domestic output had average total costs per flask that varied from $163 to $361. The average for all seven weighted by production was $238. In the following year, the ten mines producing 80 per cent of domestic output (including the same seven plus three other mines) had average total costs that varied from $173 to $583. But the weighted average for all ten was $231, only $60 higher than the lowest cost producer's average and even lower than the weighted average for 1956, which indicated that most of the metal was produced in the lower part of the range. At the same time the more than 100 other operators producing 20 per cent of the output all had costs at least as high as the upper part of the cost range for these ten mines."

It should now be apparent that one of the major factors--if not the most important single factor--in determining the cost of mining is the magnitude of operations and resulting efficiency of scale. Yet this cannot be synthesized from any government-published statistical index.

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5. Brooks, David B., "The Supply of Individually Mined Minor Metals and Its Implications for Subsidy Programs," Land Economics, Vol. 40, No. 2, Feb., 1964, pp. 21-22.

6. Ibid., pp. 22-23.

Although the weighted cost average for all major producers decreased in 1957, it should be noted that costs for the most efficient producer in 1956 increased at least six per cent in the following year. The decreased weighted average can be accounted for by the most efficient mine's increasing its share of total production.

Representative Wayne Aspinall (D - Colorado) in a 1966 letter to the federal government's General Services Administration stated that many United States mines are not able to produce mercury at under $400 per flask.[7]

Average mine costs underground in the United States range from $20 to $30 a ton, according to Mr. Samuel H. Williston, President of the American Quicksilver Institute.[8] Surface mining costs plus furnacing costs rarely go below $8 to $10 per ton including stripping required and unavoidable dilution.

Assuming an average grade of 7.2 pounds per ton of ore (the latest average grade released by the United States Bureau of Mines--for the year 1964), the average cost of mining per flask would be $211 to $317 underground and $85 to $105 by surface mining. This would probably be an increase from the 1956-1957 costs, but like that figure would not be representative of costs at a marginal mine.

Alex Rorabaugh, the former operator of a small mine in California states, "a lot (of money) has been spent trying to reopen old workings, core drilling, putting in new rotary furnances, small retorts, and now leaching plants.

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[7] E&MJ Mineral Metal Markets, Vol. 40, No. 22, May 30, 1966, p. 3.

[8] Williston, S. H., Personal Communication, March 29, 1966.

Right now most are going broke at $375 f.o.b. San Francisco." He believes that $325 is the minimum market price at which the operators of small mines can hope to avoid bankruptcy.[9]

The Buttes Gas and Oil Company, owner of the Gambonini Mine in California, considers $400 to be the minimum market price at which mining operations would be feasible.[10]

Role of Ore Grade

The average grade of ore that is being mined would be expected to gradually decrease as reserves are depleted in filling the demands of consumption, barring the discovery of a major orebody. Data from 1927 through 1964 do not show a significant trend in this direction, however. Table IV below shows, for the years 1927-1964, how the average grade of ore mine has varied.[11] It shows also the variations in the number of flasks produced, the quantity of ore treated, and in the average price of mercury, in current and constant dollars.

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[9] Rorabaugh, A. D., Personal Communication, April 1, 1966.

[10] Thamer, D. H., Buttes Gas and Oil Company, Personal Communication, April 25, 1966.

[11] U. S. Bureau of Mines, Minerals Yearbook, Vol. 1, 1960 and 1964.

Table IV

MINE PRODUCTION AND PRICES, 1927-1964

Year	Average Grade of Ore (Pounds Hg/Ton)	Mine Production (Flasks)	Ore Treated (Short Tons)	Average Price of Mercury	
				(Current $)	(Constant $) (1957-9=100)
1927	8.1	11,128	99,969	118.16	226
1928	7.9	17,870	142,131	123.51	233
1929	6.0	23,682	248,314	122.15	234
1930	4.9	21,553	288,503	115.01	243
1931	6.6	24,947	260,471	87.35	219
1932	8.3	12,622	108,118	57.93	163
1933	8.2	9,669	78,089	59.23	164
1934	8.2	15,445	126,931	73.87	180
1935	8.6	17,518	135,100	71.99	164
1936	7.5	16.569	141,962	79.92	181
1937	6.6	16,508	186,578	90.18	191
1938	6.8	17,991	199,954	75.47	176
1939	7.3	18,633	191,892	103.94	246
1940	6.3	37,777	449,940	176.87	411
1941	5.1	44,921	652,141	185.02	387
1942	5.1	50,846	733,360	196.35	364
1943	6.3	51,929	613,111	195.21	346
1944	9.4	37,688	300,385	118.36	208
1945	10.8	30,763	209,009	134.89	233
1946	12.0	25,348	157,469	98.24	149
1947	12.5	23,244	139,311	83.74	103

Year	Average Grade of Ore (Pounds Hg/Ton)	Mine Production (Flasks)	Ore Treated (Short Tons)	Average Price of Mercury (Current $)	Average Price of Mercury (Constant $) (1957-9=100)
1948	10.2	14,388	103,220	76.49	87
1949	10.3	9,930	71,977	79.46	95
1950	9.3	4,535	35,115	81.26	94
1951	6.5	7,293	81,067	210.13	217
1952	7.0	12,547	135,197	199.10	212
1953	7.8	14,337	138,090	193.03	208
1954	8.1	18,543	174,083	264.39	285
1955	6.4	18,955	222,740	290.35	312
1956	7.5	24,177	244,148	259.92	270
1957	8.4	34,625	309,632	246.98	249
1958	8.6	38,067	328,155	229.06	228
1959	8.6	31,256	275,903	227.48	226
1960	9.7	33,223	258,071	210.76	209
1961	9.2	31,662	262,108	197.61	197
1962	13.6	26,277	146,523	191.21	191
1963	12.8	19,117	113,539	189.45	189
1964	7.2	14,142	149,950	314.79	314

It can be noted that the lowest grades were mined in the years 1929-1930 and 1940-1943. In both periods production, in terms of the quantity of ore treated, is very high relative to neighboring years. At both times, constant dollar prices were at unusually high levels. In 1929-1930, mining activity was spurred by an eight year record of great United States consumption, of which the domestic mining industry could generally supply no more than 50 per cent.[12] The Great Depression had no effect at all upon constant dollar prices for mercury until 1931 and 1932. The high price of mercury in 1940-1943 was sustained by the demands of World War II and the limitations on imports from Spain and Italy, until then the world's greatest mercury producers.

During the 1929-1930 and 1940-1943 periods, therefore, there was great pressure on the domestic mercury mines to increase production, resulting in the mining of lower grades of ore and in the initiation of mining activities at deposits where mineral grades were not otherwise economic. The natural consequence of these actions was an increase in the amount of ore treated, at the expense of the average grade of ore. The high prices of those years made mining such ores economically possible.

The average grade of ore processed is seen to have reached its peak in 1945-1949. Conversely, this was the time in which real prices reached their lowest levels--the war-created demands had disappeared. (Demand in 1946 fell to approximately half its 1945 level as previously stockpiled inventories were depleted.) When both demand and prices fell, a large fraction of the mines which had operated economically on lower-grade ores during World War II could

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[12] U. S. Bureau of Mines, <u>Minerals Yearbook 1960</u>, Vol. 1, pp. 784-5.

no longer earn a profit and were forced to close down. The end result was that lower grade ores could no longer be mined and the average grade of ore processed had to increase.

Figure 2 shows a fairly strong linear trend of average ore grade vs. numbers of short tons of ore treated. It is evident that as the average grade of ore drops, the quantity of ore treated increases, and vice versa. This indicates that as lesser grades of cinnabar become economic, mines are re-opened and existing operations are expanded. This, of course, should correlate with increased price.

A less strongly inverse linear trend is that of average ore grade vs. mercury production (in flasks)--Figure 3. Such a trend is particularly vague in the region of low-grade and low production. This would follow from the simple consideration that, for example, a large tonnage of low grade ore may yield the same number of flasks of mercury as a small tonnage of high-grade ore. Thus, because of an inverse linear relationship between ore grade and tonnage mined, a fairly constant output of mercury might be expected, regardless of the average grade of ore. Nevertheless, as Figure 3 shows, whenever the grade has averaged over 10 pounds per ton, output has not been greater than 30,000 flasks. The response of output as a function of price will be examined in a later section.

Grade-Price Relationship

Above it was suggested that the average grade of ore mined is a function of price--the average grade decreasing as price increases, and vice versa. Figure 4 attempts to depict this relationship. It shows average grade as a function of both current dollar and constant dollar prices. Current dollar prices are the actural prices paid for mercury as reported yearly by the

Fig. 2 Ore Grade vs. Ore Tonnage Treated

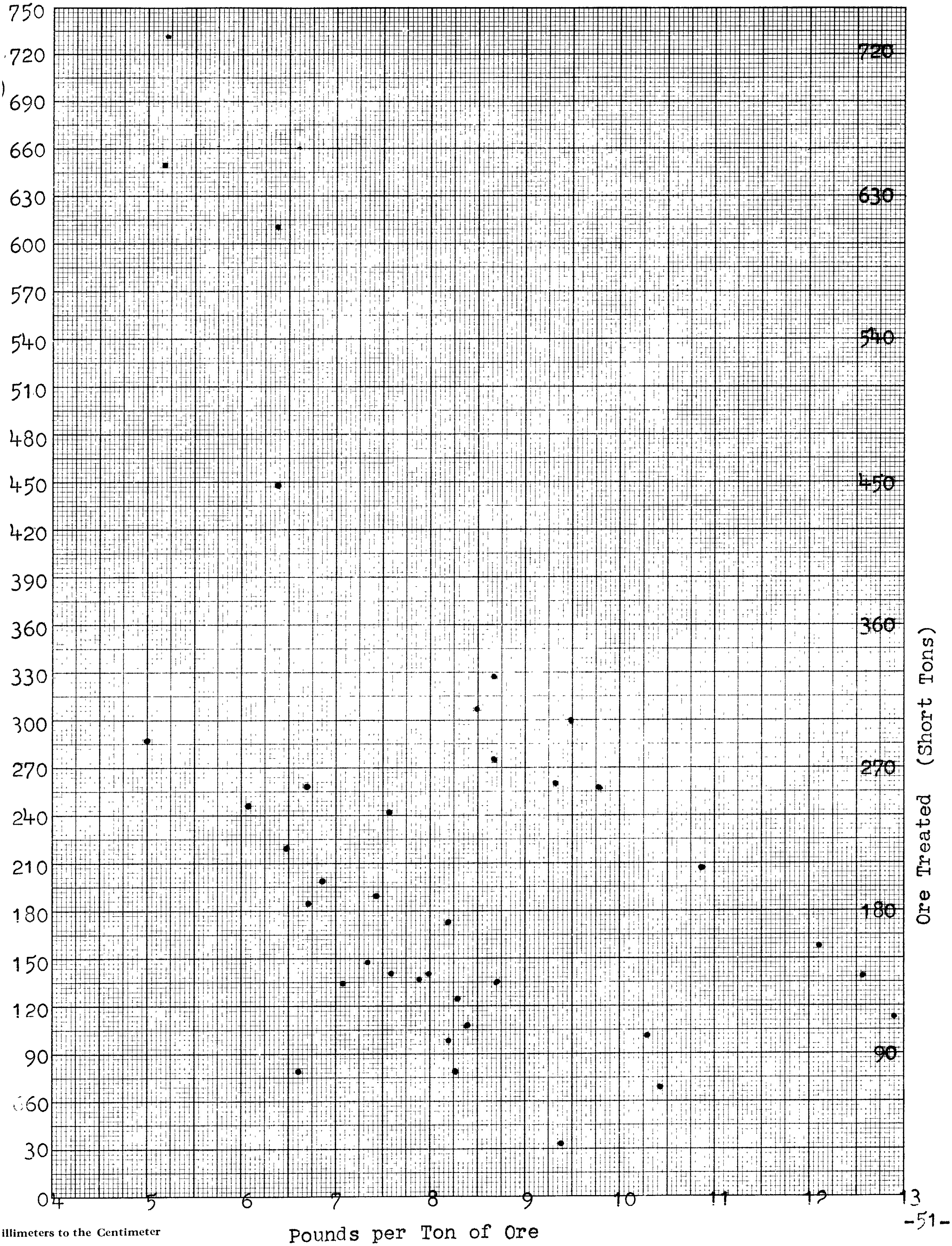
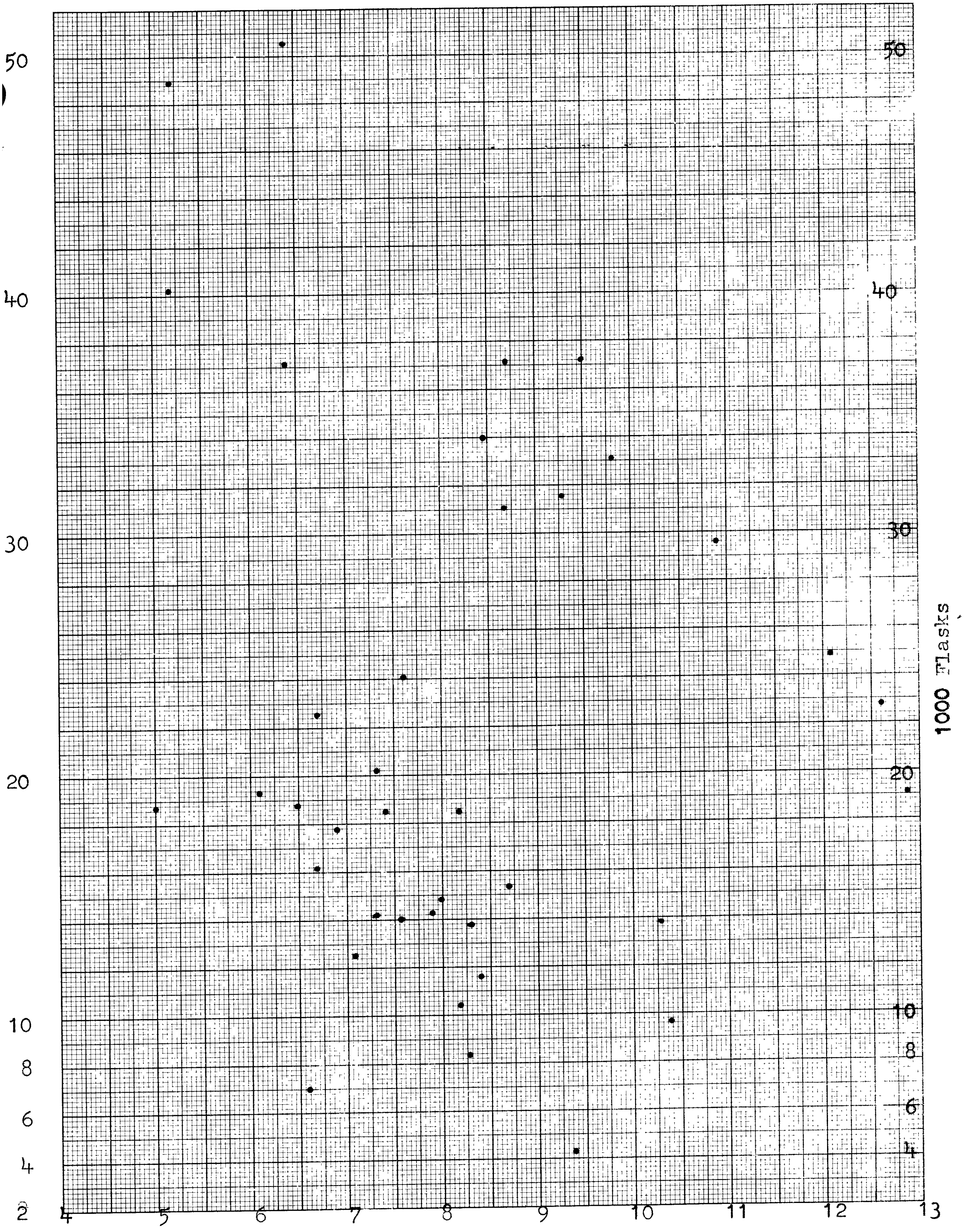


Fig. 3 Ore Grade vs. Mercury Production



Pounds per Ton of Ore

Engineering and Mining Journal. Constant dollar prices are simply current dollar prices divided by the wholesale price index of the Bureau of Labor Statistics, where 1957-1959 = 100. Both prices are tabulated by the Bureau of Mines.

Figure 4 shows that any grade of ore, from 4.9 to 12.5 pounds of mercury per ton, has been mined at a current dollar price between \$50 and \$140 and that no significant price-grade relationship is apparent within this bracket. At higher current prices, however, the lower grades tend to predominate, indicating new low-grade sources which are economically minable only at the elevated prices.

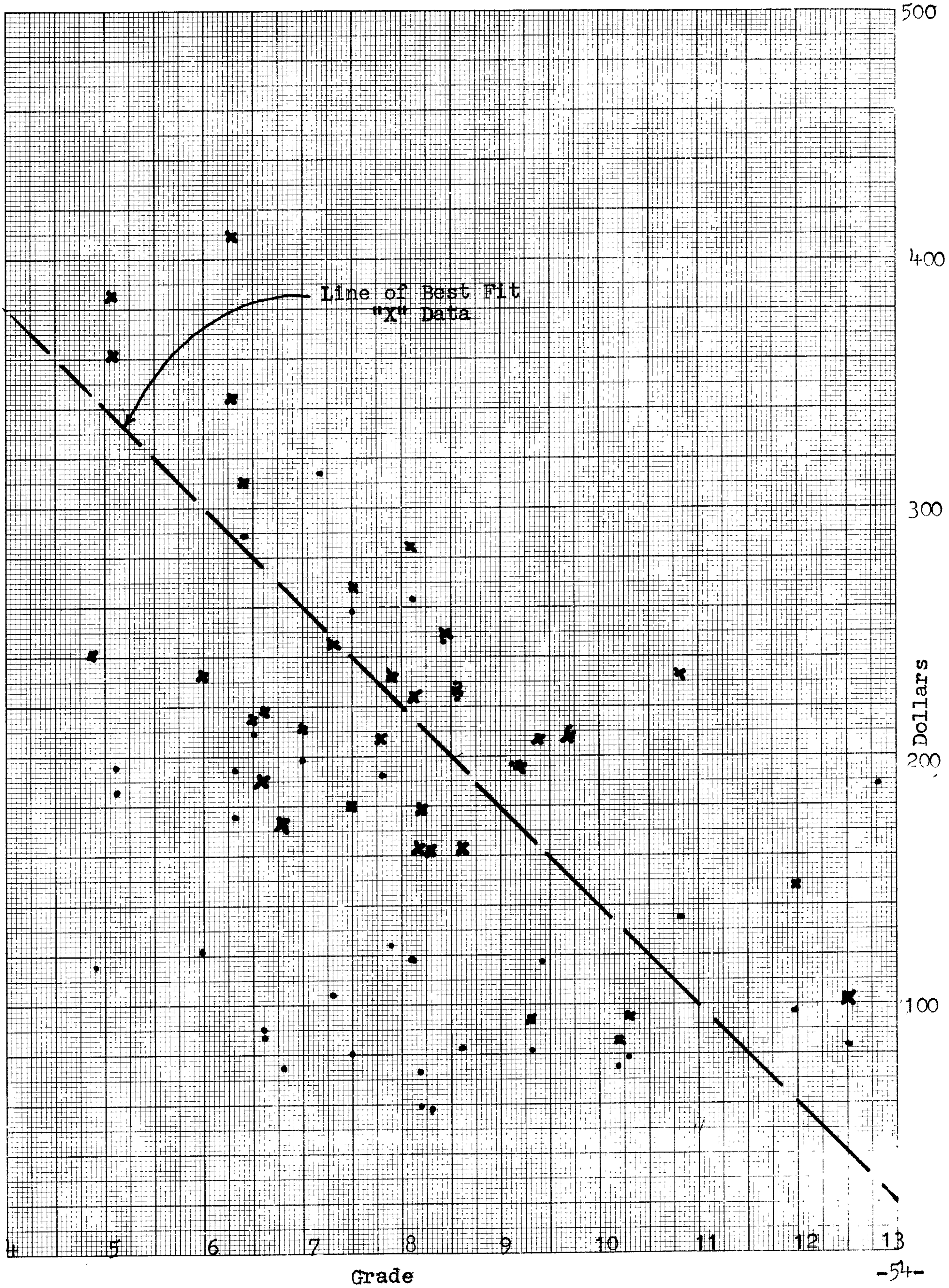
When prices are adjusted to a constant dollar basis in Figure 4, the inverse price-grade relation can be seen much more readily. Although a large variance is to be expected, a visual line-of-best fit has been passed through the data.

Its equation is:

$$\text{Price (in constant \$)} = 540 - (5 \times \text{Ore Grade})$$

•= x=

Fig. 4 Ore Grade Related to Price, Current and Constant (1957-59=100)



CHAPTER VI

PRICE BEHAVIOR

Equally as important to the marginal miner as cost is the market price of mercury. The rise in prices, beginning in 1964, made the mineral deposits at many closed mines once again appear attractive. A drop in prices, on the other hand, could just as easily force these mines to again close. Before discussing the reasons for the recent price increases, it is appropriate to summarize the past history of mercury prices.

History to 1964

United States primary production of mercury began in California before 1850 and by 1850 and by 1870 had reached 80,000 flasks yearly--more than present domestic consumption. As previously mentioned, the dominating mines were New Almaden and New Idria. Before World War I, domestic needs had always easily been met by domestic mine production. Through 1909, in fact, the United States exported half of its production. Since then, however, domestic production has satisfied consumption requirements in only seven years.

The pre-war conditions of self-sufficiency in mercury led to stable price conditions through 1914, as Table V illustrates. At the outbreak of the war in 1914, domestic production was 16,000 flasks; imports, 8000 flasks; consumption, 21,000 flasks; and the E&MJ average price was $48.31 per flask. By the end of the war in 1918, domestic consumption had climbed to 36,000 flasks, and production had doubled to 32,000 flasks. Imports were at 6,600 flasks, and world production, for the first time in several years, had fallen below 100,000 flasks. The munitions industry's demand for mercury fulminate had, as early as 1916, pulled the average price per flask to $125.49, and in 1918 it

Table V

E&MJ YEARLY AVERAGE MERCURY PRICES, 1900-1966[1]

(in current dollars)

Year	Price	Year	Price	Year	Price
1900	$ 51.00	1923	$ 66.50	1945	$134.89
1901	47.00	1924	69.76	1946	98.24
1902	48.03	1925	83.13	1947	83.74
1903	41.32	1926	91.90	1948	76.49
1904	41.00	1927	118.16	1949	79.46
1905	38.50	1928	123.51	1950	81.26
1906	40.90	1929	122.15	1951	210.13
1907	41.50	1930	115.01	1952	199.097
1908	44.84	1931	87.35	1953	193.032
1909	46.30	1932	57.93	1954	264.386
1910	47.06	1933	59.23	1955	290.348
1911	46.54	1934	73.87	1956	259.923
1912	42.46	1935	71.99	1957	246.978
1913	39.54	1936	79.92	1958	229.057
1914	48.31	1937	90.18	1959	227.484
1915	87.01	1938	75.47	1960	210.760
1916	125.49	1939	103.94	1961	197.605
1917	106.30	1940	176.86	1962	191.208
1918	123.47	1941	185.02	1963	189.451
1919	92.15	1942	196.35	1964	314.787
1920	81.12	1943	195.21	1965	570.726
1921	45.46	1944	118.36	1966	420.
1922	58.95				

1. Source: Engineering and Mining Journal.

stood at $123.47.

Following the war, consumption decreased, imports rose, and average price fell to a 1921 low of $45.46 per flask. The number of operating mines dropped from 66 in 1916 to only 11 in 1921.

The following years of the 1920's constituted a period of industrial boom. Consumption and mine production were both increasing and the price steadily climbed to average 1928 and 1929 levels of $123.51 and $122.15, respectively. In 1929, sixty-three mines were in operation.

The early 1930's were, of course, a time of depression. Consumers of mercury shared the effects along with most other industries. Price and mine output both tumbled, price hitting bottom in 1932 at $57.93. Production in 1933 was only 9,669 flasks, but for the next six years plateaued at around 17,000 flasks. The price situation gradually improved to $90.18 in 1937. Remarkably, the number of mines in operation during the 1930's has not been surpassed in American history except during the war years of 1940-1944. At no time during those years of widespread depression did the number of operating mines fall below seventy-five. Output, nevertheless, did drop. In 1933, the 75 operating mines averaged fewer than 130 flasks output each.

During 1936 and 1937, it was feared that the Spanish Civil War would cut off supplies of mercury from the world's most prolific producer. Hence, over 18,000 flasks were imported in each of those years--nearly 2-1/2 times the 7,800 flasks imported in 1935--largely for industrial stockpiles. The resulting situation was one of oversupply and the 1938 average price to American mines dropped nearly $15 to $75.47.

War broke out throughout Europe by 1939 and exports to the Western Hemisphere were cut off. The task of satisfying wartime needs fell upon domestic operators, with some assistance from Mexican sources. In 1941, a record 197 mines were operating in the United States. Prices soared, and in 1942 the Office of Price Administration set a ceiling price of $191-193 per flask. Production in 1943 reached 51,929 flasks, a modern record.

Prices suffered in 1944 because of that peak production, but were revived somewhat in 1945 by the demand anticipated for the new mercury cell battery. The failure of the promised demand to materialize plus the resumption of importing from Europe caused a depression in the industry through 1950. Prices settled at about $80.

Heavy stockpile purchasing by the federal government with counterpart funds in Italy resulted in an unequaled import level in 1949--103,141 flasks. Domestic producers reacted with all-time low output of 4,535 flasks from only sixteen mines in 1950. This figure is less than nine per cent of the production figure of but seven years previous.

But in 1950, war was again just around the corner. Due to the demands of the Korean conflict, consumption hit 56,848 flasks in 1951. However, the damage of low prices for too long was being felt. Too many mines had been closed. The domestic industry could supply but 7,293 flasks. The 1950 average price of $82.26 soared to $210.13 in 1951, and as in World War II, price ceiling controls were imposed. In spite of these controls, however, the domestic industry was being rejuvenated.

From 1955 through 1959, strong industrial demand throughout the world together with heavy purchases by the American, French, German, and British governments combined to help keep prices firm and stable. The E&MJ yearly average never fell below $227.48 and was as high as $290.35 in 1955. Domestic production expanded, encouraged by strong demand, good prices, and a Government support program which from July 9, 1954 through 1958 guaranteed domestic miners $225 per flask.

Initially, United States producers continued to sell on the open market where prices were $75 a flask higher than the Government's support price. As the market slackened, however, producers turned more and more to the Federal outlet with its secure price floor. Unfortunately, United States output reacted slowly to the support program. In 1954, production was 18,543 flasks. By 1958, it had finally managed to reach a "healthy" level--38,067 flasks--but the Government program was ending and the price was being removed.

Production actually held fairly steady from 1959 (31,256 flasks), through 1961 (32,662 flasks). The decline hit in 1962 as output fell to 26,277 flasks and then was accelerated in 1963 as--despite record high 77,963 flasks consumption--output dropped to 19,100 flasks. By that time, the average yearly price, falling since 1960, hit $189.45, the lowest since 1950. Some observers held the slightly recessed national economy responsible for the producer's plight, but other experts pinned the blame on the Government support program since it artificially maintained prices while spurring delayed-action output increases.

Some Russian and Chinese mercury entered the London market in 1961 and depressed prices there. By August, 1961, both Italian and Spanish sources withdrew from the market, claiming that they simply would not sell at such depressed prices. The Italians maintained a full production schedule while stockpiling the output. The Spanish cut back production slightly. Markets continued to flounder through 1962 in spite of a 10,000 flasks increase in consumption and 5,000 flasks decrease in production here.

By 1963 experts were predicting an imminent price up-swing. The first few months, nonetheless, looked more dismal than ever. By September, however, the

Italians were beginning to set prices below which they would not sell. When the Spanish, the only other factor powerful enough to defeat such a move, tacitly complied, the price pendulum began to reverse direction. By the end of the year, the E&MJ weekly price quotation had climbed to $228.

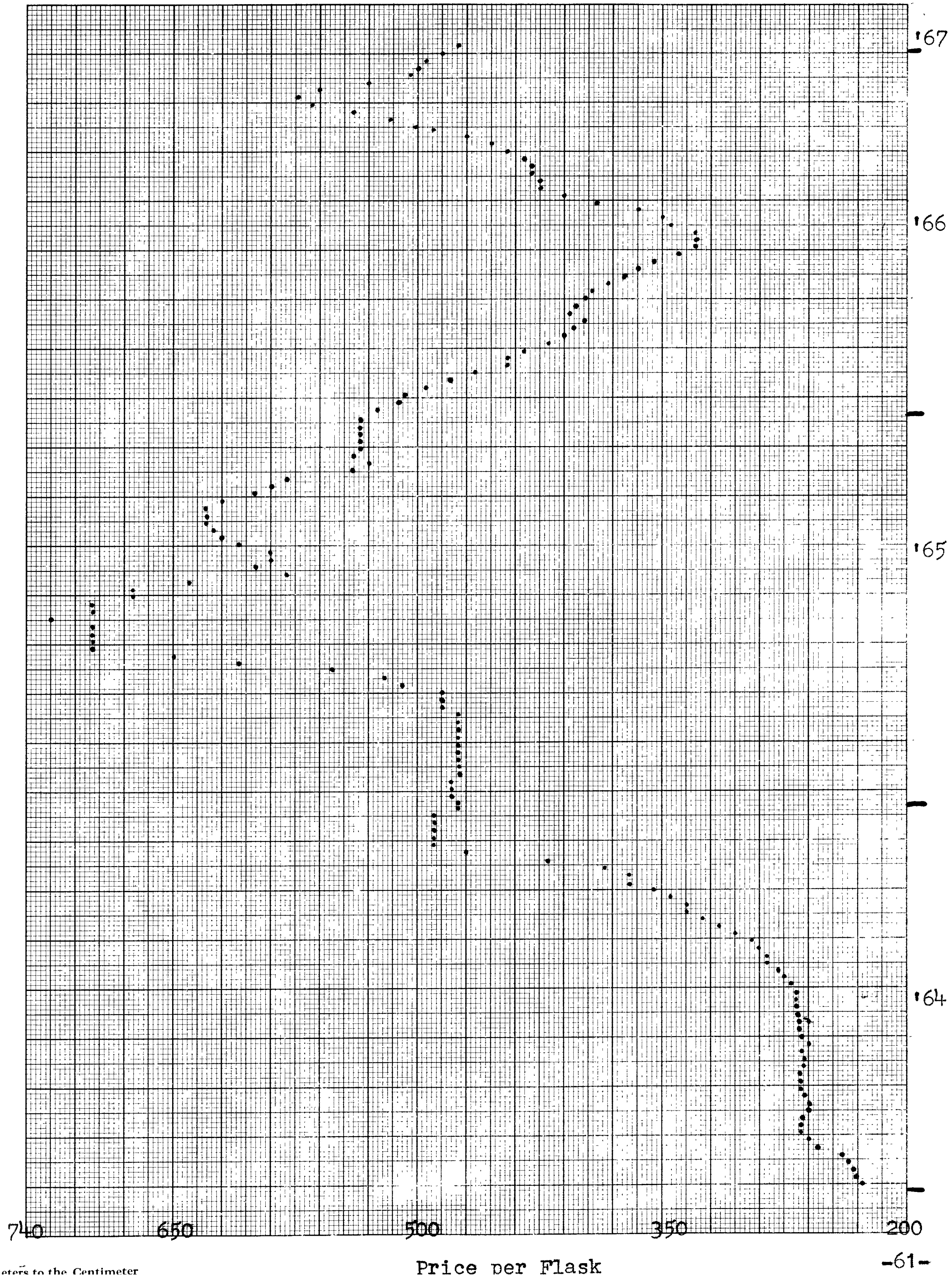
The next year, 1964, marked the start of the spectacular price surge with which this report is primarily concerned. The E&MJ average price for the year was $314.79. For 1965, the average price skyrocketed to $570.73. Figure 5 shows the weekly progressions of the price increase from 1963 through 1966.

Price Increase of 1964

What was the cause of this jump in price? How did it come about? As previously mentioned, the Italians and Spanish had removed themselves as sources from the market while stockpiling their output. After this move, world production was insufficient to satisfy the world consumption of mercury and industrial inventories were shrinking. When, in September, 1963, Monte Amiata, the major Italian producer, announced minimum sales prices for its mercury, it found many buyers willing to pay the price. Almaden, in Spain, then accepted the Italian firm's decision, thereby establishing a solid worldwide pricing base which no other nation's producers had sufficient power to undermine. American producers had no difficulty in selling their output at the new higher price. Monte Amiata had, it its unopposed and successful action, catapulted itself into a position of worldwide pricing leadership.

The later portion of 1963 and part of 1964 saw a testing of the market by Monte Amiata. Prices jumped weekly. Between February third and tenth of 1964, mercury quotations went from $240 to $255, an increase of nearly four per cent within a span of several days. Market experts were stunned by the steady rising of prices and began to predict that the miners would overprice their

Fig. 5 Weekly E&MJ mercury price, 1964 through 1966



product and prices would abruptly fall. Buyers, however, did not have the requisite inventories to stay out of the market and check prices, which continued rising firmly through February twenty-fourth--$265.

In March, the General Services Administration announced that "52,000 flasks of mercury have been found to be surplus to the Atomic Energy Commission's needs."[1] Immediately purchasers became confident that their troubles were over. Sellers, on the other hand, claimed that it would be some while before governmental surpluses found their way into private industry. The net result of the conflicting views was a stable market price between $260 and $268 from March until July.

Laborers at Monte Amiata in June began a work slowdown that was to last several weeks and aggravate an already tight supply situation. Shortly thereafter, Almaden announced that it was virtually all sold out for the rest of the year. Furthermore, business circles were soon buzzing with the rumor that the 50,000 flask AEC surplus was to be absorbed by the Department of Health, Education and Welfare. The sellers' market became very evident as a previously somewhat-stabilized price rose from $268 at the end of June to $279 at the end of July, $305 in August, $335 in September, and $370 by the end of October.

Deserate buyers were staying out of the market for weeks at a time, only to add greater pressure on the market when they finally had to return for supplies. Industry was bombarding the government with requests that the previously announced surplus be made available. The Weed Ridge Chemical Company, by September, had announced that it would "adjust its mercurial product prices each week to reflect changes in the M&MM quote."[2]

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[1] "Mercury: Market Guide," E&MJ Metal and Mineral Markets, Jan. 25, 1965.

[2] Ibid.

Plans were being announced for the reopening of mines forced to close by the low prices of previous years. But the additional output would not be immediately, nor would it be of sufficient quantity to appreciably alter the supply outlook. The price was up to $385 on November second, leaped to $420 on November ninth, soared to $470 on November sixteenth, and settled to $490 on November twenty-third--an increase of 30 per cent in just four weeks.

On November 13, eight months after the AEC surplus was first publicly announced, the General Service Administration finally unveiled plans to release at least 14,000 flasks of mercury at public auction in 1965. The immediate consequence was to substantially slow down the rate of price increase. The GSA pronouncement fell in the middle of a week in which prices were rising $50. The following increase was only $20, and thereafter prices failed to rise.

With the unevaluated, but threatening, likelihood of government disposal sales hanging over the producers' horizon, producers adopted a wait-and-see attitude. Exports to the United States are a significant protion of nearly all non-Communist nations' sales of mercury, and the spectre of a possible market collapse formed a powerful deterrent to further price hikes. That buyers, in addition, now saw potential relief ahead caused pressure in a tight supply situation to dissipate. The consequence was a fairly extended period of market stability.

From November 23, 1964 through April 16, 1965--a span of twenty-two weeks--price fluctuations were minimal. The highest quotation was $490 and the lowest $475. Even the first GSA sale, which could have had a devastating effect, did little to disturb the market stability.

In anticipation of the opening of the first bids for the GSA sale on February fifth, the price declined $5 to $475. The bids ranged from $38 to

$455.11 per flask. The GSA ultimately released 175 flasks at prices between $425 and $455.11.

On February twenty-third, the GSA announced a sale of 10,000 flasks for domestic consumption at $430 per flask on a first-come-first-serve basis. Thus the discount from the open market price was less than 10 per cent. Shortly thereafter, another 10,000 flasks were to be made available on the same basis. The price was $460 per flask in lots over 500, and $475 per flask in lots under 500.

When, in late April, the supply situation was still remaining tight and producers had judged that GSA releases would be sold as close to the open-market price as was possible, i.e., that the GSA sales would not have a disruptive effect on the market, another round of price increases was initiated. Beginning at $485 on April 16, the price was to reach $700 by May 28. The jump was generally attributed to tight supplies and GSA slowness in announcing the next disposal sale of 10,000 flasks. When the announcement came prices stablized at approximately $700 through mid-July. Between June and August, the government released mercury at $685 per flask.

After July, the demand for mercury lightened. Major purchasers had been able to build some inventories through the GSA sales. A tendency developed for consumers to delay purchases, awaiting GSA announcements. Supplies also became more abundant as reopening mines were adding their outputs to the market. In brief, activity slumped and with it, price slowly fell. Periodic flurries of activity caused temporary price hikes, but the trend was generally downward. The year ended with a quotation of $535 per flask.

In the fourth quarter of 1965, the General Service Administration--after additional industry-government conferences--announced a program of regular disposal sales. On the second Friday of each month, beginning in October, 1,500 flasks of mercury would be made to any bidder for quantities between one and five hundred flasks.

The first sale, on October 8, saw 596 flasks were awarded at prices of $600 and above. The open-market price at that time was $630. On November 12, 259 flasks were awarded at prices of $550 and above, and only 209 flasks could be sold on December tenth at prices of $523.60 or higher. The open-market prices at the time of the latter sales were $540 and $525 respectively. Undoubtedly, some bidders ended up paying higher than open-market prices because price conditions at that time were highly speculative.

For the quarter, the GSA could dispose of only 1,064 flasks slightly less than 25 per cent of the 4,500 flasks available. The government program of regular sales assured the consumer that he is not likely to be left without a source of mercury in the event of a tight commercial supply situation. This, in large part, was significant in relieving demand pressure and restoring the open market to a more normal position.

The Market in 1966

Demand pressure diminishing and mine supplies starting to accumulate at the start of 1966, the mercury market began a slow, but steady price decline. Starting with a January 10, high of $525, the market price underwent a steady weakening, with but one brief respite in April, to reach the year's low, $330, by June 13. This was actually a continuation of a trend begun in October, 1965.

One explanation of this trend may be that a large component of the active buying of mid-1965 was an over-purchasing for the purpose of reestablishing depleted inventories. A motivation for inventory purchases during a period of rising prices was a fear that the market price would soar over the $1,000 mark.[3]

Thus an important share of 1966 demand may have in activity been satisfied. Furthermore, when prices were declining, potential purchasers tended to postpone their buying, pending the further market weaknesses that were to come.

The brief April upturn was due to labor unrest at the Italian mines and production slowdowns in Western Hemisphere operations due to the Easter holidays. This situation was, of course, only temporary.

Stockpile sales by the General Services Administration did not play a large role in the declining prices. In the January 14, sale, the GSA accepted bids on only 660 flasks, with the low bid being $510 and the average $516.36 per flask. This compared with an open-market price of $525. The minimum GSA-accepted price in February was $460, as compared to the month's average open-market price of about $464. Only 265 flasks were released by the GSA at that sale. All bids for the March sale were rejected by the GSA.

In April, the GSA sold 665 flasks at $385-$390. The New York market price was $400-$415. The buyer, faced with having to pay freight from Oak Ridge and the loss of commercial credit, realized little savings, however. Any potential savings to the consumer for May and June evaporated when the GSA rejected all bids for those periods.

June marked the turning point in the 1966 market. During that month, the Italian miners announced a floor price for their product of $350 plus tariff ($19./flasks). Furthermore, heavy rains hit American producers, slowing

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[3] Personal Communication. From metal broker who requested not to be identified.

activity and forcing some marginal mines, especially in Mexico, to close down. Additionally, in July, Mexican government officials froze all mine shipments, pending auditing of each mine's books, in an effort to curb smuggling, which had reached major proportions. Prices consequently rose weekly from a June low of $330 to a November 7 high of $574.

As prices rose, interest again turned to GSA stockpile sales. In July, 870 flasks were sold on bids between $350 and $360, compared to the open market price of $365-$385. The August, September, and October GSA sales each disposed of 1,500 flasks, the maximum available. Each was at prices within a few dollars of the open market. The net effect may have been to partially modify the price rise, but the price nevertheless continued to advance.

Monte Amiata, the leading Italian supplier, announced, in August, a price rise to $406 (plus tariffs) and added that it had sold out its entire 1966 production. A further increase, to $532, was announced in September for mercury to be delivered in 1967. Moreover, Italian mining was hit again in October by labor unrest.

After November 7, prices fell off, declining for the remainder of 1966, as demand slackened and Mexican supplies became more available. From a November 7, high of $574, the market dropped to $475 by the year's end.

Prices in 1967 have been more stable than at any time since 1964. Fluctuations have not been great and the overall effect of GSA sales, as in prior years, has generally been to stabilize prices. Average monthly prices, as reported by the Engineering and Mining Journal, are as follows:

December, 1966	$484.524
January, 1967	485.762

February, 1967	$503,700
March, 1967	506,136
April, 1967	488,500

Prices have generally responded to consumer interest in the market. It sagged to $450 briefly in June, but recovered again to $485 by August.

The most notable feature of 1967, has been the start of mercury trading on the New York Commodity Exchange early in the year. Industrial opinion is that mild price fluctuations may become greatly exaggerated if the often violently speculative nature of other commodity markets is extended to mercury.

CHAPTER VII

USES

The anticipated price level for mercury depends largely upon the future level of demand. The United States Bureau of Mines classifies demand for mercury into categories as follows:

- Agricultural (including fungicides and bactericides for industrial purposes) (Variable 5 of mathematical analysis--See Chapter VIII)
- Amalgamation (Variable 6)
- Catalysts (Variable 7)
- Dental Preparations (Variable 8)
- Electrical Apparatus (Variable 9)
- Electrolytic Preparation of chlorine and caustic soda (Variable 10)
- General laboratory use:
  - Commercial (Variable 11)
  - Government (Not represented in quarterly data of Chapter VIII)
- Industrial and control instruments (Variable 1)
- Paint:
  - Antifouling (Variable 2)
  - Mildew proofing (Variable 3)
- Paper and pulp manufacturing (Variable 4)
- Pharmaceuticals (Variable 15)
- Redistilled (Variable 16)
- Other (Variable 17)

Usage Data

Historical data for these uses, as well as for total consumption, are shown in the following charts. The sources of this data are the United States Bureau of Mines *Minerals Yearbook* (from 1958) and United States Bureau of Mines *Mineral Industry Surveys* (mercury, quarterly, from 1964). It should be noted that paper and pulp manufacturing data were not separated from agriculture until 1959, nor were data for mildew-proofing paint reported prior to that year. Laboratory usage by the government is reported separately only for 1963 and 1964. For other years, it is included within "Other".

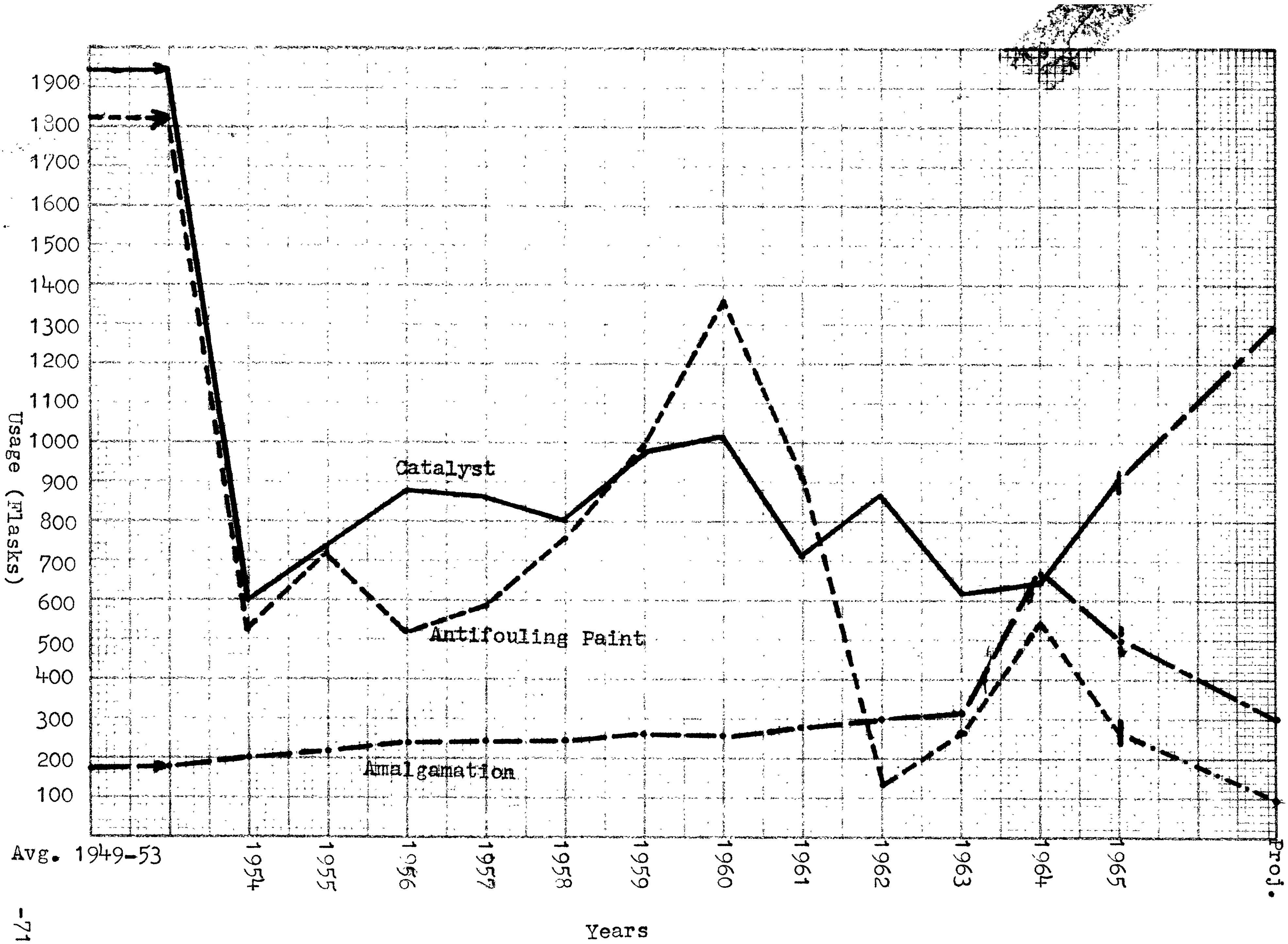


Fig. 6

Catalysts, Antifouling Paint, Amalgamation

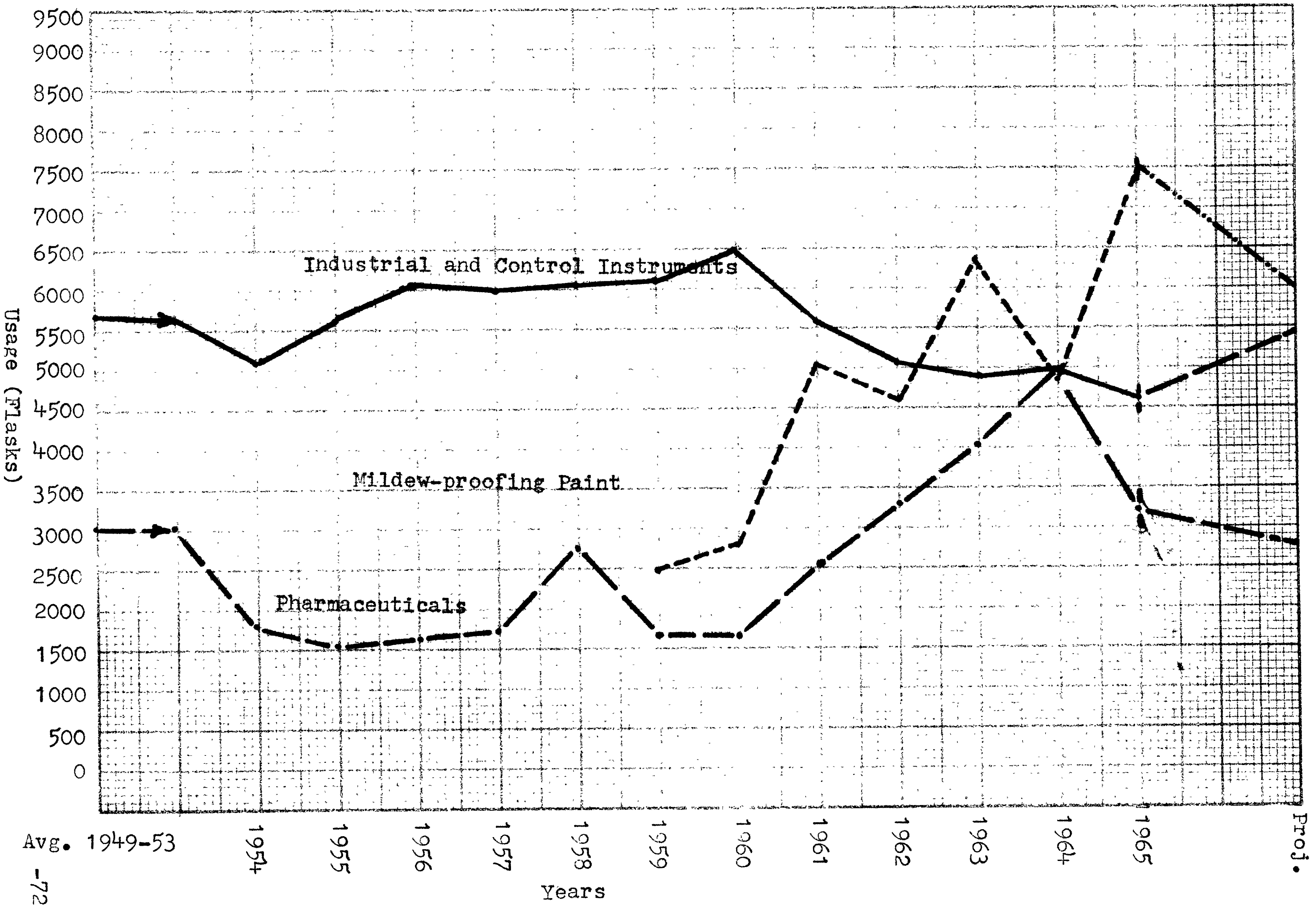
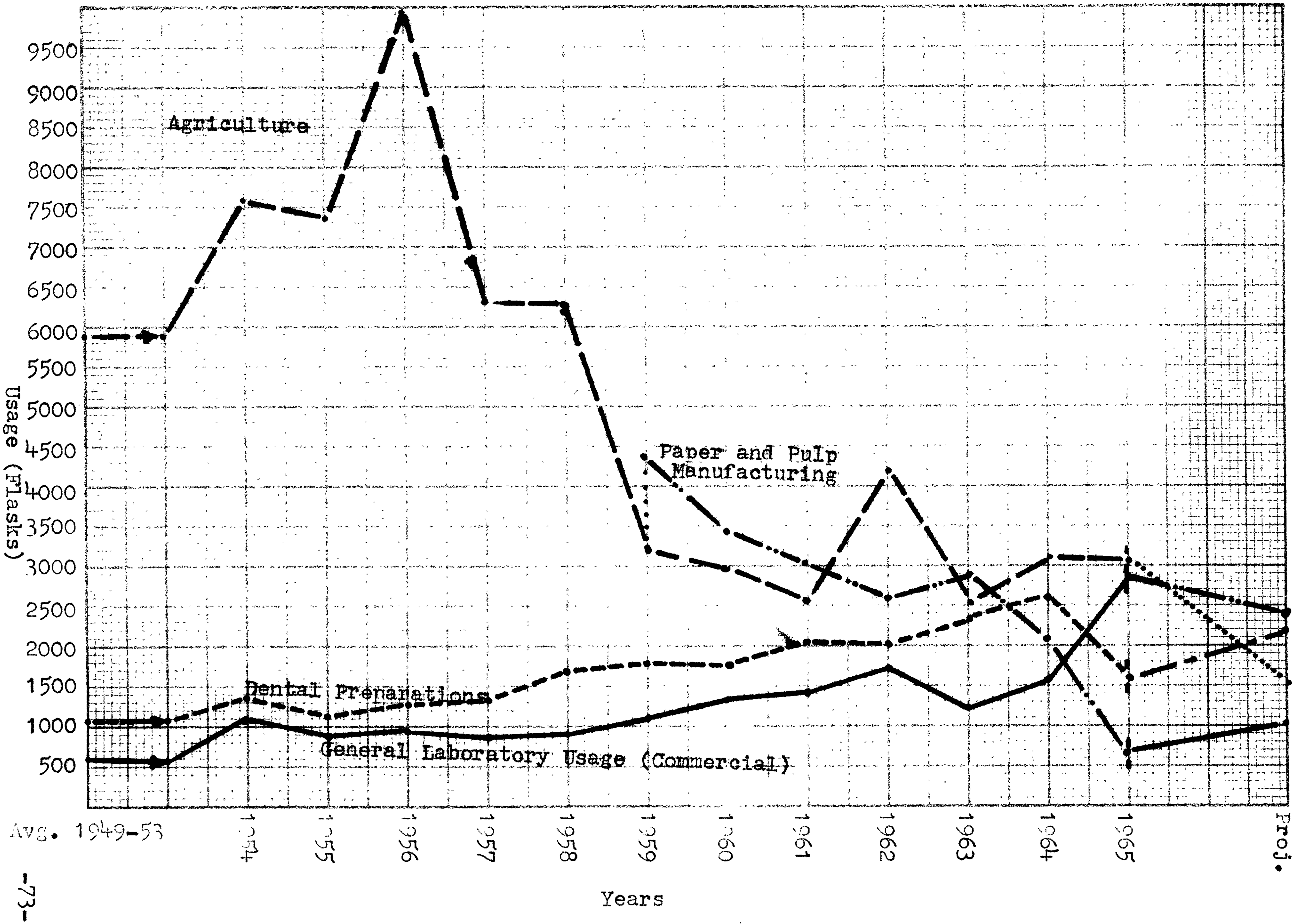


Fig. 7 Industrial and Control Instruments, Mildew-Proofing Paint, Pharmaceuticals

Fig. 8 Agriculture, Paper and Pulp Manufacturing, Dental Preparations, General Laboratory Usage (Commercial)



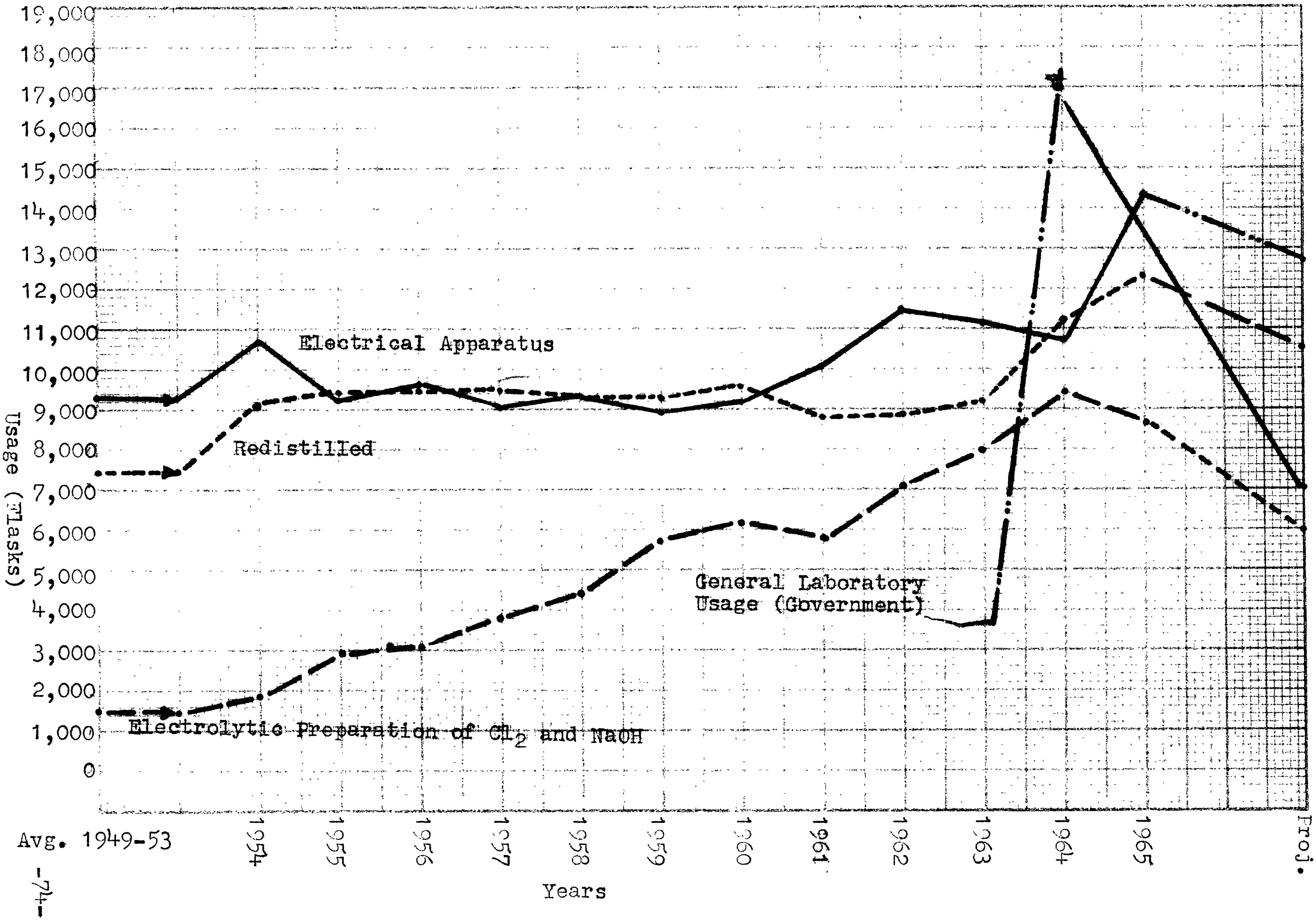
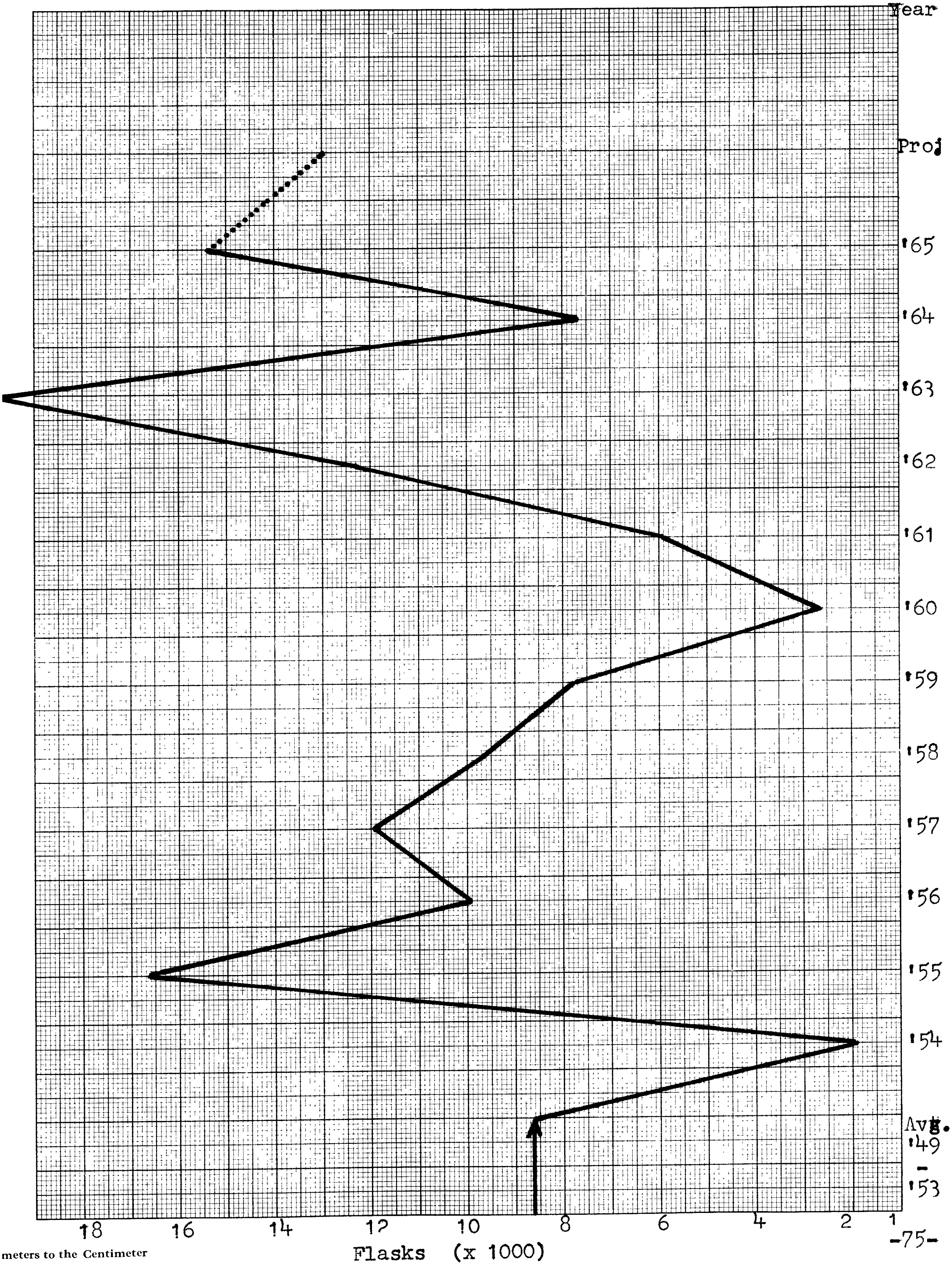


Fig. 9 Redistilled, Electrical Apparatus, Electrolytic Preparation of Cl_2 and NaOH, General Laboratory Usage (Government)

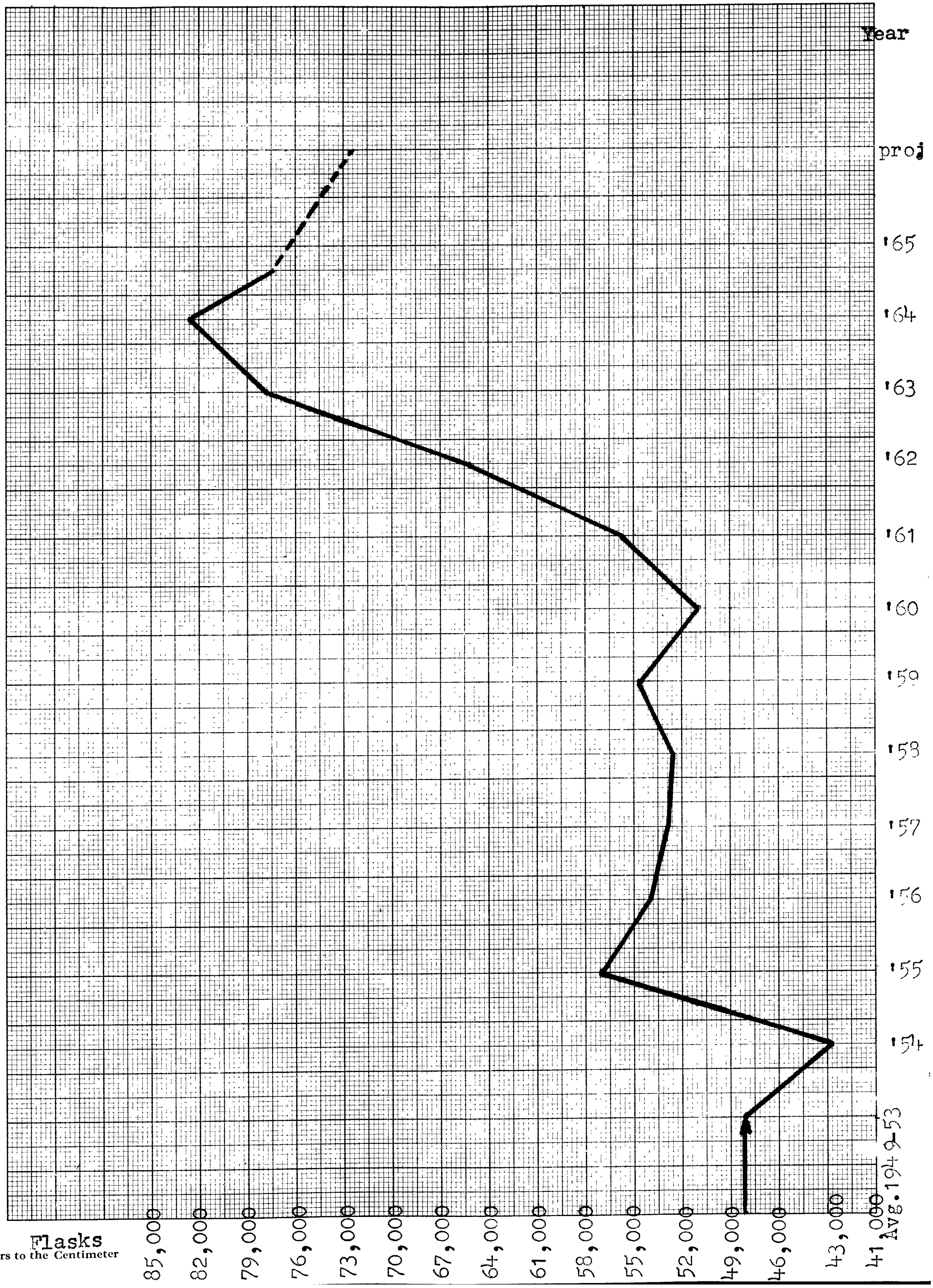
Figure 10 Other Usage



meters to the Centimeter

Fig. 11

Total Consumption



Substitution Effect

The demand curve for any typical commodity is characterized by a decrease in quantities purchased as price is increased. Thus, unless the demand for the commodity is perfectly inelastic, as the price rises, comparable items become relatively less expensive and tend to be substituted for the more expensive commodity.

In mercury, too this substitution effect will be noticed. But for many of its uses, however, mercury behaves as a "highly inelastic material"--that is, the price of the commodity has little to do with the level of demand. Except for the role of inventories, the demand might be perfectly inelastic. In the short-run, no other material can replace mercury and when inventories are exhausted mercury must be purchases in the market regardless of price.

Physical Properties

In order to understand how mercury has become, for many uses, such a highly inelastic commodity, it is necessary to explain why there are no suitable substitutes. For this, one must examine the physical properties of mercury itself.

Of all known metals, only mercury is a liquid at room temperature. In fact, it does not solidify until the temperature has dropped to -38.85° C. At 0° C, it has a specific gravity of 13.595, among the heaviest of all metals or all liquids. As a conductor of electricity few metals can surpass mercury.

In addition, the rate of expansion of mercury with temperature is nearly perfectly linear. Mercury will form amalgams or alloys with most other metals, excepting iron. Furthermore, it will not wet glass, its surface tension being 480.3 degrees per centimeter, compared to 75.6 for water.

Mercury is not oxidized by air or oxygen at room temperature, at which its vapor pressure is only 2 microns. It is thus practically unique among metals in that as a liquid it does not absorb gases. (Molten iron, for example absorbs hydrogen; liquid copper absorbs oxygen.)

It is on various of these properties that the inelasticity of demand for mercury is based. Substitutes, in many instances, are just not available. In other cases, substitutes are not economic, even at elevated mercury prices, or would result in an inferior product.

Technological advances have two basic effects upon the usage of mercury. It can develop entirely new uses. For example, the mercury cell battery was developed during World War II. Or, secondly, it can make existing applications obsolete. Fulminate of mercury, for instance, has been so thoroughly outmoded as an explosive detonator that the Bureau of Mines ceased reporting usage data for it as a separate category in 1954.

Additionally, technological advances affect the relative efficiency of processes utilizing mercury and thus may lead to more ready substitution, either favorable or unfavorable to mercury. Economically, this would increase the sensitivity of mercury consumption to price for such a process. For several present applications, such as in many control instruments, there is no substitution for mercury and therefore its usage is independent of price.

Projections

For a detailed treatment of the many applications of mercury, the reader is referred to an excellent report by D. R. Williamson.[1] The emphasis here will

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1. Williamson, D. R., "Mercury Prices and Consumption," Colorado School of Mines Mineral Industries Bulletin, Vol. 8, No. 3., May, 1965, 20pp.

be on obsolescence, substitutions, and new applications.

Agricultural usage faces a long-run decline. Because use is based upon mercury's chemical, rather than physical, properties, mercury faces pronounced substitution, especially at high prices. It is being replaced by organic and copper compounds, which behave as effectively and are not as expensive. Projected yearly consumption is 1500 flasks.

Use of mercury for amalgamation was considerably above normal for 1964 and 1965. Projected usage, 300 flasks yearly, is more consistent with the stable levels of 1954-1963, showing some slight yearly growth. The Homestake Mining Company, largest gold mining company in the United States, consumes nearly 90 per cent of the mercury used in this category. Since 1962, its average usage has been about 260 flasks yearly.[2] It reports no possibility of substitution without major capital investments. Usage of more than 275 flasks yearly is unlikely, however, since the mine is operating near its capacity. Small amounts of mercury are used by the Primary Battery Division of Thomas A. Edison Industries for amalgamating copper surfaces of parts.[3] That company expects use to remain constant and reports there is no possibility of substitution.

The use of mercury as a catalyst is based, of course, on chemical properties. Its use in this area has been declining since 1947. Projected yearly usage is 1700 flasks. Substitution is the major reason for its decline. A

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2. Schmidt, Claude E., Metallurgical Superintendent, Homestake Mining Company, Lead, South Dakota, Personal Communication.

3. Thomas A. Edison Industries, Primary Battery Division, Bloomfield, New Jersey, Personal Communication.

former use of mercury reports "mercury was used as catalyst in processes which have become obsolete."[4]

The use of mercury in dental preparations is also subject to substitution. Replacements include metal powder, porcelain, and plastics. Growth in usage should result, however, from the expansion of dental services to a growing population. Forecast use is 2200 flasks yearly. Between 1954 and 1964, the use of mercury by dentists had increased 70 per cent.

Electrical apparatus is a consumer of large amounts of mercury. Growth is closely connected with the national economy and substitution is often difficult because of mercury's unique electrical and physical properties. Westinghouse[5] uses mercury in rectifiers and electronic tubes and expects requirements to decline, largely because of developments in solid-state and semi-conductor devices. On the other hand, the S.S.T. Corporation,[6] a dealer, expects electronics to be an area of major development for the future. A long-run estimate of usage is 12,700 flasks yearly.

Demand for mercury for construction of new facilities for the electrolytic preparation of chlorine and caustic soda was a major contributor to the imbalance of supply and demand leading to the increase in prices. One method involves the use of a stream of slowly moving mercury as a cathode in a mercury cell.

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[4] Personal Communication from chemical company. Source confidential. (Information here and at several subsequent points has been obtained directly from relevant companies. Many of these have released data which they consider confidential and have requested that their names not be published in connection with the data. Such instances will be footnoted as above.)

[5] Marsh, Merle E., Purchasing Agent, Raw Materials, Westinghouse Electric Corporation, Personal Communication.

[6] Turner, G. H., S.S.T. Corporation, Personal Communication.

A non-mercury method is the "diaphragm cell." Both are of equivalent efficiency and yield the same end products. Contaminants is present in caustic soda generated from the diaphragm cell, but that from the mercury can be used for making synthetic fibers without additional handling.

In January, 1965, eleven chlorine-caustic soda plants, using mercury cells, were scheduled or planned.[7] A 100 ton per day chlorine plant reported would require 5,100 flasks for initial production.[8] Additional flasks are required for annual replacement of lost mercury. Several chemical companies[9] estimate a minimum of five per cent yearly growth in demand for mercury for this use. One of these companies reports the mercury cell process would be profitable until mercury prices rose to $800 per flask. Substitution is not likely. Some decrease is to be expected, however, as construction of new facilities is completed and initial requirements are satisfied. Projected usage is 6,000 flasks per year for replacement. Mercury required for new or expanded facilities is concluded within "Other."

Commercial laboratory usage has been increasing since 1953. Westinghouse estimates its requirements for this purpose will increase by five per cent yearly.[10] In general, however, demand should be price-sensitive, since mercury is not being used for production and is not likely to be engineered into products under high price conditions. Projected yearly usage is 2400 flasks.

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7. Williamson, D. R., Op. cit., p. 16.

8. Ibid.

9. Personal Communications. Sources confidential.

10. Marsh, Merle E. Op. cit.

Governmental laboratory usage is expected to be less price-sensitive as it is more likely to be concentrated on areas of national security. Details of course, are not available, but prime areas of research are thought to involve rocket parts and propulsion and atomic energy. Government stockpiles of mercury are being depleted, however, by the GSA sales, to which the Atomic Energy Commission has greatly contributed. This, necessarily, will have an effect upon government research. Projected annual usage is 7,000 flasks.

For industrial and control instruments, the long-run consumption outlook is 5,500 flasks per year. This has been an area of price sensitivity. Generally, for flow- and orifice-meters, purchasers prefer the non-mercury type as being less expensive to buy and easier to maintain. Demand for mercury meters is declining. In other types of control units, demand is remaining level.

Anti-fouling paint is practically obsolete, being replaced by copper oxide and plastic paints. Mercury mildew-proofing paint is currently popular, but the outlook is for eventual substitution. Predicted annual demand is 100 flasks and 6,000 flasks respectively.

The use of mercury in the paper and pulp industry is steadily declining. The reason is that organomercurials are not allowed for use in slime control in conjunction with the manufacture of paper and paperboard for food containers. Since even newsprint ultimately finds its way, through waste paper, to mills manufacturing paper and paperboard for food containers, there is less and less desire to use organomercurials, even in mills not making food containers. Projected annual usage is 1,000 flasks.

In the pharmaceutical field, antibiotics, sulfa drugs, iodine, and various antiseptics and disinfectants are rapidly replacing mercurial drugs. The only mercurial drug now in widespread use is mercurochrom. Projected usage is 2,800 flasks per year.

Although classified by the Bureau of Mines as a use, redistillation is actually a component of secondary production. Its magnitude is not price-dependent, but fluctuates, rather, with the scarcity of supply. For example, was over 40 per cent greater in 1965 than in 1963. Since economic mercury deposits are being more and more depleted, redistillation should assume more importance. But since marginal mines are now opening to ease the lack of supply, the projected demand for redistilled mercury, 10,600 flasks yearly, is below the 1965 level of demand. Projected annual demands for other supply components are as follows: mine production, 22,400 flasks; total secondary production, 16,000 flasks; imports, 38,000 flasks; total supply, therefore, 76,400 flasks.

The most fluctuating category of demand is "Other." At times, this has included government laboratory usage and usages which would reveal confidential company information if enumerated in separate categories. Also included is usage for new or expanded chlorine-caustic soda facilities. Use for rocket parts or fuel would also be included.

In 1948, 1951, 1953, 1955, 1957, 1958, 1962, 1963, and 1965, the leading use of mercury was for "Other." Subject to possible intense fluctuations, the anticipated long-run demand is 13,000 flasks per year.

The projected long-run demand for all uses, as defined by the Bureau of Mines, is 76,400 flasks annually.

CHAPTER VIII

ANALYSIS

A major objective of this investigation is to determine, if possible, a future equilibrium point of supply and demand and the resultant equilibrium price. A demand consideration is that some new uses will unfold because of advancing technologies. Some existing uses, through technological change, may be made obsolete. Other applications will become uneconomical through price increases over years past and, thus substitutes will be employed. These, together, will cause fundamental changes in the demand curve and were reviewed in Chapter VII.

Supply is affected by opening and closing of mines in response to price, by changes in the scale of operations at producing mines, by imports, by inventory policies of miners, dealers, and consumers and, not least importantly, by government policies, concerning the acquisitions and disposals of stockpiles.

Methods

Three methods are utilized in an attempt to determine a stable long-run price. The leastquantitative, but possibly most knowledgeable, are the opinions of numerous industry leaders. Secondly, each source of demand (use) and source of supply can be separately analysed and, by projection techniques, an aggregate supply-demand picture may be developed. Most quantitative is a mathematical treatment based on regression analysis and correlation techniques. It is this method which will be discussed first.

Mathematical Analysis

Quarterly data from January 1961 through March 1966, were obtained from the United States Bureau of Mines for each of fourteen usage catagories, as well as for total usage, mine production, secondary production, imports, and price. These data were imput to a computer in which a step-wise regression analysis program determined the linear equation of best fit, according to the sum-of-least squares criterion, for price as a function of all other variables.

In addition to the equation of best fit, a covariance matrix and a correlation matrix were computed for each pair of variables. The mean and standard deviation were also calculated for each variable.

The quantities were found for each nine cases, in which price data were related to usage data of the corresponding quarter, then to usage data of each of the four preceding quarters, and finally to data of each of the four succeeding periods. As a convention for subsequent discussions and charts, a time shift is considered positive where usage leads the price and negative where price leads usage. In other words, when the price of period Q + 1 is a function of usage of period of Q, the time shift is defined as +1, but when the price period Q - 1 is involved, the time shift is defined as -1.

Table VI shows the computed equations of best fit for each of the nine cases. The variables are defined in Table VII. The usage and price data imput to the computer are given by Table VIII.

Table VI

EQUATION OF BEST FIT

Case 1: Time Shift = -4

$$\begin{aligned} X_{19} = {} & 163.584 - .234X_1 - 1.082X_2 - .066X_3 - .262X_4 - \\ & .210X_5 - \qquad - .728X_7 + .249X_8 - .010X_9 + \\ & .200X_{10} + .076X_{11} + .045X_{12} - .009X_{13} - .027X_{14} + \\ & .108X_{15} + .104X_{16} \end{aligned}$$

Case 2: Time Shift = -3

$$\begin{aligned} X_{19} = {} & -1678.949 + .481X_1 - .252X_2 - .058X_3 + .060X_4 + \\ & .210X_5 - 5.912X_6 + .136X_7 - .127X_8 - .057X_9 + \\ & .745X_{10} + .122X_{11} - .033X_{12} + .016X_{13} - .001X_{14} - \\ & .236X_{15} + .373X_{16} \end{aligned}$$

Case 3: Time Shift = -2

$$\begin{aligned} X_{19} = {} & -217.654 + .493X_1 - .114X_3 - .137X_4 - \\ & .171X_5 - 2.836X_6 + .516X_7 - .778X_8 - .191X_9 + \\ & .192X_{10} - .089X_{11} - .011X_{12} + .019X_{13} - .011X_{14} - \\ & .223X_{15} - .187X_{16} - .160X_{17} + .147X_{18} \end{aligned}$$

Case 4: Time Shift = -1

$$\begin{aligned} X_{19} = {} & 210.229 + .505X_1 + .009X_2 + .051X_3 - .020X_4 + \\ & .006X_5 - 1.779X_6 + .471X_7 - .649X_8 - .041X_9 + \\ & .186X_{10} - .111X_{11} - .050X_{12} + .012X_{13} - .011X_{14} - \\ & .114X_{15} + .057X_{16} - .002X_{17} \end{aligned}$$

Case 5: Time Shift = 0

$$\begin{aligned} X_{19} = {} & 328.143 + .365X_1 - .016X_2 + .045X_3 - .073X_4 - \\ & .014X_5 - .350X_6 + .353X_7 - .564X_8 + .016X_9 + \\ & .006X_{10} - .116X_{11} - .035X_{12} + .018X_{13} - .004X_{14} \\ & - .003X_{17} \end{aligned}$$

Case 6: Time Shift = +4

$$\begin{aligned}X_{19} = {} & -3499.357 + 2.278X_1 + 2.513X_2 - .132X_3 \\ & .958X_5 - 12.117X_6 - .792X_7 - .616X_9 + \\ & 1.958X_{10} + .173X_{11} - .170X_{12} + .015X_{13} - .030X_{14} - \\ & 1.167X_{15} + .787X_{16} + .061X_{17}\end{aligned}$$

Case 7: Time Shift = +3

$$\begin{aligned}X_{19} = {} & -2285.298 + 1.842X_1 + .978X_2 - .337X_3 + .025X_4 \\ & - 10.159X_6 + 1.162X_7 - 1.605X_8 - .684X_9 + \\ & 1.346X_{10} - .164X_{11} - .160X_{12} + .051X_{13} - .033X_{14} - \\ & 1.022X_{15} - .297X_{17} + .290X_{18}\end{aligned}$$

Case 8: Time Shift = +2

$$\begin{aligned}X_{19} = {} & 580.186 + .204X_1 - .317X_2 - .023X_3 + .385X_4 - \\ & .216X_5 - 2.180X_6 + 1.249X_7 - .709X_8 - .040X_9 + \\ & .323X_{10} - .277X_{11} - .087X_{12} + .024X_{13} - .021X_{14} - \\ & .116X_{15} + .098X_{16} - .026X_{17}\end{aligned}$$

Case 9: Time Shift = +1

$$X_{19} = 842.970 + .209X_1 - .061X_2 - .217X_4 - .048X_5 - .882X_6 - .457X_7 - .590X_8 - .076X_9 - .082X_{10} - .379X_{11} - .061X_{12} + .015X_{13} + .005X_{14} - .214X_{15} - .079X_{16} - .094X_{17} + .075X_{18}$$

Table VII

DEFINITION OF VARIABLES

1. Industrial and control instruments
2. Paint: Antifouling
3. Paint: Mildew Proofing
4. Pulp and Paper Manufacturing
5. Agriculture
6. Amalgamation
7. Catalysts
8. Dental Preparation
9. Electrical Apparatus
10. Electrolytic Preparation of Cl_2 + NaOH
11. General Laboratory Use (Excluding Government)
12. Mine Production
13. Secondary Production
14. Imports
15. Pharmaceuticals
16. Redistilled
17. Other
18. Total Consumption
19. Price

Table VIII

QUARTERLY DATA INPUT FOR COMPUTER ANALYSIS

	Industrial and Control Instruments X_1	Antifouling X_2	Meldew Proofing X_3	Pulp and Paper Manufacturing X_4
1961	1027	236	998	807
	968	388	1492	628
	1052	205	1297	712
	1025	76	1248	389
1962	973	46	1669	1021
	826	19	500	376
	758	14	999	352
	949	10	1319	317
1963	988	61	1673	781
	879	46	2054	798
	700	31	1468	698
	937	117	618	414
1964	945	68	1476	553
	840	233	2362	510
	897	112	678	445
	930	89	1264	449
1965	874	30	1756	273
	856	112	2448	136
	950	53	2364	94
	745	36	978	95
1966	829	33	2012	147

	Agriculture	Amalgamation	Catalysts	Dental Prep.
	X_5	X_6	X_7	X_8
1961	1029	71	190	434
	401	61	124	478
	540	64	127	540
	433	86	126	535
1962	921	82	52	378
	1296	63	231	376
	1545	60	278	521
	1036	86	292	590
1963	555	76	81	517
	584	59	109	495
	706	67	152	501
	511	99	149	607
1964	1112	206	157	529
	593	152	172	524
	839	138	100	443
	661	147	124	743
1965	768	128	143	510
	959	119	158	441
	666	136	168	339
	733	153	352	151
1966	838	119	132	206

	Electrical Apparatus	Electrolytri Preparation of A_2 + NoOH	General Laboratory Use	
			Commercial	Government
	X_9	X_{10}	X_{11}	
1961	2669	1358	334	
	2019	1355	282	
	1987	1452	281	
	2766	2030	412	
1962	3048	1803	501	
	1900	1792	356	
	2696	1856	248	
	2803	1856	438	
1963	2770	1631	979	
	1705	1995	339	
	2678	2126	241	
	2991	2180	281	
1964	2630	2764	1516 (340	) 17,000 *
	1666	2463	(342	)
	3107	2483	(281	)
	2387	1915	(323	)
1965	2530	1759	286	
	3988	2107	235	
	2261	1984	260	
	3214	2769	121	
1966	3231	2939		373 **

* Excluded from mathematical analysis

** Included in analysis as is commercial usage

	Mine Production	Secondary Production	Imports
	X_{12}	X_{13}	X_{14}
1961	8150	1300	3061
	8700	4010	1244
	7220	1570	1936
	7530	1480	6270
1962	6420	1250	7652
	6740	1300	9629
	6670	1550	5298
	6500	1600	9086
1963	4760	2150	8234
	5870	1950	12,577
	5100	4650	10,238
	3190	1700	12,028
1964	3030	2100	12,339
	3680	1650	11,499
	3190	1300	10,316
	3360	18,700	6949
1965	3955	12,400	5215
	5220	14,900	3225
	4830	14,200	5550
	4695	4200	3845
1966	4255	2400	6977

	Pharmaceuticals	Redistilled	Other	Total	Price
	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}
1961	484	2334	409	13,400	$207.69
	570	2275	491	12,400	203.12
	730	1906	4160	16,200	190.32
	735	2499	744	14,000	189.29
1962	1052	2718	6151	22,100	$191.17
	1046	2121	1394	13,200	192.00
	655	1877	929	13,800	192.00
	580	2314	3150	16,900	189.67
1963	675	2586	2275	16,600	$186.88
	1378	2359	5531	19,500	183.59
	945	1991	10,824	24,600	183.82
	1081	2278	4743	18,100	203.52
1964	1508	2665	1029	17,000	$252.49
	1843	3229	484	16,400	265.12
	897	2086	1303	14,700	300.78
	1046	2960	3009	17,100	440.76
1965	587	3055	608	14,200	$476.25
	1043	2912	1240	17,800	612.38
	836	3350	12,075	27,200	631.18
	784	2587	1066	14,700	563.18
1966	1150	2354	948	16,300	$459.48
					369.00

Table IX above shows the correlation of each variable with price for each of the time shift cases. It appears significant that correlation of price with total usage (Variable 18) is nearly inconsequential for all cases tested.

Equations-of-best-fit and their associated time shift values, along with the correlation values, appear to offer the most promising approach toward a quantitative forecast of mercury prices.

As a first step, the computer, using its equation of best fit determined a theoretical price for each quarter and compared the calculation to the actual price. The difference, termed the "residual" (actual price - calculated price) is tabulated below. (Table X) In this table are, also, for each case, the average residual and the average of the absolute value of the residual: $\sum \frac{R}{n}$ and $\sum \frac{|R|}{n}$ respectively where R = residual value and n = number of quarters in each case.

Table IX

CORRELATION WITH PRICE

Time Shift									
Variable	+1	+2	+3	+4	0	-1	-2	-3	-4
1	-.211	-.208	-.205	-.207	-.254	-.289	-.308	-.229	-.313
2	-.144	-.066	-.035	+.035	-.182	-.183	-.163	-.200	-.237
3	+.356	+.368	+.195	+.124	+.433	+.385	+.312	+.304	+.203
4	-.674	-.550	-.415	-.326	-.733	-.842	+.698	-.629	-.604
5	-.046	-.094	-.082	-.178	-.037	-.034	-.054	-.099	-.099
6	+.612	+.681	+.803	+.825	+.579	+.482	+.382	+.304	+.259
7	+.056	-.146	-.223	-.214	+.182	+.282	+.280	+.196	+.285
8	-.196	+.155	+.319	+.378	-.423	-.659	-.748	-.755	-.797
9	+.371	+.206	+.163	+.034	+.393	+.369	+.447	+.333	+.385
10	+.321	+.358	+.554	+.695	+.382	+.442	+.535	+.524	+.561
11	-.379	-.327	-.283	-.211	-.372	-.357	-.328	-.260	-.266
12	-.526	-.652	-.787	-.881	-.413	-.307	-.213	-.156	-.072
13	+.812	+.808	+.638	+.416	+.755	+.533	+.367	+.282	+.150
14	-.233	-.041	+.203	+.473	-.338	-.410	-.495	-.530	-.558
15	+.018	+.211	+.371	+.543	+.018	-.069	-.085	-.095	-.127
16	+.645	+.661	+.566	+.515	+.629	+.503	+.308	+.246	+.153
17	+.021	-.036	-.215	-.141	+.070	+.047	-.047	+.033	-.107
18	+.159	+.121	-.005	+.057	+.222	+.169	+.066	+.114	-.041

NOTE: +1.00 represents perfect direct linear relationship
0.00 represents randomness (no relationship)
-1.00 represents perfect inverse linear relationship

Table X

TABULATION OF RESIDUALS

Time Shift

Quarter	-4	-3	-2	-1	0	+1	+2	+3	+4
1					+1.11	+14.86	-26.63	-12.24	-0.73
2				-0.05	-10.67	-29.60	-7.28	+9.11	+0.43
3			+1.90	+0.77	+1.10	+17.59	+22.07	+2.07	+0.05
4		+0.55	-0.73	-0.83	+8.33	+7.37	-15.08	-10.99	-0.23
5	+0.92	-0.12	+1.57	+1.01	-4.88	-3.31	+34.13	+5.79	+0.40
6	-0.73	-0.40	+2.98	+0.95	-5.36	+10.02	+7.73	-0.32	+0.13
7	+1.71	+1.41	-5.03	-2.18	+10.10	-22.90	-25.10	+4.24	-0.00
8	-0.89	-1.63	+2.34	+2.23	-6.72	+17.27	+56.24	+8.16	+0.42
9	+0.09	+0.63	-2.33	-1.17	+5.75	-6.66	-19.45	-0.94	-0.13
10	-2.57	-1.58	-4.09	-1.92	+10.39	-16.28	-17.60	+3.98	-0.14
11	+1.91	+1.59	+3.79	+1.15	-7.02	+15.63	-4.60	-7.58	-0.28
12	+2.07	+1.39	+2.80	-0.32	-13.18	-29.18	-40.83	-3.51	+0.03
13	+0.16	+1.20	+3.41	-0.63	-11.67	-28.07	-47.99	+1.81	-0.12
14	+0.11	-0.32	-1.81	+0.69	+7.11	+25.31	+29.82	-5.30	-0.02
15	-1.80	-1.35	-8.96	-0.69	+26.13	+30.78	+55.25	+7.35	-0.18
16	+0.15	-0.64	-0.58	+0.56	+0.14	+6.45	+19.96	+2.31	-0.01
17	-2.63	-1.80	+6.41	+1.10	-12.84	-3.12	-8.06	-5.00	+0.01
18	-1.45	-0.51	-1.91	-0.59	+6.83	+5.28	-0.38	+1.04	
19	+3.29	+2.61	-3.69	-1.17	+7.96	-5.26	-12.20		
20	-0.93	-0.45	-1.51	-0.72	+4.84	-6.19			
21	+0.59	-0.58	+5.45	+1.81	-17.45				
$\sum \frac{R}{n}$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$\sum \frac{\lvert R \rvert}{n}$	1.29	1.04	3.23	1.03	8.55	15.06	23.71	5.10	0.19
Ratio[1]	6.79	5.47	17.00	5.42	45.00	79.26	124.79	26.84	1.00

[1] Ratio of $\sum \frac{R}{n} \Big/ \min. \sum \frac{|R|}{n}$

In each case it can be seen that the positive residuals counterbalance negative residuals, so that the linear equations of Table VI indeed qualify as "best fit." The question now remains as to which of the equations is better than the others. The calculations of average absolute residual, shown in Table X, indicate that the equation of Time Shift +4 is easily the most satisfactory, although the negative time shifts may also lend to reasonable equations. Comparisons among cases are facilitated by calculation of the ratio of average absolute residual (for each time shift) to minimum average absolute residual.

It may be significant that the equation of Time Shift +4 results in the minimum residual for fourteen of the seventeen quarters to which it could be applied. The equation seems especially accurate for the latter quarters, those which deviated most drastically from the relatively stable price levels of the early 1960's. The implication is that the mercury market, as a whole, is one in which the demand at a particular time is a major influence on the price at least four quarters hence.

In other words, considering the mercury market as a whole, the price level appears to be particularly sensitive to source of supply and demand at least four quarters previous.

The relatively low average absolute residual values of the -1, -3, and -4 Time Shift equations might indicate that a few sources of demand are sensitive to the price levels of previous quarters. Their behavior is contrary to the behavior of the market as a whole.

In order to determine how a particular source of demand (or supply) reacts with market price, it is necessary to refer to the tabulation of coefficients of correlation with price for each time shift--Table IX. The variables are defined in Table VII.

Those cases which have economic meaning are as follows:

I. High positive correlation in positive time shift: Change in demand influences corresponding change at later period.

II. High positive correlation in zero time shift: Immediate change in price in same direction as change in demand; or immediate change in supply in same direction as price change.

III. High negative correlation in negative time shift: Change in price influences opposing change in demand at later period.

IV. High negative correlation in positive time shift: Change in supply influences opposing price change at later period.

V. High negative correlation in zero time shift: Immediate change in demand opposing price change; or immediate change in price in opposing change in demand.

VI. High positive correlation in negative time shift: Price change influences corresponding change in supply at later period.

VII. Low positive or negative correlations in all time shifts: Unclear or random relationship between supply or demand and price.

From Table IX, the variables can be classified into cases, as defined above. Correlations between 0 and ± .500 are not considered significant.

<u>I</u>

Amalgamation

Electrolytic preparation of chlorine and caustic soda

Pharmaceuticals

Redistilled

II

Amalgamation

Secondary Production

Redistilled

III

Pulp and Paper Manufacturing

Dental Preparation

IV

Mine Production

V

Pulp and Paper Manufacturing

VI

Secondary and Production

VII

Industrial and Control Instruments

Antifouling Paint

Mildew - Proofing Paint

Agriculture

Catalysts

Electrical Appartus

General Laboratory Use

Imports

"Other" uses

Total Usage

The category which supports the contention that price is largely dependent upon the level of demand in past periods is Category I. This is supplemented from the supply viewpoint, by Category IV.

Of the four variables in Category I, amalgamation, pharmaceuticals, and electrolytic preparation of chlorine and caustic soda all have the greatest positive correlations in the +4 Time Shift. Mine production is the only supply source in Category IV. Its most negative correlation is likewise in the +4 Time Shift.

The correlation factors of mine production and electrolytic preparation of Cl_2 and NaOH in the +4 Time Shift are not exceeded by any other variable in any time position. It is significant that nearly all informed sources interviewed (miners, dealers, consumers, state officials, etc.) mentioned either lack of mine supply or increased consumption by chlorine and caustic soda plants or both as the prime cause, in their opinions for the rapid increase in the price of mercury.

Simulation

Of the nine equations,therefore the one most suitable for forecasting is that of Time Shift +4. Given data of any specific quarter, one should be able to forecast the price four quarters hence. The residuals for that equation, in Table 5, testify to its efficiency with known data. A test of the equation is to use the last known quarterly data that of I, 1966 (Table 3) to predict the average price of I, 1967.

Averaging the monthly price quotes for January, February, and March, 1967, as reported in the Engineering and Mining Journal, the average price for that period is \$498.53. The price forecast by the equation is \$763.34. The residual, in this instance, is -\$264.81, several magnitudes higher than any previously encountered.

There is an obvious need to improve upon the equation of Time Shift +4 if the quantitative data available is to be of use in forecasting. For this, data on correlation of each variable with price were examined to determine, if possible, which time shift positions were most relevant to the individual variables. With these and the nine computer-derived equations, synthesis of a new, perhaps more meaningful, equation was anticipated. The available quarterly data were used as test data.

A number of new equations were tested. Not one satisfactorily met its objectives. Residuals, each time, were high. The price per flask was often unrealistically high--over \$1000--or even became negative.

Simulation, using the test data of Table VIII, proved completely unsuccessful. Possibly, then, projected data for supply and demand might hold more promise in conjunction with the mathematical analysis.

Projection Analysis

It is possible, by analyzing each use and source of supply and demand separately, to project consumption figures for an estimated five years from now. It is of interest to test the nine computer-derived equations with these data.

The projections are as follows (in flasks per quarter):

Table XI[4]

PROJECTED QUARTERLY SUPPLY AND DEMAND FOR MERCURY

X_1	Industrial and control instruments	1375
X_2	Antifouling paint	25
X_3	Mildew-proofing paint	1500
X_4	Pulp and paper manufacturing	250
X_5	Agriculture	375
X_6	Amalgamation	75
X_7	Catalysts	425
X_8	Dental preparation	550
X_9	Electrical apparatus	3175
X_{10}	Electrolytic preparation of Cl_2 and NaOH	1500
X_{11}	General laboratory use	600
X_{12}	Mine production	5600
X_{13}	Secondary production	4000
X_{14}	Imports	8500
X_{15}	Pharmaceuticals	700
X_{16}	Redistilled	2650
X_{17}	Other	3250
X_{18}	Total consumption	18,100
X_{19}	Price--not projected	

Below are the price forecasts from each equation:

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4. Projected from Figures 6-11, Chapter VII.

Table XII

PRICE FORECAST FOR EACH TIME SHIFT

Time Shift	Price Forecast
+4	-$162.34
+3	1180.92
+2	688.95
+1	332.74
0	424.20
-1	509.80
-2	812.62
-3	154.60
-4	153.87

The above projections, obviously, are inadequate for any quantitative forecasting. The +4 Time Shift case which, for correlation analysis considerations, seemed promising yields a negative price. The ± 0 Time Shift case predicts a price of $424.20. This may very likely be a realistic and reliable forecast. However, its general credibility is diminished by the overall inconsistency of the remaining forecasts obtained from projected data.

Expert Opinion

Thus the quantitative results obtained from quarterly test data and projected usage data---with the possible exception noted above---must be rejected. The remaining method of analysis is the "expert" opinion of numerous industry leaders.

Opinions were solicited from nearly 200 firms involved with the mining, trading, and consuming aspects of the mercury industry. Of these, 84 replied; several saying only that the requested information could not be released or was not known, others referring to published literature. Some of the opinions of the remaining 59 firms have been cited elsewhere in this investigation.

It is significant only sixteen of these ventured quantitative estimates of the long-run price of mercury. The majority seem to feel that too many external factors (such as labor disputes and governmental actions) are involved to make possible an intelligent guess. Dealers, probably most knowledgeable of all, generally regard this information as extremely confidential. One noted that its future price estimate, in the particular case of mercury, is not even made known to a large portion of its office staff.[5]

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[5] Personal Communication from dealer. Source confidential.

Hence, typical non-qualitative replies include: "Our purchases of mercury are not of sufficient volume to qualify us as experts. We do not feel competent to render opinions on the subject of mercury pricing."[6] "Any information given here would be from trade papers rather than experience."[7] "No estimate--due to uncertainties caused by imports and U. S. government sales."[8] "The price of labor (will determine the long-run price of mercury)."[9]

Quantitative opinions were tabulated by taking the mid-point of any cited price range and rounding to the nearest twenty-five dollars. In addition to the sixteen replies from firms in the industry, a thorough search was made of literature published since 1963. Only one estimate was found there and is included in the tabulation below.[10]

Table XIII[11]

INDUSTRIAL PRICE OPINION

$250:	Chemical company *
$300:	Chemical company *
$325:	Electronic equipment manufacturer *
$350:	Chemical company *; Chemical company *; Thomas A. Edison Industries, Primary Battery Division; chlorine and caustic soda manufacturer. *
$375:	Instrument manufacturer *

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[6] *Personal Communication* from petroleum company. Source confidential.

[7] *Personal Communication* from utility. Source confidential.

[8] *Personal Communication* from mining company. Source confidential.

[9] *Personal Communication* from miner. Source confidential.

[10] Bailey, Edgar H., and Prscoe M. Smith, "Mercury--Its Occurrence and Economic Trends," *Geological Survey Circular 496*, Washington: U. S. Geological Survey, 1964, p. 6.

[11] *Personal Communication* except Bailey and Smith (above).

* Source confidential.

$400: Westinghouse Electric Corporation; S. S. T. Corporation (dealer); Buttes Gas and Oil Company (Gambonini Mine); Culver-Baer Mercury Mines.
$425: Consumer (amalgamation) *
$450: Bailey Meter Company
$500: Bailey and Smith; Mining company *
$800+: Mining company *

Weighted average: $406

It should be noted, from the above tabulation, that as a rule consumers estimate low and miners high. Both, no doubt, tend to be somewhat unrealistic here. Unfortunately, the result will be that several marginal mines will reopen in anticipation of high or rising prices only to meet with financial disaster. This has happened at every period of high prices in the past. Only a fraction of the marginal mines can make a profit over the long run. But one need only consult the Engineering and Mining Journal each month to compile a lengthy list of mines being reopened.

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* Source confidential.

CHAPTER IX

CONCLUSION AND RECOMMENDATIONS

Has this investigation and analysis perhaps been done in vain? Is there possibly no answer to the question, "What will be the future long-run price of mercury?"

Over the short-run, G. D. Barth, in his Engineering and Mining Journal review of 1966 mercury developments, states it is impossible to predict average 1967 prices."[1]

Concerning long-run market implications for minor metals such as mercury, David Brooks, in an extension of his doctoral work, is equally pessimistic: "If events of recent years have proved anything, it is that there is no fixed demand for major metals, much less for minor metals; there is only a demand for materials that can perform certain functions in certain ranges of cost. Given this situation, it may be that the concept of long-run demand does not have much meaning for many minor metals. Rather, there is a series of new and sometimes quite different short-run demand situations. As a result, it is not possible to take a given demand situation and project to the period when expansion schedules will be complete and other dynamic forces will have worked themselves out."[2]

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1. Barth, G. D., "Mercury," Engineering and Mining Journal, Vol. 168, No. 2., February, 1967, p. 143.

2. Brooks, David B., Supply and Competition in Minor Metals, Washington: Resources for the Future, Inc., 1965, p. 22.

Despite these outstanding objections, the writer does make a price forecast. On the basis of the evidence he has seen, it appears that the future long-run price of mercury will be approximately $400, with fluctuations of varying intensity about this price.

The writer concedes that much additional research could have been done which could have materially affected the conclusion he has reached. The most significant shortcoming of this investigation is the lack of a definitive mathematical model. Different equations would have resulted had restrictions been placed on the signs of the coefficients pertaining to each variable in the equations of best fit. Variables of demand would have been kept positive and those of supply kept negative to be consistent with economic logic.

Future research might benefit by investigating other mathematical approaches. Simulation techniques in conjunction with dynamic programming and feedback systems would appear to be particularly beneficial. A macroeconomic approach, such as has been used in the cases of copper and aluminum, might be attempted, although the writer feels that such a method loses much of its relevance when the sales of a commodity is more influenced by technological change than by overall economic growth. Improvements could also be effected in the projected data fro the usage analysis. The method used in this investigation did not explicitly consider the interaction of the data with price.

Further investigation would benefit other areas also. Little was said about the role of imports, although the United States relies on foreign sources for nearly half its mercury. Inventory levels have a psychological effect on buyers and should be more thoroughly explored. Data on historic and current mining costs are rarely published, but would contribute greatly to a better understanding of the supply side of the market.

Finally, a 1967 development is the beginning of mercury trading on the New York Commodity Exchange. Historical data are absent, but the situation should be watched closely for new insights into the nature of the mercury market.

To summarize briefly, the high cost of mercury was a result of supply and demand imbalance. Scarce supply was a result of years of low prices postponing the development of needed reserves. Prices had not kept pace with rising labor and processing costs. The situation was critically aggrevated by labor slowdowns at a time when inventories were low.

Demand shared a causative role in the high price. Consumption has been at a high level for several years and at a crucial time industrial inventories proved insufficient. The market was especially strained by the demands of chlorine and caustic soda plants for large quantities of mercury with which to start production at new facilites.

Correlation analysis indicates that the market is more responsive to demand than to supply. Otherwise, quantitative analysis of quarterly and projected data has not been impressive. The most reasonably prediction from these equations is a long-run price of $424.20. Industrial sources yield an average price forecast of $406.

The writer concludes that if it is possible to predict long-range prices at all, a realistic estimate is $400 per flask. There are several areas in which the forecasting methods used might be improved and some have been suggested.

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