IC 8598

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Bureau of Mines Information Circular/ 1973

An Economic Appraisal of the Supply of Copper From Primary Domestic Sources

UNITED STATES DEPARTMENT OF THE INTERIOR

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TABLE 14. - Geographical distribution of domestic copper resources available at a copper price of $2 per pound

(Million short tons)[1]

Area	Measured			Indicated and inferred		
	Ore	Average grade, percent	Recov-erable metal	Ore	Average grade, percent	Recov-erable metal
Alaska.................	-	-	-	730	0.82	5.2
Arizona, New Mexico, Colorado, and Utah....	8,600	0.71	57	16,000	.42	50
California and Nevada..	470	.77	2.6	1,100	.39	3.3
Montana, Washington, and Idaho.............	1,100	.84	4.9	7,970	.27	14.4
Michigan and other States................	710	1.1	6.8	8,000	.58	36
United States..........	10,880	.75	71.3	33,800	.43	108.9

[1]Due to rounding, these totals may differ slightly from the actual data derived in this report. Recoverable metal shown includes copper leached from material not classified as ore that would be moved or otherwise made accessible for economic metal recovery as a result of mining.

The following sentence should be added to footnote 1 of table 10 (page 38) and table 12 (page 39).

Recoverable metal shown includes copper leached from material not classified as ore that would be moved or otherwise made accessible for economic metal recovery as a result of mining.

On page 40 the measured silver figures in table 15 should be changed as follows:

Michigan and other States..........43 million ounces
United States.....................604 million ounces

On page 114 paragraph 2 should read as follows:

Estimated capital requirements (table C-15) including facilities, utilities, and working capital are $29.1 million or $1,937 per ton of daily capacity.

On page 114 paragraph 3 should read as follows:

Total annual operating cost (table C-16) including direct, indirect, and fixed costs is $7.4 million or $1.38 per ton of material processed.

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Bureau of Mines
Information Circular 8598

AN ECONOMIC APPRAISAL OF THE SUPPLY OF COPPER FROM PRIMARY DOMESTIC SOURCES

by

Harold J. Bennett, Lyman Moore, Lawrence E. Welborn, and Joseph E. Toland

ERRATA

On page 21, table 6 should be replaced with the following version:

TABLE 6. - Summary of estimated capital investment for copper flotation concentrators of selected design capacity

Capacity, tons per day	Plant cost, dollars[1]	Plant cost per ton of daily capacity, dollars	Working capital, dollars	Total investment, dollars
[2]5,000	12,615,000	2,520	797,000	13,412,000
[3]6,000	18,069,000	3,010	974,000	19,043,000
15,000	27,361,000	1,820	1,695,000	29,056,000
23,000	48,405,000	2,100	2,699,000	51,104,000
40,000	75,878,000	1,900	3,864,000	79,742,000
72,000	114,236,000	1,590	6,446,000	120,682,000

[1]Plant cost includes equipment, buildings, and facilities and utilities; not included are land and water rights.
[2]Does not have a byproduct molybdenum circuit.
[3]This concentrator is designed for use in processing the native copper ores.

On page 39, table 14 should be replaced with the following version:

Information Circular 8598

An Economic Appraisal of the Supply of Copper From Primary Domestic Sources

by Harold J. Bennett, Lyman Moore, Lawrence E. Welborn, and Joseph E. Toland
Intermountain Field Operation Center, Denver, Colo.

UNITED STATES DEPARTMENT OF THE INTERIOR
Rogers C. B. Morton, Secretary

BUREAU OF MINES
Elburt F. Osborn, Director

/ d

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TABLES--Continued

AN ECONOMIC APPRAISAL OF THE SUPPLY OF COPPER FROM PRIMARY DOMESTIC SOURCES

by

Harold J. Bennett,[1] Lyman Moore,[1] Lawrence E. Welborn,[2] and Joseph E. Toland[3]

ABSTRACT

This study was performed by the Bureau of Mines to evaluate the potential supply of primary copper from domestic resources. A tonnage-price relationship was developed indicating the quantity of copper that could be produced economically from known deposits at various copper prices and at various rates of return on the required capital investment. Costs of production are based on estimated capital and operating costs for mining, concentrating, smelting, and refining the copper. Total known recoverable copper resources are 189 million short tons of which 83 million tons could be economically recovered assuming a price of $0.50 per pound of copper, credit for the recovery of byproducts, and a 12-percent rate of return on capital investment. The quantities of recoverable byproducts associated with the 83 million tons of recoverable copper are molybdenum, 1.8 million tons, gold, 43 million troy ounces, and silver, 740 million troy ounces.

INTRODUCTION

Personnel of the Bureau of Mines are continually analyzing the domestic supply and demand of mineral commodities to provide data to formulate mineral policy. Since World War II the United States has become a major world importer of many mineral commodities basic to an industrialized economy. Prior to World War II the United States was virtually self-sufficient for its supply of copper and was a major exporter. Currently the competition for foreign sources of raw materials has increased owing to population growth and rising standards of living. To further complicate the situation, countries possessing raw materials desire to upgrade their standard of living by employing surplus labor resources to convert the raw materials into consumer products for domestic use and for export. Therefore, it is necessary that we continually appraise our mineral supply position noting the conditions affecting the availability of these minerals from domestic sources.

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[1]Mining engineer.
[2]Mining engineer (now manager of financial planning with AMAX Lead and Zinc, Inc.).
[3]Mathematician, Division of Automatic Data Processing.

This study, based on 1970 data, is an evaluation of domestic copper resources. The objectives are as follows:

1. To estimate the capital investments and operating costs for appropriate mining and concentrating methods, for smelting and refining facilities, and for transportation of intermediate products to a smelter and refinery.

2. To determine the quantity and quality of domestic copper resources and the physical conditions that affect production from each deposit.

3. To perform a cost study for each deposit using the developed resource and cost data. Results of these analyses indicate the unit prices and associated tonnages of copper and byproducts which can be produced at specific prices.

4. To combine and analyze the price-production relationships for all deposits to show the domestic copper production potential at various metal prices and at varying returns on the capital investment.

Not included in the study are resources in which copper is produced as a byproduct or coproduct and small high-grade deposits that may produce occasionally with exceptionally high costs. Data pertaining to the production of copper from the nickel-copper deposits of Minnesota are contained in a previous Bureau of Mines publication (9).[4] A similar study of domestic copper resources was performed by the Bureau of Mines based on 1964 data and the results published (20).

Results of the current study differ from those of the previous studies because of the time interval in which additional resource data became available; also, results in this publication are shown directly in terms of unit price and associated quantity of recoverable metal, whereas in the other study results were shown as the ratio of production costs and unit price and the associated quantity of recoverable metal. In this current study greater emphasis was placed on developing detailed costs and evaluation methods that can be easily followed and reproduced by interested readers.

The reader is also referred to these other publications for a much more comprehensive discussion of the copper industry than that presented in this report. In 1965 the Bureau of Mines published "Copper, A Materials Survey" (10) which brought together fundamental data and information about copper and discussed nearly every phase of the copper industry, including history, occurrences, mining and milling methods, metallurgical processes, uses, prices, supply, demand, and trade. A more recent report was the economic analysis prepared for the General Services Administration by Charles River Associates in 1970 (2). The report presents information about the structure of the industry, an analysis of the historical data, and forecasting methods using econometrics. The current "Mineral Facts and Problems, 1970 Edition" (16), and Minerals Yearbooks of the Bureau of Mines provide general information about the copper industry and recent statistical data.

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[4]Underlined numbers in parentheses refer to items in the bibliography preceding the appendixes.

ACKNOWLEDGMENTS

Personnel who aided in the collection of resource and cost data for this report on a part-time basis were William R. Hardwick, formerly of the Bureau of Mines office in Tucson, Ariz., James H. Aase, Ardella W. Ikner, Leonard P. Larson, and Robert C. Weisner of the Denver office, and Guy Johnson of the Bureau of Mines office in Minneapolis, Minn. John Duda of the Bureau of Mines Process Evaluation Group, Morgantown, W. Va., developed the costs for smelting and refining facilities.

Acknowledgment is given to other supporting personnel of the Bureau of Mines Denver office, to members of the copper industry, and government agencies who provided services, guidance, and data for the completion of the study.

STRUCTURE OF THE DOMESTIC PRIMARY COPPER INDUSTRY

In 1970 the United States was a net importer of primary copper. The total domestic primary production available for consumption was 1.7 million tons. Total domestic consumption of refined copper was 2.0 million tons; the difference between domestic primary production and total consumption was made up by copper from domestic secondary and foreign primary and secondary sources.

Mining operations in 1970 in five Western States accounted for 93.3 percent of the domestic mine production. The percentage attributed to operations in these States was as follows: Arizona, 53.3 percent; Montana, 7.2 percent; New Mexico, 9.6 percent; Nevada, 5.9 percent; and Utah, 17.3 percent.

The major consuming industries are in the Eastern, Midwestern, and to a lesser degree, Far Western States. In 1970 most of the consumption was by 35 eastern firms.

The procedure required to produce a marketable product includes mining, concentrating, smelting, and refining. Copper content of the economic ores averages about 0.6 percent, whereas the metallic content of the finished marketable product is 99.9 percent. In each phase, after mining, the metal content of the product is increased. The mined ore is concentrated to produce a 20- to 30-percent copper product. This product is smelted resulting in blister copper having a metal content of 98 to 99.5 percent copper. The blister copper is refined to eliminate and recover the impurities, thus resulting in a 99.9-percent copper product.

In the mining phase the material is broken, the waste rock discarded, and the ore transported to the concentrating facilities. Efficient mining of a copper deposit segregates the ore into various types based on its amenability to different processing methods and the mineral content. The copper sulfide minerals, if of sufficient grade, are concentrated by methods entirely different from those used for oxides and carbonates. Material too low grade to warrant processing is discarded as waste or placed on a dump from which the copper can be reclaimed later. Waste may occur as unmineralized overburden or as low-grade or barren material encountered within the boundaries of the ore body.

The greatest portion of domestic production is obtained from low-grade deposits in the western part of the United States. High-grade deposits were a significant source of copper during the early history of the domestic copper industry. These deposits still contain a large resource, only part of which can be economically recovered under current economic conditions. Production has shifted to low-grade deposits which can be economically exploited using high-volume, low-cost mining methods.

In 1970 approximately 85 percent of the domestic copper was produced using open-pit surface methods to mine the low-grade deposits (fig. 1). Block caving, a high-volume underground method used to exploit low-grade deposits, accounted for 40 percent of the copper produced by underground methods. Five companies accounted for 75 percent of the 1970 mine production; 11 companies with 25 mining operations accounted for 92 percent of the 1970 mine output.

The concentrating method required to recover minerals from the mined material is dependent upon the characteristics of the mineral and host rock. An operation may utilize more than one method to process the material. The two most common recovery methods are by flotation and leaching. The copper sulfide minerals are normally recovered by flotation and the oxides and other leachable copper minerals by leaching.

Recovery of the copper-sulfide minerals requires the liberation of the minerals from the host rock by crushing and grinding, concentration of the liberated minerals by flotation, and dewatering by filtration to produce a copper concentrate. The concentration ratio (the ratio of copper in the concentrate to copper in the ore) is often as great as 50 to 1 and may be as high as 100 to 1.

The resulting concentrate at many of the copper operations contains copper, molybdenum, gold, and silver. If economical, the concentrator will have a byproduct molybdenum recovery section in which the copper and molybdenum are separated by a flotation process. The gold and silver are recovered later when the concentrates are smelted and the copper refined.

Leachable copper minerals are recovered using a process whereby the minerals are leached from the rock with a sulfuric acid solution. After passing through the leach material the solution is collected and pumped into vats containing iron, often shredded scrap tin cans. Copper in the solution is replaced by iron and precipitated as cement copper. The cement copper, averaging between 70- and 80-percent copper content, is dewatered and shipped to a smelter.

Copper can also be recovered from the leach solution by an electrolytic-deposition process in combination with or separate from a solvent-extraction process. Smelting and refining of the copper recovered from the solution using the electrolytic process can be bypassed because the high-purity product which results is comparable to a refined product.

Generally the cost to mine the leachable material is borne by the sulfide ore and the cost of the leach process is economically justified through

FIGURE 1. - The open pit and concentrator at the Berkely mine, The Anaconda Company, Butte, Mont.

revenues from the copper recovered by the leaching process. Exceptions to this are the copper operations in which the leachable ore is of sufficient grade to economically bear the cost of mining and of preparing the ore for the leach process.

In 1970 approximately 10 percent of the mine output of copper was produced by dump and in-place leaching and an additional 4 percent by heap or vat leaching of copper ore.

The concentrates produced by flotation and precipitation-leach facilities are further concentrated by smelting, a pyrometallurgical process. Heat is applied to the concentrates and a lime-silica flux in a reverberatory furnace. A reaction occurs and a copper-iron-sulfur product called matte is formed. Waste rock, flux, and excess iron combine to form slag, which is discarded. The matte is transferred to a second furnace called a converter and air is blown into the molten material causing the iron and sulfur to oxidize. The iron oxide combines with silica to form slag and the sulfur forms a gas and is expelled as sulfur dioxide. Molten copper is cast into anode mold and sent to a refinery. However, part of the molten copper may be upgraded to fire-refined copper by melting it in a furnace and removing the principal impurity, oxygen, in a reducing atmosphere.

Small mining operations do not have their own smelting facilities because the high capital costs of smelting equipment restricts these plants to large capacities. Concentrates produced by operations are sold or processed for a fee by companies operating custom smelters. In 1970 there were 16 smelters operating in the United States for a total designed charge capacity of 8.6 million tons. Ninety-six percent of this capacity was in the Western States of which 50 percent was in Arizona.

Copper contained in the anodes produced at the smelters is electrolytically refined to remove impurities and precious metal byproducts. In this process the anode copper is dissolved in a solution and then redeposited by an electric current to form copper cathodes.

Refining facilities are predominantly located on the east coast close to major marketing areas and to port facilities to receive imported copper. Total designed refinery capacity in 1970 was 2.7 million tons; 51 percent of this on the east coast. Western States have 1.3 million tons of capacity with 63 percent of this total in the Southwest.

The copper industry is vertically integrated to a large degree. Some mine operations may sell an ore, others sell a concentrate, but the major portion of domestic copper is produced by companies integrated from mine through fabrication.

In 1970 four companies[5] controlled approximately 70 percent of the mine production capacity, 85 percent of the smelting capacity, and 81 percent of

[5]These four companies are Phelps-Dodge Corporation, Kennecott Copper Corporation, American Smelting and Refining Company, and The Anaconda Company.

the refining capacity. The same four companies owned, or had considerable interests in, fabricating facilities that consumed over 50 percent of the copper. Two of these companies controlled smelting and refining facilities which processed most of the copper produced by independent companies.

Transportation is a significant part of the cost of producing copper. Therefore, it is essential to remove as much waste as possible near the mining operation. Generally, the concentrators are located adjacent to the mining operations, whereas smelters may serve one or more mining operations. Location of the refinery is not as important. Since the copper content of the smelter and refinery product is approximately equal, there is a growing tendency to locate the refinery with the smelter at the mine.

ESTIMATION OF COPPER PRODUCTION COSTS

Capital investment and operating costs to produce a marketable product have been estimated for various segments of the industry. These segments consist of mining, concentrating, smelting, and refining. Freight costs to transport the material to the smelting and refining facilities are also included. The latter costs were obtained from the Transportation Section of the General Services Administration.

The investment and operating costs (based on 1970 values) were estimated for seven open-pit mining operations of different capacity, one room-and-pillar operation, one block-cave operation, and one cut-and-fill operation. Similar data were estimated for five copper concentrators of different capacity based on examples of those used at porphyry copper operations and one concentrator typical of what may be used to process ores from the native copper deposits. Costs were also estimated for copper dump leach operations using the cementation and the solvent extraction processes.

The capital investments for the different mining and processing facilities include the costs of mobile and stationary equipment, construction, engineering, facilities and utilities, and working capital. Facilities and utilities is a broad category which includes the costs of the water system, fire protection, roads, fences, and fuel and power distribution. Working capital is a revolving cash fund required for operating expenses such as labor, supplies, taxes, and insurance.

The total operating cost is a combination of direct, indirect, and fixed costs. Direct costs include materials, utilities, direct and maintenance labor, and payroll overhead. Indirect costs include technical and clerical labor, administrative costs, facilities maintenance and supplies, and research. Fixed charges include local taxes, insurance, depreciation, and deferred expenses.

The capital investments and operating costs were adjusted to allow for differences in such characteristics as overburden thickness, haulage distance, ore hardness, and the metallurgical qualities of the ore. In this study the capital costs of plants constructed prior to 1970 were adjusted by dividing the estimated base 1970 costs by a factor selected for the appropriate year from the graph shown in figure 2. $\left(\frac{1970\ \text{cost}}{2.1} = 1950\ \text{cost.}\right)$ This graph is based on a weighted average of the price indexes for labor and materials. Maintenance cost was increased by a factor of 2.3 if a plant was constructed prior to 1955.

Capital and operating costs for the smelter and refinery are based on available published data and information obtained during interviews with people in industry. The process technology is that used in the most recently constructed smelting and refining facilities. This portion of the study was done by the Bureau of Mines Process Evaluation Group at Morgantown, W. Va.

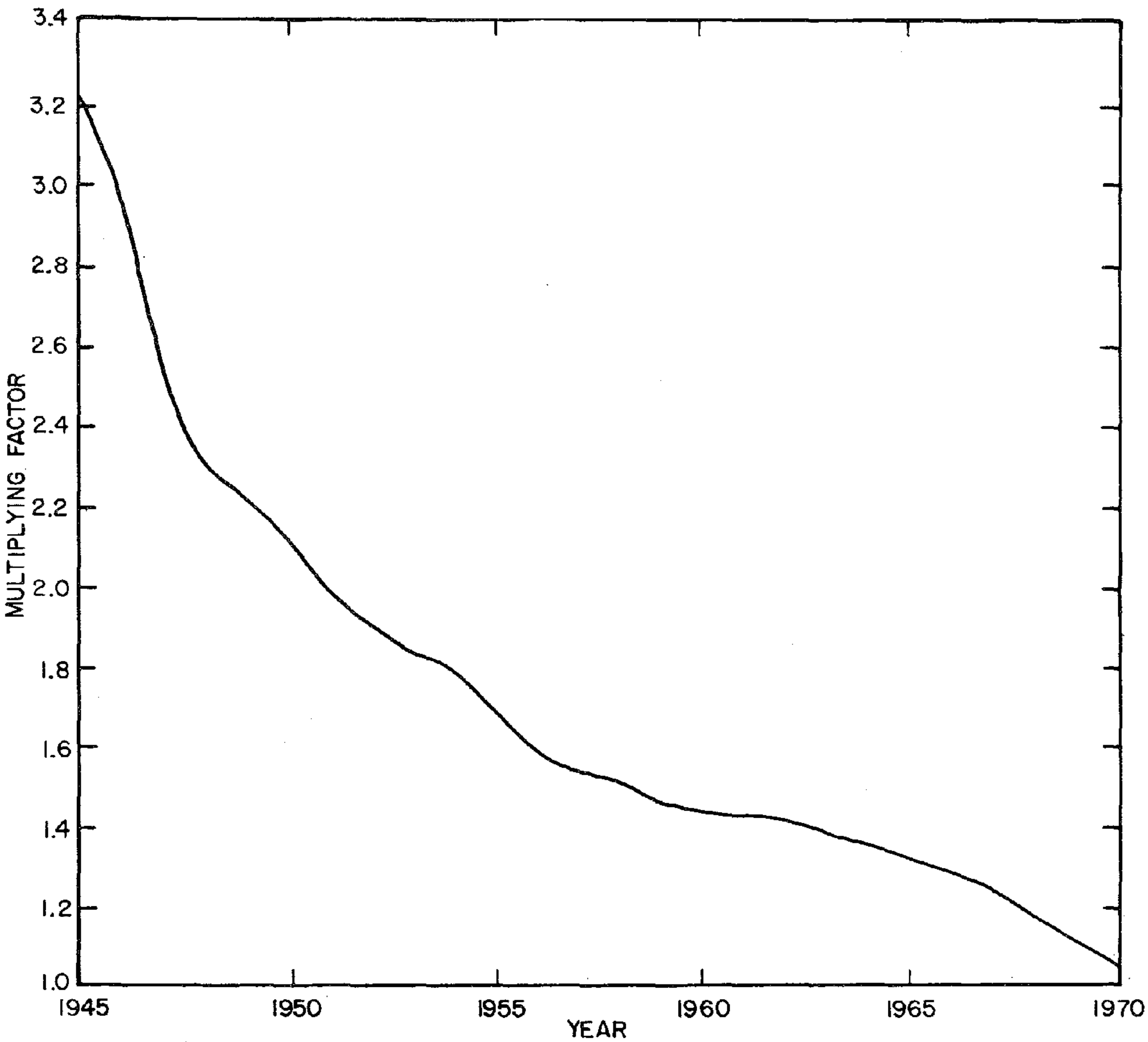

FIGURE 2. - Composite index based on 50 percent labor and 50 percent material, 1947-1949 = 100, with factor for adjusting capital costs of plants constructed prior to 1970.
(Courtesy, Industrial Research Service, Inc., Dover, N.H.)

Mining

Both surface and underground mining methods were evaluated in this study with the major emphasis placed on open-pit operations. Capital and operating costs were estimated for open-pit operations extracting 30,000, 40,000, 50,000, 80,000, 100,000, 150,000, and 180,000 tons of material per day. Similar costs were estimated for a 6,000-ton-per-day (tpd) cut and fill, a 25,000-tpd room and pillar, and a 30,000-tpd block-cave mining operation. These tonnages are total material excavated and include ore and waste material.

Exploration and engineering costs include drilling, bulk sampling, mining tests, concentrating tests, and engineering studies. Drilling costs are based on an estimate of drilling required to delineate the ore body. Drill footage depends on the size, shape, depth of cover, and uniformity of the deposit. Rotary drilling was assumed for barren rock overlying the ore zone and core drilling for the ore zone. Deflections were used to explore deep ore zones. Unit drilling prices vary greatly depending on rock characteristics, size of hole, and depth. Typical prices used were as follows: Rotary drilling $3 to $6 for holes 300 to 3,500 feet deep; core drilling $9 to $15 for holes 300 to 3,500 feet deep; and drilling engineering and geological expense 10 percent of drilling cost. Bulk sampling costs vary depending on the depth of the ore zone. Typical unit costs used were as follows: Shaft sinking $800 per foot; drifting $60 per foot; and raising $100 per foot. Mining tests, concentrating tests, and feasibility studies vary depending on present knowledge and complexity of the deposit. Typical costs were $300,000 for an extension of a producing deposit; and $1 million for a new deposit adaptable to proven production methods.

Open Pit

The surface mining operations analyzed in this report are representative of those used in the domestic copper industry today. All are based on the use of drilling and blasting to break the rock, shovel loading, and truck haulage. For uniformity, work at all mines was scheduled for three shifts per day 357 days per year. Equipment utilization was estimated as drills, 50 percent; shovels and loaders, 70 percent; trucks and other haulage vehicles, 80 percent; and road maintenance equipment, 50 percent. Utilization is defined as the ratio of the time a piece of equipment is operating to total time. These percentages are the approximate average of apparent utilization as reported from a large number of mines.

The selection of optimum sized equipment for the various sized mines followed industry preference as shown by recent equipment purchases. A Bureau of Mines computer program based on time studies was used to balance shovel size and truck size to varying open-pit haulage distances and profiles. Unit performance attainable at the various mines was estimated from performance records of equipment now in use at each mine. The amount of equipment required follows from the workload, unit performance, and utilization factor.

Thus, capital and operating cost estimates made for the representative mines are standardized as to work schedules and utilization factors, but are individual with respect to mining conditions such as rock hardness, breakability, and fragmentation needed for milling or leaching; length and profile of haul; amount of ore sorting required; climatic conditions, etc.

Capital Investment

Capital costs include acquisition of the property, exploration and development, equipment and construction costs, facilities and utilities, and working capital.

Acquisition costs are a nominal fee to acquire lease rights; a 5-percent royalty assessed on net smelter return is considered in the financial analysis as payment for minerals extracted from the deposit.

Exploration costs are based on an estimate of the work required to provide sufficient data to prove the quantity and quality of the resources to economically justify a mining operation on a particular deposit. The major part of the cost consists of drilling and engineering expenditures.

An estimate of the development cost includes the work to prepare the deposit for production. For an open-pit operation this work primarily consists of removing overburden (waste material) to expose the ore body.

Equipment and construction costs include the cost of all the mobile equipment in the pit and the cost of permanent structures such as the mine administration buildings, shops, and changehouse.

Working capital is a function of operating cost and therefore does not vary directly with the capital investment.

Tables A-1, A-5, A-7, A-9, A-11, A-13, and A-15 in appendix A contain a summary of the capital investment for the open-pit mines indicating the amount required for exploration, development, equipment, and working capital. Associated with each is a brief description of the operation; for illustration purposes tables itemizing the equipment, structures, material, and installed costs are included for the 40,000-tpd operation. Similar data, which differ relative to size and quantity of equipment and facilities, were prepared for the other operations.

The estimated investment per ton of daily capacity in the open-pit operations, as shown in table 1, only partially exhibits an economy of scale owing to differences in the equipment requirements. These differences reflect the variation in equipment operating schedules, haulage distance, and rock characteristics at deposits for which these costs were estimated.

Because each cost estimate is not based on the same deposit, the exploration and development cost will vary because these costs are a function of thickness of overburden, thickness, and longitudinal extent of the ore body, type of overburden, and uniformity of the ore. These estimates are examples of the investment required to exploit copper mineralized deposits each having varying characteristics which affect investment.

TABLE 1. - Summary of estimated capital investment for selected open-pit mining operations

Capacity,[1] tons per day	Plant cost, dollars[2]	Plant cost per ton of daily capacity, dollars	Working capital, dollars	Lease option and exploration and development, dollars	Total investment, dollars
30,000	5,171,500	172	1,089,000	3,418,100	9,678,600
40,000	6,321,100	158	1,349,600	1,857,600	9,528,300
50,000	5,944,800	119	1,320,900	2,251,200	9,516,900
80,000	14,104,100	176	2,349,100	12,215,800	28,669,000
100,000	13,224,500	132	2,831,500	6,010,200	22,066,200
150,000	22,373,300	149	4,494,500	7,700,000	34,567,800
180,000	19,607,000	109	4,501,200	24,150,000	48,258,200

[1]Capacity in terms of total material excavated and includes ore and waste.
[2]Plant cost includes mine equipment and plant, facilities and utilities; it does not include investment for property acquisition, exploration, development, or working capital.

Mine capital costs for known domestic deposits were estimated by extending costs shown in appendix A for a type mine to the conditions expected at the deposit and then scaling the modified cost to the size of the new operation. The values of the type open-pit mines were modified to reflect differences in haulage length and profile. The quantity of haulage and road equipment needed was changed in proportion to the total time needed per trip for loading, traveling, dumping, and returning at the type mine and at the mine being evaluated. Other apparent capital cost differences due to different rock characteristics or mining environment were estimated subjectively. The modified cost for the type mine was then scaled exponentially to the size of the mine being evaluated using the following equation: $C = K(A/B)^b$. This equation relates the unknown cost (C) of a plant of size A to the known cost (K) of a similar plant of size (B) multiplied by the ratio of the sizes (A/B) raised to an exponential power (b). Exponential scale factors used were: 5,000 to 10,000 tpd, 0.7; 10,000 to 20,000 tpd, 0.8; 20,000 to 50,000 tpd, 0.9; over 50,000 tpd, 0.95.

For illustration purposes only, to estimate the cost of a 9,000-tpd mining operation using the modified cost for the 30,000-tpd type operation the following procedure would be used. The modified cost of the 30,000-tpd operation is scaled to 20,000 tpd using a 0.9 factor; this obtained value is then scaled to 10,000 tpd using a 0.8 factor; this resultant is in turn scaled to a 9,000-tpd operation using a 0.7 factor.

The principal scaling factors used in this study were 0.9 and 0.95 since there were few operations where the daily production rate of mined material was less than 20,000 tpd.

Operating Cost

Although most open-pit mining operations use similar equipment for drilling, blasting, loading, and hauling the material, there are deposit characteristics which increase the mining cost per pound of recoverable copper among the various operations. Economy of scale may exist for a particular operation but is not necessarily the controlling factor when comparing different operations.

Factors that affect the operating cost are the physical shape of the ore body, topography, rock hardness, variability of mineralization, climate, ground-water conditions, etc. The physical shape of the ore body and topography affect the haulage distance, waste to ore ratio, and haulage profile. Rock hardness affects the penetrating rate of the drill, breakability of the material, the blasting agent requirements, and wear of equipment. Climate affects equipment performance due to temperature extremes and the amount of service equipment required to maintain the equipment and blasting agent requirements.

Estimates of consumption of face supplies such as bits, steel, and explosives for each mine are based on available mine-operating reports. Machine operating supplies such as power, fuel, tires, replacement parts, etc., are based on the capital equipment list and on unit costs as shown on mine-operating reports or equipment manufacturers' estimates. Direct labor needed for equipment operation follows from the equipment list. Equipment maintenance labor was estimated from available company reports and equipment manufacturers' advice.

A summary of the estimated operating costs for the selected open-pit mining operations is contained in table 2. The data indicate economy of scale; the smaller capacity operations have comparatively higher production costs which tend to stabilize as the capacity is increased. These costs, direct, indirect, and fixed, include operating and maintenance labor, supplies, administration and overhead, depreciation, amortized future equipment requirement, deferred expenses, taxes, and insurance. Tables A-2, A-6, A-8, A-10, A-12, A-14, and A-16 in appendix A contain more detailed data pertaining to the operating costs of the specific operations.

TABLE 2. - Summary of estimated operating costs for selected size open-pit mining operations

Capacity, tons per day	Operating cost, dollars per ton of material mined[1]			
	Direct	Indirect	Fixed	Total
30,000	0.267	0.038	0.089	0.394
40,000	.243	.042	.071	.356
50,000	.191	.033	.054	.278
80,000	.214	.028	.100	.342
100,000	.207	.032	.064	.303
150,000	.217	.021	.071	.309
180,000	.176	.022	.069	.267

[1]Operating cost does not include royalty or Federal income tax; the operating cost does include amortized capital for future pit equipment, deferred expenses, depreciation, local taxes, and insurance. Operating cost may from time to time include a substantial amount of waste removal for future production. Tons of material mined includes ore and waste.

Table 3 contains operational data of various segments (drilling, blasting, loading, and hauling) of the open-pit mining operations indicating the variance in cost that does occur because of rock characteristics, haulage distance and grade, and other operational factors.

Drilling and blasting costs are less at the 50,000- and 100,000-tpd operations because the rock is comparatively softer and more easily broken. Secondary blasting is minimal; explosive consumption is low; also, the shovels can more easily dig and load the broken material. Some operations have an added cost because a slurry-type blasting agent is required in the wet holes.

The cost data vary for each segment of each operation, but an economy of scale may be indicated as one high-cost factor is offset by a low-cost factor averaging to an overall lower cost.

Pollution control costs such as mine dump revegetation are not included.

Open-pit operating costs for known domestic deposits were estimated similarly to capital costs. Costs for the type mine were modified to show changed haulage cost and subjective adjustments were made to reflect differing rock and mining environment. Modified operating costs for the type mine were then scaled to the size of the mine being evaluated. Exponential factors used were 0.9 for mines under 40,000 tpd and 0.95 for larger mines.

Underground

Capital and operating costs were estimated for underground mining operations using block-cave, cut-and-fill, and room-and-pillar methods, which were judged to be suitable to extract the major portion of the resources requiring underground mining methods. Selection of the general mining procedure, open-pit or underground, is based upon economics and indicates the most profitable and feasible manner in which to extract the ore.

Description of Mining Methods

The block-cave method is used for large low-grade porphyry deposits that cannot be mined by surface techniques because of the physical dimensions of the ore body or the thickness of the overburden. Block caving is not a selective mining method. To be amenable to block caving the deposit must be uniformly mineralized and possess a fracture system so that caving will be self-sustained after being induced by undercutting.

In this hypothetical operation, shafts with connecting drifts provide access to the deposit. Blocks of ore are initially undercut to allow the ore to cave and flow by gravity through a series of passages to a haulage level. Flow of the ore is controlled by chutes. The ore is transferred via train haulage to the appropriate shafts for hoisting to the surface (fig. 3).

In 1970 there was only one operation using this method to extract copper ore. The method was described in detail in a Bureau of Mines publication (4).

TABLE 3. - Mine operating data and cost estimates for various phases of the operation at selected open-pit mines

Operation	Mine size (tons of material handled per day)						
	30,000	40,000	50,000	80,000	100,000	150,000	180,000
Drilling:							
Hole size....................inches..	11	9	7-3/8	9	9	9	12-1/4
Drill horsepower.....................	600	500	215	500	500	500	600
Penetration rate......ft/8-hr shift..	325	400	376	360	430	550	375
Bit life...ft, for steel rotary bit..	1,500	1,100	2,324	788	1,500	675	1,500
Drill hole spacing...............ft..	25 x 25	20 x 24	25 x 25	24 x 18	23 x 26	30 x 30	30 x 30
Cost per ton................dollars..	0.038	0.018	0.013	0.026	0.019	0.017	0.019
Blasting:							
Type explosive.......................	AN-FO	AN-FO and slurry	AN-FO	AN-FO	AN-FO	AN-FO and slurry	AN-FO and slurry
Proportion wet holes........percent..	0	50	0	0	0	25	75
Powder factor..........lb AN-FO/ton..	0.70	0.35	0.197	0.36	0.17	0.26	0.31
Cost per ton................dollars..	0.030	0.037	0.012	0.032	0.010	0.034	0.049
Loading:							
Size shovel...................cu yd..	6 and 8	6 and 15	9	9	15	15	15
Loading rate.............tons/shift..	5,630	[1]5,740	9,600	9,100	10,000	12,800	12,900
Cost per ton................dollars..	0.050	[1]0.054	0.025	0.041	0.041	0.031	0.030
Haulage:[2]							
Average haul length.....ft, one way..	4,000	6,400	10,700	7,700	9,200	14,700	8,700
Average elevation change.........ft..	125	135	390	144	336	730	170
Truck capacity.................tons..	85	75	85	85	85	120	120
Haulage rate.......tons/truck/shift..	1,540	1,830	1,755	1,620	1,490	1,340	2,210
Cost per ton................dollars..	0.110	0.093	0.108	0.116	0.117	0.149	0.085

[1]Weighted average of both shovel sizes.

[2]Haulage statistics are weighted averages of the haul lengths, elevation changes, tonnages, and costs for the haulage of ore, leach, and waste material.

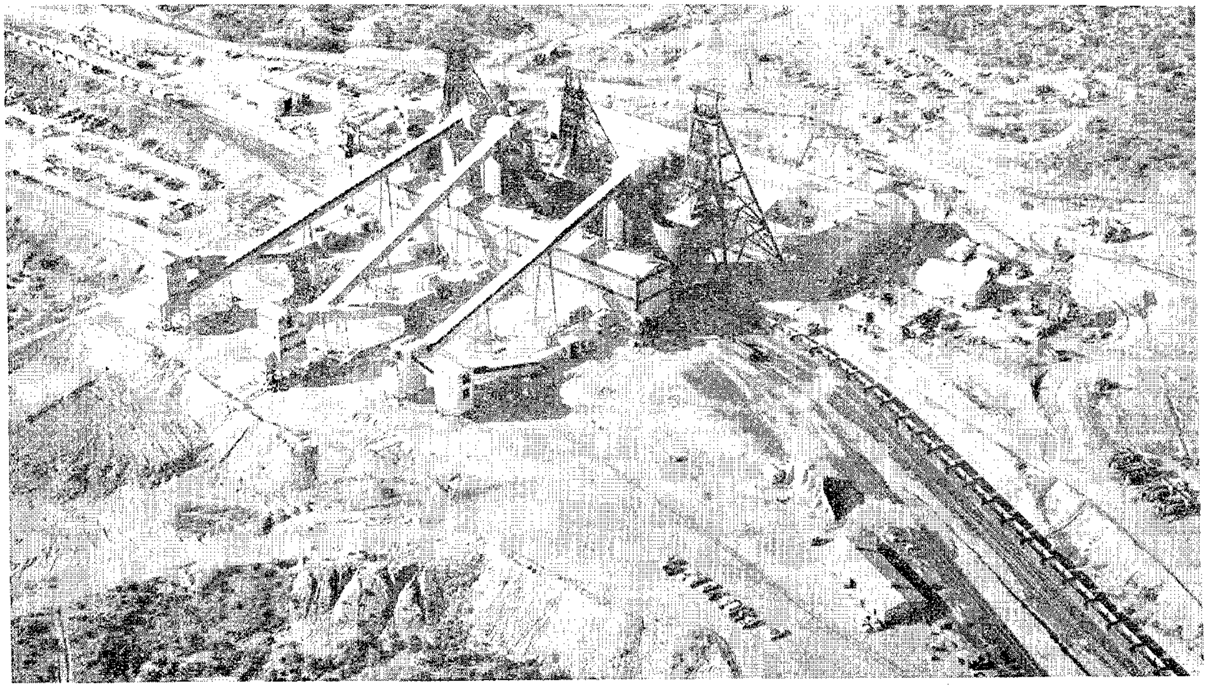

FIGURE 3. - Ore hoisting, crushing, and loading facilities at the San Manuel mine, Magma Copper Company, San Manuel, Ariz. Designed to lift and crush 62,000 tons of ore per day from production levels as deep as 2,675 feet underground.

The cut-and-fill operation was designed to extract ore from a vein-type deposit using the mill wastes to fill the openings to provide a working platform during the mining of the ore and ground support after the ore had been removed.

Entrance is gained to the ore body via shafts and connecting drifts; the ore body is mined in succeeding equally spaced intervals or levels in the vertical dimension. Within each level, rooms are excavated removing horizontal segments the length and width of the room; initially a certain thickness of segment is removed. As mining proceeds fill material is returned from the surface filling the void created by the excavated material. When a complete segment has been removed from the room, the cycle is repeated using the material placed in the void as a working surface to mine the next ascending segment. In this fashion the mining cycle is repeated until the level has been completely mined and filled, then a succeeding lower level is mined.

Mobile trackless equipment is used to drill, load, and convey the ore from the rooms to a passage which transfers the material to a train haulage unit on the haulage levels. The ore is transported to the shafts and hoisted to the surface.

The room-and-pillar mining method is used to extract ore from a tabular horizontal ore body. In the designed 25,000-tpd operation, entrance to the ore body is via adits. Ore is sized underground and conveyed to concentrating facilities on the surface. Pillars, supplemented by rock bolts, are strategically spaced in the working areas to provide roof support.

Mobile trackless equipment is used to drill, load, and haul the ore to a crusher prior to conveying to the surface.

Capital Investment

The investment costs for underground mines can be broken down into categories that are similar to those for the surface mines. However, the nature of the development costs for the two are considerably different.

The development cost for an underground operation includes the costs of shaft sinking and of driving drifts and raises. The mine must be equipped with hoisting facilities, hauling, pumping, and ventilating equipment.

A summary of the estimated capital investments for the three typical underground methods described in this report is shown in table 4. The investment costs are shown in more detail in appendix B.

TABLE 4. - Summary of estimated capital investment for selected underground mining methods

Mining method and capacity, tons per day	Plant cost, dollars[1]	Plant cost per ton of daily capacity, dollars	Working capital, dollars	Lease option and exploration and development, dollars	Total investment, dollars
Cut and fill, 6,000	12,936,000	2,160	3,980,000	15,006,000	31,921,000
Room and pillar, 25,000...........	15,753,000	630	8,575,000	13,534,000	37,863,000
Block cave, 30,000.	25,184,000	840	6,709,000	30,990,000	62,883,000

[1]Plant cost includes mine equipment and plant, facilities and utilities; it does not include investment for property acquisition, exploration, development, or working capital.

Capital costs at existing or projected underground mines were estimated similarly to those for surface operations. Development and equipment costs were modified by adjusting shaft and development cost to reflect different depths, haulage lengths, and amount of stope preparation. Subjective modifications were made to reflect differing rock, ventilation, and drainage conditions. Size-scale factors were applied as with open-pit mines. Exponential factors used were as follows: 1,000 to 10,000 tpd, 0.6; 10,000 to 15,000 tpd, 0.7; 15,000 to 25,000 tpd, 0.8; over 25,000 tpd, 0.9.

Operating Cost

Underground mine operating costs are based essentially on requirements the same as those for a surface operation. A summary of the estimated operating costs for the three typical mines is shown in table 5. These costs are presented in detail in appendix B.

TABLE 5. - Summary of estimated operating costs for selected underground mining methods

Mining method and capacity, tons per day	Operating cost, dollars per ton of material mined[1]			
	Direct	Indirect	Fixed	Total
Cut and fill, 6,000.......	5.411	0.535	1.050	6.996
Room and pillar, 25,000...	2.697	.258	.295	3.250
Block cave, 30,000........	1.838	.204	.413	2.455

[1]Operating cost does not include royalty or Federal income tax; the operating cost does include amortized capital for future equipment requirements, deferred expenses, depreciation, local taxes, and insurance.

Underground operating cost estimates made for known deposits were also based on the costs at one of the three typical underground mines that have been modified to reflect the mining conditions expected in the deposit being evaluated. General adjustments made to costs were 1.0 percent change for each 500-foot change in hoisting depth and from minus 0.5 percent to plus 2.0 percent change in operating cost for each 1.0-foot change in stoping width from the 18-foot standard used in the cut-and-fill type study. The operating cost was decreased 2.0 percent for each additional foot over the 18-foot width and increased 0.2 percent for each foot less than 18 feet. Subjective adjustments were made to allow for other differences in mining conditions. Exponential size-scale factors used were as follows: 0.9 for underground mines of under 20,000 tpd size and 0.95 for mines of over 20,000 tpd.

Concentrating

Concentrating methods to recover both sulfide and oxide copper minerals were considered. Capital and operating costs were estimated for concentrators using the flotation process having designed capacities of 5,000, 6,000, 15,000, 23,000, 40,000 and 72,000 tpd. Flowsheets of all are similar and typical of that employed at the porphyry copper operations with the exception of the 6,000-tpd concentrator which is applicable to the native copper ores in Michigan.

Capital and operating costs were estimated for operations leaching copper from material placed on dumps and recovery of the copper from the solution using chemical precipitation and solvent extraction (fig. 4).

Flotation

Flotation is by far the most common method in use today for concentrating copper ores. It is basically a process in which the minerals of the finely ground ore are separated through the use of reagents and air bubbles. By

FIGURE 4. - Concentrator, leach dump, and leach precipitation plant at the Esperanza operation, Duval Corporation, near Tucson, Ariz.

using the proper reagents it is possible to selectively coat the surfaces of the particles of the valuable copper minerals. When air bubbles are passed up through the mixture the bubbles attach themselves to the conditioned copper minerals and carry them to the surface. The copper-rich minerals are removed from the surface by an overflow system and collected.

Process Description

The material, delivered to the concentrating facilities from the mine, is sized by crushing, grinding, and screening. This is done to facilitate the liberation of mineralized material from the barren rock. The material is transferred as a slurry to the flotation units where it is separated into two products, waste and concentrates.

Crushing is done by primary, secondary, and tertiary crushers which reduce the material to about a minus 3/4 inch. (Size of reduction varies with each plant and is dependent upon mineral and host rock characteristics.) Further size reduction, often to a minus 65 mesh, in rod and ball mills, prepares the material for the flotation section of the plant. In the flotation section, appropriate reagents (chemicals) selectively collect the copper-rich sulfide minerals and depress other minerals as waste material. The sulfide minerals are skimmed off the liquid slurry while the waste is removed at a lower horizon.

Concentrates containing the sulfide minerals are transferred to smelting facilities where the material is further upgraded from a concentrate containing 20 to 30 percent copper to a 99-percent-plus copper product.

The waste material is transferred to a tailings disposal area containing facilities to reclaim water which is reused in the concentrating facilities.

Capital Investment

Appendix C contains a cost analysis of the various size concentrators using the flotation process. In the costing procedure each process was separated into sections; for the concentrators these sections were primary crushing, secondary and tertiary crushing, grinding, flotation, molybdenum recovery, copper filtering, lime preparation, and tailings disposal (fig. 5). The costing of each section included the development of a flow diagram and a table listing the quantity, size, horsepower, capital, and installation costs for the items of equipment for that section. A complete set of tables and figures is included for the 15,000-tpd concentrator. The tables and figures not included for the other concentrators would be similar except for the capacities. Item numbers on the listing correspond to item numbers located near the individual articles of equipment on the flow diagram. Concentrator equipment is based on published flowsheets of various size plants; equipment costs were obtained from manufacturers or scaled up by use of factors. Each flow diagram is generalized and does not show parallel flow in all instances; this situation can be determined by comparing the quantity of equipment on the tables with that on the flow diagram.

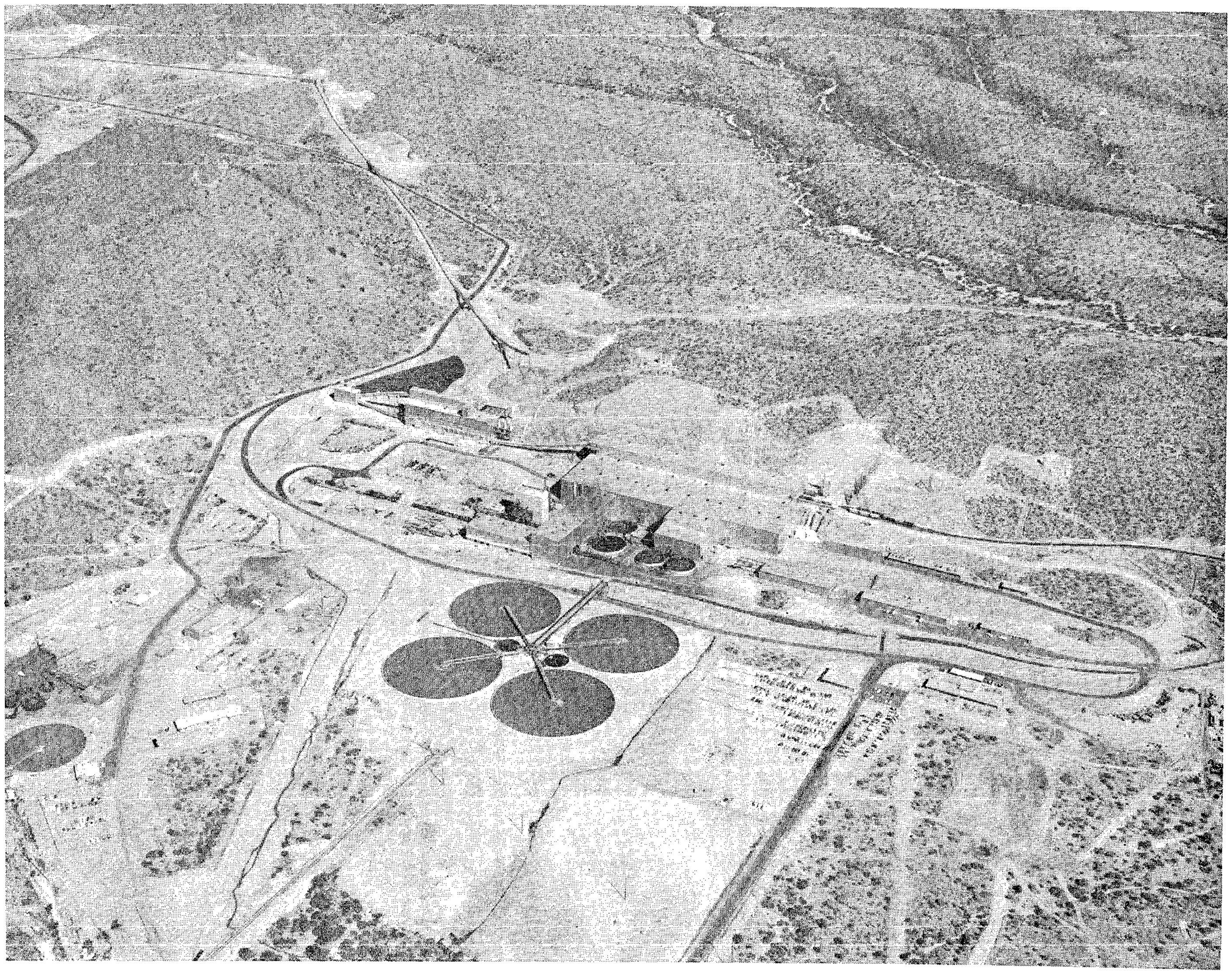

FIGURE 5. - Copper concentrator at the Sierrita Mine, Duval Sierrita Corporation, near Tucson, Ariz. Circular tanks in foreground reclaim 80 to 85 percent of the process-water for reuse in the processing of the copper ore.

Table 6 contains a summary of the estimated capital investment for the concentrators using the flotation process. Total investment, including working capital, varies from $13.4 million for the 5,000-tpd concentrator to $120.7 million for the 72,000-tpd concentrator. Disregarding the 6,000-tpd concentrator which is of unique design, there is an economy of scale proceeding from the smaller to the larger capacities. Each concentrator has essentially the same type of equipment but there are minor variations due to characteristics of the ore.

TABLE 6. - Summary of estimated capital investment for copper flotation concentrators of selected design capacity

Capacity, tons per day	Plant cost, dollars[1]	Plant cost per ton of daily capacity, dollars	Working capital, dollars	Total investment, dollars
[2]5,000	12,615,000	2,790	797,000	13,412,000
[3]6,000	18,069,000	3,190	974,000	19,043,000
15,000	27,361,000	2,000	1,695,000	29,056,000
23,000	48,405,000	2,240	2,699,000	51,104,000
40,000	75,878,000	1,990	3,864,000	79,742,000
72,000	114,236,000	1,690	6,446,000	120,682,000

[1]Plant cost includes equipment, buildings, and facilities and utilities; not included are land and water rights.
[2]Does not have a byproduct molybdenum circuit.
[3]This concentrator is designed for use in processing the native copper ores.

Operating Cost

For uniformity the average operating costs at all the concentrating facilities are based on a three-shift-per-day, 357-day-per-year operation. Some sections, such as the primary, secondary, and tertiary crushing facilities, may operate a two-shift-per-day, 6- or 7-day-per-week schedule, which was considered in computing the average operating costs.

Consumption of operating supplies, such as grinding media and reagents, was estimated on the basis of published data. Power consumption was derived from the equipment horsepower requirements. Operating and maintenance labor requirements were developed from either estimated or published manpower requirements.

Table 7 shows the estimated operating costs for the different capacity concentrators. With the exception of the 6,000-tpd plant, which is of unique design, there is an economy of scale proceeding from the smaller to the larger capacities.

Concentrating capital and operating cost estimates for known deposits were scaled from the typical concentrators shown in appendix C. Exponential size-scale factors used for capital costs were as follows: 1,000 to 5,000 tpd, 0.6; 5,000 to 10,000 tpd, 0.7; 10,000 to 20,000 tpd, 0.8; 20,000 to 40,000 tpd, 0.9; over 40,000 tpd, 0.95. Factors used for scaling operating costs were 0.9 for concentrators of under 15,000-tpd size and 0.95 for larger concentrators.

TABLE 7. - Summary of estimated operating costs for copper concentrators of selected design capacity

Capacity, tons per day	Operating cost, dollars per ton of material treated[1]			
	Direct	Indirect	Fixed	Total
5,000	1.205	0.199	0.627	2.031
6,000	1.214	.153	.741	2.108
15,000	.795	.136	.453	1.384
23,000	.806	.118	.519	1.443
40,000	.734	.094	.466	1.294
72,000	.664	.084	.391	1.139

[1]Operating costs include depreciation, insurance, and local taxes, but do not include royalty, profit, or Federal income tax.

Leach

There are many variations of the leaching process which are used in the copper industry (15). Basically the process involves preparing the material for application of an acid solution, applying the acid solution to the material, and recovering from the solution the copper which has been leached from the leachable material.

In this study a cost analysis was prepared for a leach operation consisting of two sections: (1) bedding of the material (dump formation) and application of an acid solution to the dump, and (2) recovery of copper from the acid solution. There are two methods of recovering the copper from the acid solution, precipitation by iron and electrowinning. The dump formation and application of solution is common to both methods.

Estimated investment and operating costs charged to the bedding operation are those required to prepare or position the material and apply the acid solution. The leachable material is delivered to the leach area or dump during the process of mining the mill-grade sulfide ore; this cost is not charged to the leach operation. Upon delivery of the material to the leach area dozers are used to prepare the dump surface for leaching. The acid solution, conveyed to the leach area via pumps and pipes, is applied to the surface and percolates through the dump dissolving the copper minerals and is collected in a pond at the base. Thence, the pregnant solution (copper-bearing acid solution) is transferred via pipes to a retaining pond adjacent to the copper-recovery facilities.

The designed capacity of the bedding and circulation section of the operation described in this report is 2,000 tpd of leachable material and 3,000 gpm of circulating solution. Investment costs include equipment, facilities, and utilities to transfer the leach liquor from the solution tank to the dump and to return the pregnant liquor to a storage pond.

Tables D-1 and D-2, appendix D, contain a list of the equipment and costs for this section and a summary of capital investment. Figure D-1 in appendix D is a flow diagram of the section.

Total capital investment including working capital is $1.02 million.

The estimated operating costs including direct, indirect, and fixed costs of the bedding and circulating section are itemized in table D-3, appendix D. These costs were as follows: direct, $0.125; indirect, $0.024; and fixed, $0.133, totaling $0.282 per ton of ore bedded.

Precipitation With Iron

A simple method of recovering copper from pregnant acid solution after it has been circulated through the leach dump is by precipitation with metallic iron. The iron is placed in tanks and the pregnant solution is circulated through the tanks. The iron replaces the copper in solution, metallic copper is precipitated, and is collected from the bottom of the tanks. A mobile crane equipped with a magnet or clamshell and a front-end loader are used to recharge the precipitation tanks with scrap iron and to remove the precipitated copper which is mixed with impurities. The sludge, called "cement copper," contains about 60 percent copper. It is dried and transported to a smelter.

Barren solution is returned to the leach dump after makeup water and acid are added to maintain the proper pH. The amount of acid to be added varies with the operation; some require little or no makeup acid while others require relatively large amounts depending on the characteristics of the ore.

A disadvantage of this method is an accumulation of iron salts in the barren solution. These salts tend to precipitate on the surface or in the upper part of the dump forming impervious layers that slow or prevent the passage of leaching solution through the dump and decrease the copper recovery.

Capacity of the operation for which capital and operating costs are estimated is 3,000 gpm of solution resulting in an annual copper production of 3,000 tpy. Figure D-2 of appendix D is a flow diagram of the precipitation section. Also contained in this appendix are tables listing the equipment and associated installation costs, total capital investment, and operating costs.

The estimated investment requirement including working capital is $0.73 million.

Total estimated operating cost, composed of direct, $0.035, indirect, $0.005, and fixed, $0.011, is $0.051 per pound of recoverable copper. The total cost of producing a pound of copper as cement copper based on the cost of bedding 2,000 tons of leach material per day, circulating 3,000 gpm of solution, and producing 3,000 tpy of copper by precipitation on iron is $0.085.

Solvent Extraction

The solvent extraction method uses the liquid ion-exchange process and electrolytic deposition to recover copper from the pregnant leach liquor solution. The leach liquor from the dump is not suitable for copper removal by electrolytic deposition because the copper content is too low. The ion-exchange process is used to increase the copper content from 1 to 1-1/2 grams per liter to a content of 25 to 30 grams per liter. The copper ions are extracted from the weak acid solution by an organic carrier and in turn are stripped from the organic carrier by a strong acid.

In the extraction section, the copper in the pregnant leach liquor is removed from the aqueous leach liquor and combined with a solution composed of a chemical, LIX64N (a patented General Mills Chemical, Inc., trade name),[6] and an organic carrier, kerosene. This solution, 8 percent LIX64N and 92 percent kerosene, is continuously mixed with the circulating pregnant leach liquor. Copper in the aqueous pregnant leach liquor combines with the mixture of LIX64N and kerosene. The mixture of organic and aqueous solutions flows to a quiet zone and the kerosene mixture, being lighter than water, floats and is separated. After separation the copper-enriched solution is transferred to the stripper section. The barren leach liquor is recycled to the leach dump.

In the stripper section the copper is stripped from the LIX64N and kerosene solution by a sulfuric acid solution having a controlled pH. The copper-bearing acid solution (electrolyte) is fed to the electrolytic plant while the solution of LIX64N and kerosene, stripped of copper, is recycled to the extraction section.

In the electrolytic plant, copper is deposited as a high-purity copper product comparable to the output of an electrolytic copper refinery. The spent electrolyte is recycled to the stripper section.

Flow diagrams of the solvent extraction and electrolytic process are contained in appendix D. Included are tables listing equipment and installed costs, total capital requirements, and operating costs.

Capacity of the solvent extraction plant is 3,000 gpm of circulating leach liquor; capacity of the electrolytic plant is 7,000 tpy of recovered copper.

Estimated total capital requirement including working capital is $6.4 million.

The total operating cost, composed of direct--$0.049, indirect--$0.009, and fixed--$0.038, is $0.096 per pound of recovered copper.

Table 8 contains a summary of the estimated capital requirements for each of the various phases of the copper-leach operation.

Use of the solvent extraction process eliminates the usage of scrap iron which is a source of the undesirable iron salts which accumulate in the dump as the leach liquor circulates to the leachable material.

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[6] Reference to specific brands does not imply endorsement by the Bureau of Mines.

TABLE 8. - Summary of estimated capital investment for various phases of a copper-leach operation

Phase and capacity	Plant cost, dollars	Working capital, dollars	Total investment, dollars
Bedding, 2,000 tpd ore; circulating, 3,000 gpm solution......................	[1]1,031,000	41,000	1,072,000
Precipitation (cementation), 3,000 tons of copper/yr..........................	[2]638,000	90,000	728,000
Solvent extraction and electrowinning, 3,000 gpm solution; 7,000 tons of copper/yr............................	[3]6,153,000	260,000	6,413,000

[1]Includes equipment, facilities, and utilities to prepare the dump for leaching after delivery of leach material to the dump, and to transfer the leach solution from the precipitation plant to the dump and return the pregnant solution to a storage pond near the leach facilities.

[2]Includes construction of the precipitation plant and the purchase of equipment required to charge the scrap iron, remove the cement copper, and prepare it for shipment.

[3]Includes construction of the solvent extraction and electrowinning plants and the purchase of equipment, facilities, and utilities required to produce refined copper ready for marketing.

In comparing the cost of recovering copper from leach solutions using the precipitation method and the solvent extraction and electrowinning method, the quality of the end product should be considered. The product of the precipitation method must be processed by smelting and refining before fabricating, whereas the product from the solvent extraction and electrowinning process requires no further processing prior to fabrication.

Smelting

The copper concentrates and precipitates from the concentrators and the mine leach facilities are shipped to copper smelters for further processing. Smelters currently in use are designed to receive concentrates varying in copper content from 15 to 40 percent and to convert them into blister copper containing approximately 99 percent copper. The concentrates are normally supplemented by varying amounts of copper precipitates whose copper content ranges from 50 to 80 percent.

Process Description

Current copper smelting technology uses large amounts of heat to separate the copper from the sulfur, iron, and minor amounts of other elements in the concentrates and precipitates. To accomplish this separation, the concentrates and precipitates are taken through several processing steps within the smelter. Certain other materials are added at different points in the processing to facilitate the separation of the copper. Appendix E contains smelter data including flow diagrams, equipment cost lists, composition and flow rate of material streams, estimated capital requirements, operating costs, and supply consumption.

The first step in the smelting process for the concentrates is treatment in a reverberatory furnace. The reverberatory furnace used in the copper industry is typically 25 to 35 feet wide and in excess of 100 feet long. It is charged with copper concentrates and precipitates, silica rock, lime rock, and dust and slag recycled from other parts of the smelter. The entire charge is heated to in excess of 1,900° F at which point the smelting reactions occur. Natural gas is the fuel normally used to heat the charge, although powdered coal and oil can be used.

While in the reverberatory furnace, a portion of the sulfur in the charge will combine with oxygen and be given off as sulfur dioxide. The major part of the iron will combine with the silica rock to form slag. This slag is removed from the furnace and discarded. The copper combines with sulfur, iron, and minor amounts of other materials to form copper matte.

Molten copper matte is transferred from the reverberatory furnace to a converter by means of large ladles supported by overhead cranes. There are different types and sizes of converters. A configuration often used in the domestic copper industry is a cylinder 13 feet in diameter and 30 feet long mounted with the axis horizontally so that the drum can rotate approximately one-quarter turn about this axis. Two to three converters are required to handle the output of the average reverberatory furnace.

The converting process begins with a partial charge of copper matte. In this process oxygen-enriched air is blown through the converter charge. The oxygen combines with the sulfur in the matte in an exothermic reaction which provides the heat required to maintain the converter bath at a temperature of 2,100° to 2,200° F. As the converting cycle progresses, copper concentrates and precipitates, silica rock, copper scrap, and additional amounts of matte are added to the charge. The direct charging of concentrates into the converter is a relatively new innovation but is gaining acceptance in the industry.

Slag is removed from a converter several times during the converting cycle. This slag is transferred to the reverberatory furnace for recovery of the 3- to 4-percent copper it contains. The exhaust gases and dust from a converter are collected, cooled, and mixed with those from the reverberatory furnace. The combined flow is filtered for removal of the particulate matter and chemically treated for removal of a portion of the sulfur dioxide. Copper is removed from the converter at the end of the converting cycle. It is 99 percent pure at this point and is referred to as blister copper. The 1-percent impurity includes gold, silver, and minor amounts of other metals.

The impurities in the blister copper have a very detrimental effect on its electrical properties and render it much more susceptible to corrosion. The major portion of these impurities will be removed at an electrolytic refinery after the blister copper leaves the smelter. However, experience has shown that the electrolytic refining process is improved if the copper is first fire refined.

Fire refining is accomplished in one of two different types of furnace. One type is similar to a reverberatory furnace and the other to a converter. The objective of fire refining is to oxidize and remove certain metals such as iron and nickel which are contained in the blister copper. This is done by heating the charge to approximately 2,000° F and then bubbling oxygen-enriched air through it, after which the iron and nickel are slagged off; at this point the metal will contain varying amounts of copper oxide. The copper oxide is reduced to copper by bubbling natural gas through the melt. Prior to the use of natural gas, the reduction of the copper oxide was accomplished by thrusting green logs into the molten copper.

Upon completion of the fire refining, the blister copper is cast into 700-pound anodes and readied for shipment to an electrolytic refinery. An anode is simply a sheet of copper which is approximately 36 inches square and 1-3/4 inches thick.

Pollution Controls

A subject of increasing concern is the provision of adequate air pollution controls for copper smelters. Uncontrolled, a copper smelter will release large amounts of sulfur dioxide to the atmosphere. At the present time there is not a completely acceptable method for removing sulfur dioxide from the stack gases. Two processes for the removal of sulfur are currently in use in this country, the contact sulfuric acid process and the dimethylaniline absorption process. The latter process is only being used on a limited basis for testing and has not yet been implemented for an entire smelter.

The Environmental Protection Agency has established guidelines based on ambient air quality which could require the removal of 90 percent of the sulfur in the feed at many of the nonferrous-metal smelters. Several States using these guidelines have enacted laws requiring the removal of 90 percent of the sulfur contained in the feed to the smelter. The position of the copper industry is that the 90-percent figure is unrealistically high in that the technology needed to economically achieve this level does not yet exist. Action taken by industry includes the cutback of production at certain smelters to 80 or 85 percent of normal during periods of adverse meteorological conditions; the installation of additional contact sulfuric acid plants with the intent of being able to recover more of the sulfur oxides; and added emphasis on research aimed at reducing the amount of air pollution attributable to copper smelting. The increased costs resulting from these efforts are not yet known but estimates vary from 4 to 6 cents per pound of recovered copper (17).

Capital Investment

The cost of constructing a copper smelter using current smelting technology is concentrated in the procurement and erection of the reverberatory furnace and the converters. The cost of the materials-handling equipment required to move raw materials to these components and to remove the completed product and wastes is a relatively minor part of the total capital cost.

As indicated in the previous section on pollution controls, the cost of sulfuric acid plants and other pollution control devices will most likely become a significant part of the smelting costs. The smelting costs used in this report were developed by the Process Evaluation Group of the Bureau of Mines. These costs are based upon current domestic smelting practices except that they have been increased to allow for the installation of available pollution control equipment. The Bureau of Mines estimates, as detailed in appendix E, indicate that the cost of pollution control equipment is approximately 20 percent of the capital costs.

The capital investment required for the smelter described in this report is $42.1 million. This includes $2.4 million for working capital.

Operating Cost

The smelter operating costs were also developed by the Bureau of Mines. The labor and material costs closely approximate those that would be incurred by an operating smelter. Some of the costs, such as utility rates, will vary according to the location of the smelter but, in general, the costs are those prevailing nationally in 1970.

The total annual operating cost shown in table E-5 of appendix E has been adjusted to allow for a credit of $3 per ton of sulfuric acid recovered from the stack gases. This figure is considerably below the market price for sulfuric acid in many parts of the United States, but may well be above the regional market price in the Southwest once all the smelters there have their sulfur recovery plants in operation.

Based on a 12-percent discounted cash flow and allowing for Federal income tax at 50 percent of gross profit, the unit smelting cost for the smelter data used in this report is calculated to be $0.064 per pound of blister copper.

Refining

The blister or anode copper produced by a smelter is not of sufficient purity for most of the uses of copper. An electrolytic refinery provides an efficient and economical method for removing the major part of the remaining 0.5 to 1.0 percent impurities.

The basic principal of electrolytic refining is that the application of an electric potential across two metallic electrodes immersed in an ionized solution will result in the transfer of positive metal ions from the positive electrode to the negative electrode. Specifically, in the electrolytic refining of copper, the ionized solution is an aqueous solution of sulfuric acid and copper sulfate, the positive electrode (anode) is the anode copper received from the smelter, and the negative electrode (cathode) is a thin sheet of pure copper. Upon completion of the process, the copper in the anode has been transferred to the cathode and the impurities in the anode copper have been deposited on the bottom of the tank containing the solution.

Process Description

An electrolytic refinery is designed to perform the previously described electrochemical process on a mass-production basis. The primary section of a refinery is the tankhouse. The tankhouse is augmented by various materials-handling facilities and a melting and casting section where the completed cathodes are melted and cast in more marketable shapes. The refinery described below is one designed to produce 300,000 short tons of copper per year.

The electrolytic transfer of the copper from the anodes to the cathodes is accomplished in rectangular shaped tanks which are referred to as cells. The annual capacity of the refinery is essentially a function of the total number of cells.

There are three different types of cells. Primary production of cathode copper is accomplished in the commercial cells. Most large refineries will have 1,000 to 1,500 commercial cells. A second type of cell is the starter cell. Starter cells are used to prepare the thin copper sheets which are used as cathodes in the commercial cells. A final type of cell is the liberator cell. The liberator cells serve to remove the buildup of copper and nickel ions in the electrolyte (ionized solution).

The tankhouse must be designed and operated so that the composition and temperature of the electrolyte are maintained within very close tolerances. To accomplish this, the cells are arranged so that there are different circuits of flow. The electrolyte in these circuits is reheated at specific points in its flow and a portion of the electrolyte removed and replaced by fresh electrolyte. The electrolyte that is removed is transferred to the liberator cells for treatment.

The anodes and cathodes are arranged in the cells so that the broad sides of the sheets are adjacent and parallel. The anodes and cathodes alternate with one another with approximately 1-1/2- to 2-inch spacing between a given cathode and the two adjacent anodes. There will normally be 40 to 50 cathodes and a similar number of anodes in each cell. The exact number will be fixed by the design of a particular refinery. Power is supplied to the cathodes and anodes by a system of bus bars.

Approximately 2 weeks is required for a cathode to develop from the initial thin sheet of copper to a completed sheet of copper weighing 300 pounds. The rate of deposition of copper on the cathode must be carefully controlled if the completed cathode is to be of acceptable quality. If the rate is too rapid, impurities will be carried over from the anode to the cathode.

If the process is properly controlled then, all but a minor fraction of the impurities will collect on the bottoms of the cells. This material is referred to as anode mud and will normally contain significant quantities of gold and silver. The anode mud is periodically removed, washed, filtered, dried, and packaged in sealed drums. It is then shipped to a precious metals refinery for recovery of the precious metals.

The copper cathodes produced in the electrolytic cells are sufficiently pure for most end uses. However, the shape of the completed cathode is not suitable for sale to most copper fabricators. The more common shapes for marketable electrolytic copper are wirebar and copper billets of assorted sizes and shapes.

The function of the melting and casting section is to convert the cathodes to the sizes and shapes desired by the customers of a particular refinery. The cathodes received from the tankhouse are washed to remove the electrolyte from their surfaces and are then placed in a gas-fired or electric-arc furnace for melting.

In the electrolytic refinery detailed in appendix F of this report the molten copper is placed in an induction furnace until it is required for casting. It is transferred from the induction furnace to the casting machines by ladles supported by overhead cranes. The two types of casting machines included in this report are a casting wheel for wirebars and a continuous casting machine for billets. The cast product is cooled, inspected, and readied for shipment.

Capital Investment

The cost of the tankhouse comprises the major part of the capital costs of an electrolytic refinery. In the past it has been necessary to use lead sheathing on the insides of the cells and the electrolyte transfer system to protect them from the corrosive action of the sulfuric acid. The initial material cost of the lead and the associated installation costs are quite high. The advent of modern plastics, such as polyvinyl chloride, will cause the use of lead and similar materials to be phased out.

The total estimated capital cost of the refinery included in this report is $57,024,300. Major expense items in this total are the tankhouse with 59 percent of the total, the melting and casting section at 18 percent, and associated facilities and utilities at 14 percent. The balance of the capital cost is the working capital and the initial cost of the catalysts.

Operating Cost

Refinery operating costs are concentrated in wages, electric power, and natural gas. The total annual operating cost, including depreciation, of a 300,000-tpy refinery is estimated to be $19,684,000. This cost is partially offset by the sale of copper oxide, nickel sulfate crystals, and spent 60° Bé sulfuric acid. The copper oxide is recovered from the gases given off by the melting furnaces and the nickel sulfate crystals and sulfuric acid are recovered from used electrolyte. The unit operating cost is estimated to be $0.040 per pound of refined copper. If the value of the recovered precious metals were credited against operating cost, then the operating cost would be significantly less. The precious metals value has been kept separate because it varies greatly between different ore deposits. Many electrolytic refineries process blister copper on a toll basis with the owner of the blister copper retaining ownership of the precious metals after they have been separated.

Transportation

In this study transportation cost has been defined as the sum of those costs incurred when the mining company releases the copper ore, concentrate, precipitate, or blister to a shipper. In most instances, this point of release is the concentrator where the concentrates are loaded for shipment to a smelter. There are a few mines where the copper ore is shipped from the mine to the concentrator. In other instances the smelter is located adjacent to the mine and concentrator and the copper is released to the shipper as blister copper.

The domestic copper industry relies almost entirely on rail haulage for the transportation of copper outside the mine. Exceptions to this include the mines where it is necessary to haul the copper concentrates by truck to the closest railhead. Truck haulage is also used in a few instances to transport concentrates limited distances from a concentrator to a nearby smelter. The use of water transportation is virtually nonexistent.

Transportation Patterns

There are several factors which influence transportation patterns in the copper industry. As is generally true in the minerals industry, the transportation routes are anchored at remotely located mines and concentrators. The objective then is to transport the copper to market but at the same time to provide for further processing of the concentrates.

An important factor in the cost of transporting copper is its purity at the various processing stages. Recoverable copper metal makes up less than one part in a hundred of average-grade copper ore. For this reason it is prohibitively expensive to transport the copper long distances in its ore form. However, once the copper has passed through the concentration stage the ratio of copper to waste material has been reduced to one in four. The significance of this is seen in the fact that concentrators are, almost without exception, located near mines.

Once the penalty of transporting uneconomic material has been reduced to reasonable proportions, the economics of constructing processing units in efficient sizes becomes apparent. Many mining companies ship their concentrates several hundred miles to a smelter and some ship them in excess of 1,000 miles. However, the economics of constructing a smelter closer to the concentrators than to the markets for copper is seen in the fact that eight of the 16 domestic copper smelters are located in Arizona. Of the remaining nine smelters seven are located close to large producing copper deposits and the other two on the coast to receive foreign concentrates.

Both blister copper, the form of the copper as it leaves the smelter, and the refined copper produced by an electrolytic or fire refinery contain in excess of 99 percent copper metal. Hence, transportation cost has little effect on the location of copper refineries as long as they are located somewhere along the route from the smelter to the major copper markets. Figure 6 shows the tremendous flow of blister copper from the copper producing regions

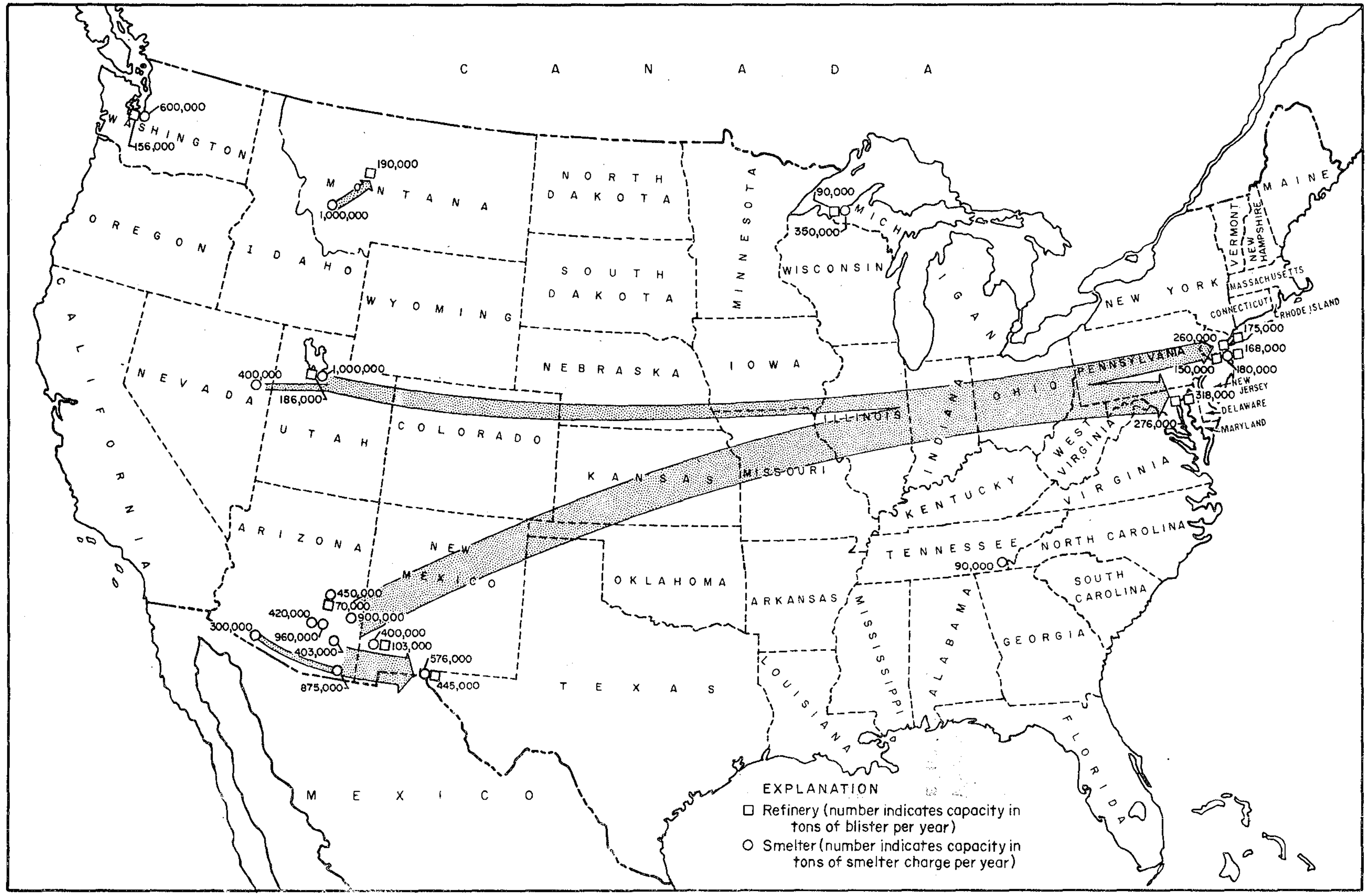

FIGURE 6. - Flow of domestically mined blister copper within the United States.

of the Western United States to the markets on the east coast. Of the domestic copper smelting capacity, 96 percent is located west of the Mississippi River. For copper refining, only 44 percent of the domestic capacity is located in the West. It should be noted, however, that part of the copper refining capacity on the east coast exists to refine blister copper imported into the United States.

Freight Rates

The cost of rail transportation is highly variable. Rail tariffs are based upon the commodity being transported, the value of the commodity, the size of the shipment, and the length of the haul. The different railroads are not entirely consistent in how they treat these factors when formulating their tariffs. Whether or not a given rail route involves intrastate or interstate travel is also important, since these two forms of travel come under different regulatory agencies.

The freight rates used in the computation of transportation costs in this study are shown in table 9. The cities shown in the left-hand margin of the table are the origins of the shipments of concentrates and blister copper and the cities shown across the top of the table are the destinations. There are two entries in the table for each rail route. The uppermost is the cost of transporting a short ton of material over a route and the lowermost entry is the cost in dollars per ton-mile. These freight rates are based on the appropriate minimum carload weights and commodity classifications. The carload minimums average around 100,000 pounds, but are as low as 40,000 and as high as 180,000 pounds. The basic commodity classifications are copper ores and concentrates and secondly, blister copper.

Figure 7 is a graph of the transportation costs shown in table 9 plotted against the respective lengths of the hauls. The grouping of the points indicates the importance of the length of the haul as a factor determining the freight rate. There may be some significance in the fact that all but one of the nine points grouped in the lower-left corner of the graph represent intrastate routes.

It should be noted that the costs shown in table 9 and plotted in figure 7 may not in all cases be the actual freight rates paid by the mining industry. These rates were obtained from published rail tariffs using parameters that are believed to be the same as those used by the different mining companies. For example, the value placed on the concentrates or the blister when they are submitted for shipment will greatly affect the freight rate.

TABLE 9. - Cost per ton[1] and per ton-mile[2] to transport copper concentrates and blister copper over selected rail routes

Origin	Destination													
	Concentrates								Blister					
	Anaconda, Mont.	Clifton, Ariz.	Douglas, Ariz.	El Paso, Tex.	Hayden, Ariz.	McGill, Nev.	Miami, Ariz.	Tacoma, Wash.	Baltimore, Md.	El Paso, Tex.	Great Falls, Mont.	Hurley, N. Mex.	Perth Amboy, N.J.	Tacoma, Wash.
Ajo, Ariz.	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	18.62 .038	NAp	NAp	NAp	NAp
Anaconda, Mont.	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	6.76 .034	NAp	NAp	NAp
Battle Mountain, Nev.	NAp	NAp	NAp	NAp	NAp	NAp	NAp	11.60 .012	NAp	NAp	NAp	NAp	NAp	NAp
Bisbee, Ariz.	NAp	NAp	0.67 .023	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Butte, Mont.	0.44 .017	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	22.60 .033
Casa Grande, Ariz.	NAp	NAp	NAp	NAp	3.34 .028	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Clifton, Ariz.	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	11.80 .054	NAp	NAp	35.00 .014	NAp
Douglas, Ariz.	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	11.80 .034	NAp	NAp	35.00 .013	NAp
Ducktown, Tenn.	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	27.18 .033	NAp
El Paso, Tex.	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	33.80 .016	NAp	NAp	NAp	35.00 .015	NAp
Hayden, Ariz.	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	33.80 .013	NAp	NAp	16.08 .041	NAp	NAp
Kingman, Ariz.	NAp	NAp	NAp	NAp	14.20 .032	NAp	NAp	16.60 .010	NAp	NAp	NAp	NAp	NAp	NAp
McGill, Nev.	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	33.80 .013	NAp	NAp	NAp	NAp	NAp
Miami, Ariz.	NAp	5.07 .015	4.72 .022	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	35.00 .013	NAp
Pima, Ariz.	NAp	NAp	4.72 .024	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Prescott, Ariz.	NAp	NAp	16.93 .041	21.00 .034	NAp	NAp	12.06 .048	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Ray Junction, Ariz.	NAp	NAp	NAp	NAp	1.10 .073	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Ruth, Nev.	NAp	NAp	NAp	NAp	NAp	2.72 .124	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Sahuarita, Ariz.	NAp	NAp	NAp	14.79 .043	3.44 .021	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Salt Lake City, Utah	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	33.80 .015	NAp	NAp	NAp	NAp	NAp
San Manuel, Ariz.	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	18.62 .040	NAp	NAp	35.00 .013	NAp
Silver City, N. Mex.	NAp	NAp	17.01 .056	4.12 .031	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Tacoma, Wash.	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Wabuska, Nev.	14.43 .015	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp

NAp Not applicable.
[1]The larger number for each origin and destination is cost per ton of material shipped.
[2]The smaller number for each origin and destination is cost per ton-mile of material shipped.

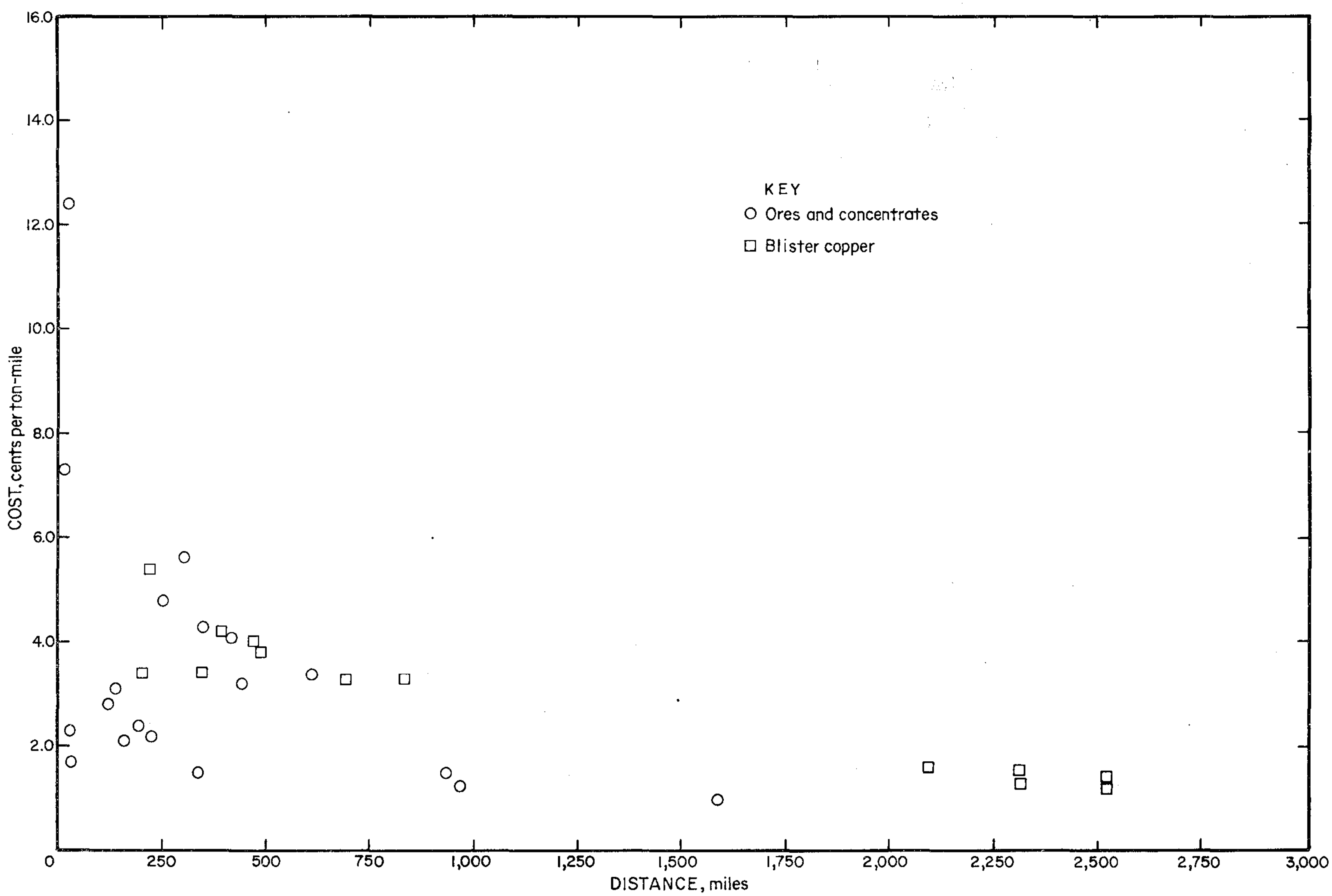

FIGURE 7. - Cost of rail transportation for copper ores, concentrates, and blister for selected rail routes.

Safety Programs

Each segment of the copper producing industry has a safety program designed to its particular needs.

A typical safety staff of a large underground metallic mine includes a supervisory safety engineer, an assistant, three safety inspectors, and an office secretary. Reportedly, the cost of safety personnel plus safety equipment could be as much as $0.14 per ton of ore.

The safety personnel at open-pit mines and concentrators usually consist of a safety engineer to organize safety work and maintain safety records.

A typical smelter operation (400,000 tpy) would employ a safety supervising engineer and three safety inspectors, while a refinery may only require a safety engineer.

In most instances the safety staff occupies an advisory and training capacity with the responsibility of enforcing the safety regulations delegated to the supervisor at the job site.

Safety programs financed by the companies include preparation of safety manuals; conducting safety indoctrination classes; providing safety, first aid, and mine rescue training, as well as special equipment and clothing; and furnishing incentive awards for competitive safety programs. The safety department is usually responsible for the fire prevention equipment and training.

These safety programs sponsored by the companies are supplemented by State and Federal Government programs consisting of regulation enforcement and training.

ESTIMATION OF COPPER RESOURCES

Summary

The total known domestic resource of copper economically available at a price of $2 per pound, assuming 12-percent return on the capital investment required for the facilities to mine, concentrate, smelt, and refine the material, is about 180 million short tons. Eighty-three million tons could be recovered economically assuming a copper price of $0.50 per pound. The quantity of recoverable copper at $0.50 per pound would increase to 92 million tons for a 6-percent rate of return and 106 million tons for a 0-percent rate of return.

Total recoverable molybdenum associated with the copper resource at $2 per pound is 2.3 million tons; recoverable gold, 59 million troy ounces; and recoverable silver, 1,180 million troy ounces. Assuming a copper price of $0.50 per pound and a 12-percent rate of return the quantities of byproducts economically recoverable are as follows: molybdenum, 1.8 million tons; gold, 43 million troy ounces; and silver, 740 million troy ounces.

The importance of the revenues obtained from the byproducts is indicated by the decrease in the economically recoverable copper resource from 83 million tons to 65 million tons at a copper price of $0.50 per pound and a 12-percent rate of return, if no credit is allowed for byproduct revenues.

If no restrictions are placed on the scheduling of production from deposits and if no time is allowed for development, then the maximum annual production potential at a copper price of $2 per pound is 6.9 million tons of copper. Under the same conditions with a 12-percent rate of return and a price of $0.50 per pound of copper, the production potential decreases to 2.5 million tons of copper per year.

Estimation Methods

Information on the average grades, ore tonnages, and different physical characteristics affecting production from domestic copper deposits was obtained from numerous sources. The more important sources were U.S. Geological Survey and Bureau of Mines publications, professional journals, industry publications, company annual reports, company prospectuses filed with the Security Exchange Commission, data made available to the Bureau of Mines by private companies, and in certain instances the personal knowledge and judgments of Bureau of Mines engineers.

For deposits currently in production, the present mining and milling production rates and capacities and other available production specifics were adopted for use in this study. For deposits not in production, appropriate mining and concentrating methods, production rates, and other production parameters were assumed. The production methods and rates chosen conformed as closely as possible with one of the mine and concentrating configurations assumed as standard in this report to result in an economic life of reasonable duration.

The resource data as related to the unit price developed in this study can be used to indicate reserves and potential resources; reserves being material which can be mined, processed, and marketed at a profit under the economic and technologic conditions prevailing at the time of the evaluation.

A further distinction has been made in this study by presenting the resource data as measured, indicated, and inferred. Measured ore requires that the tonnage be computed from dimensions determined from openings and drill holes, and the grade computed from results of detailed sampling. Indicated ore tonnages and grades are computed partly from specific measurements and partly from geologic inference. Inferred ore tonnages and grade estimates are based largely on geologic knowledge of the deposit.

As exploration and development reveals better knowledge of tonnage and grade, portions of material may be reclassified to higher categories. Historically, domestic resources that can be produced economically have increased annually owing to exploration and technologic improvements which enable the mining of lower grade material or the processing of material previously wasted.

The grade of ore that can be mined and processed economically differs from mine to mine depending upon factors that influence cost. Location, water supply, transportation, and physical and metallurgical characteristics are some of these factors. Similarly, the grade of the ore processed is dependent upon the unit price of copper; a price increase proportionately greater than a rise in costs will increase the supply of copper from sources that were previously uneconomical to exploit.

Tables 10 through 15 contain data relating to the geographic distribution of copper resources of ore, and the recoverable copper and associated byproducts of molybdenum, gold, and silver by measured, indicated, and inferred categories at a copper price of $0.50, $0.75, and $2 per pound. The major portion, approximately 79 percent, of the estimated measured resource of copper ore is in Arizona, Colorado, New Mexico, and Utah. The portion attributed to Colorado is insignificant as compared to that of the other three States. In terms of recoverable metal content these four States contribute 80 percent of measured resources; in 1970 these States accounted for 80.2 percent of the annual domestic primary production.

TABLE 10. - Geographical distribution of domestic copper resources available at a copper price of $0.50 per pound (million short tons)[1]

Area	Measured			Indicated and inferred		
	Ore	Average grade, percent	Recoverable metal	Ore	Average grade, percent	Recoverable metal
Alaska	-	-	-	-	-	-
Arizona, New Mexico, Colorado, and Utah	7,600	0.74	52	5,200	0.63	23
California and Nevada	230	.89	1.3	75	.62	.51
Montana, Washington, and Idaho	420	.84	2.2	[2]620	.28	1.0
Michigan and other States	300	1.2	2.8	-	-	-
United States	8,550	.76	58.3	5,895	.60	24.51

[1] Due to rounding, these totals may differ slightly from the actual data derived in this report.
[2] Predominantly leach material.

TABLE 11. - Geographical distribution of the domestic resources of molybdenum, gold, and silver recoverable as byproducts from the production of copper metal available at a copper price of $0.50 per pound[1]

Area	Measured			Indicated and inferred		
	Molybdenum, million pounds	Gold, million ounces	Silver, million ounces	Molybdenum, million pounds	Gold, million ounces	Silver, million ounces
Alaska	-	-	-	-	-	-
Arizona, New Mexico, Colorado, and Utah	1,600	21	320	1,900	21	300
California and Nevada	2.3	.49	2.2	2.5	.47	1.2
Montana, Washington, and Idaho	-	.40	65	-	.01	15
Michigan and other States	-	-	38	-	-	-
United States	1,602.3	21.89	425.2	1,902.5	21.48	316.2

[1] Based on the following prices: Copper, $0.50 per pound; molybdenum, $1.70 per pound; gold, $41 per ounce; and silver, $1.60 per ounce. Due to rounding, these totals may differ slightly from the actual data derived in this report.

TABLE 12. - Geographical distribution of domestic copper resources available at a copper price of $0.75 per pound (million short tons)[1]

Area	Measured			Indicated and inferred		
	Ore	Average grade, percent	Recoverable metal	Ore	Average grade, percent	Recoverable metal
Alaska	-	-	-	500	1.0	4.4
Arizona, New Mexico, Colorado, and Utah	8,300	0.73	56	8,400	.58	35
California and Nevada	460	.75	2.5	190	.48	.9
Montana, Washington, and Idaho	950	.93	4.6	1,320	.51	4.5
Michigan and other States	430	1.0	3.5	370	1.2	3.8
United States	10,140	.76	66.6	10,780	.59	48.6

[1]Due to rounding, these totals may differ slightly from the actual data derived in this report.

TABLE 13. - Geographical distribution of the domestic resources of molybdenum, gold, and silver recoverable as byproducts from the production of copper metal available at a copper price of $0.75 per pound[1]

Area	Measured			Indicated and inferred		
	Molybdenum, million pounds	Gold, million ounces	Silver, million ounces	Molybdenum, million pounds	Gold, million ounces	Silver, million ounces
Alaska	-	-	-	-	-	-
Arizona, New Mexico, Colorado, and Utah	1,600	21.3	330	2,100	30	390
California and Nevada	2.3	1.0	35	2.5	.47	1.2
Montana, Washington, and Idaho	190	.41	190	-	.41	24
Michigan and other States	-	-	43	-	-	-
United States	1,792.3	22.71	598	2,102.5	30.88	415.2

[1]Based on the following prices: Copper, $0.75 per pound; molybdenum, $1.70 per pound; gold, $41 per ounce; and silver, $1.60 per ounce. Due to rounding, these totals may differ slightly from the actual data derived in this report.

TABLE 14. - Geographical distribution of domestic copper resources available at a copper price of $2 per pound (million short tons)[1]

Area	Measured			Indicated and inferred		
	Ore	Average grade, percent	Recoverable metal	Ore	Average grade, percent	Recoverable metal
Alaska	-	-	-	730	0.44	5.2
Arizona, New Mexico, Colorado, and Utah	8,600	0.71	57	16,000	.42	50
California and Nevada	470	.77	2.6	1,100	.39	3.3
Montana, Washington, and Idaho	1,100	.84	4.9	2,600	.26	14
Michigan and other States	710	1.1	6.8	8,000	.58	36
United States	10,880	.75	71.3	28,430	.42	108.5

[1]Due to rounding, these totals may differ slightly from the actual data derived in this report.

TABLE 15. - Geographical distribution of the domestic resources of molybdenum, gold, and silver recoverable as byproducts from the production of copper metal available at a copper price of $2 per pound[1]

Area	Measured			Indicated and inferred		
	Molybdenum, million pounds	Gold, million ounces	Silver, million ounces	Molybdenum, million pounds	Gold, million ounces	Silver, million ounces
Alaska..............	-	-	-	-	-	-
Arizona, New Mexico, Colorado, and Utah..	1,600	21.3	330	2,400	33	490
California and Nevada	2.3	1.5	41	20	3.0	30
Montana, Washington, and Idaho..........	190	.41	190	220	1.3	47
Michigan and other States.............	-	-	-	-	-	-
United States........	1,792.3	23.21	561	2,640	37.3	567

[1]Based on the following prices: Copper, $2 per pound; molybdenum, $1.70 per pound; gold, $41 per ounce; and silver, $1.60 per ounce. Due to rounding, these totals may differ slightly from the actual data derived in this report.

Generally, the recovery factor used to estimate the recoverable metal content of deposits now being mined was obtained from 1969 production data for individual deposits. For deposits having no production history, the concentrator recovery was estimated at 87 percent, and smelter recovery at 97 percent. For those resources consisting of leachable waste material it is difficult to establish an overall recovery factor. Experience indicates that recovery is less than 50 percent.

Financial Evaluation of Copper Production

A financial evaluation was performed for each domestic copper deposit to determine the unit copper price that would justify production from the deposit. It was stipulated that the revenue derived from production must cover all capital and operating costs and provide a 12-percent rate of return on the investment.

In the computer program used for the evaluation, the rate of return was set and a trial-and-error method used to determine the corresponding price. If the initial price for copper selected to compute the revenues from copper would not yield the stipulated revenue, the price was increased or decreased until the price selected provided a discounted annual cash inflow equal to the discounted values of the initial capital expenditures or cash outflows. Cash flows were computed deducting all operating costs from gross revenues which are the combined revenues of byproducts recovered from the ores.

Capital expenditures were those required for exploration, development, equipping the mine, and for construction and equipping the concentrating plant, smelter, and refinery. Capital was added periodically, dependent upon the depreciation schedule, to replace worn equipment.

Operating costs included mine, concentrator, smelter, and refinery direct and indirect operating costs, in addition to taxes, insurance, transportation, and royalty. Depreciation and depletion were deducted for computing taxable income and then combined with net income to obtain the annual cash flow. Smelting and refining costs include a 12-percent return on the capital investment required to construct the smelting and refining facilities.

Transportation is the cost to transport the concentrates to the smelter and the blister copper to the refinery. Royalty, a fee in lieu of an acquisition cost, is computed at 5 percent of the net smelter return. Net smelter return is defined as gross revenue minus the sum of transportation cost to the smelter, smelting cost, and refining cost. Depletion was calculated using the percentage depletion method. Depletion rates used for the various commodities were as follows: Copper, gold, and silver, 15 percent; and molybdenum, 22 percent.

Life of the individual existing operations was obtained using current production rates and estimated reserves; expected life at a deposit having no production facilities was estimated using an assigned production rate and estimated resources.

Figure 8 is a simplified flow diagram of the procedure used for the evaluation.

Economic Analysis of Resource Estimates

The results of the financial evaluations of the individual deposits were combined to give aggregate results for all of the domestic copper resources. The evaluations were done using several different rates of return, the use of 100- and 50-percent equity capital, and with and without credit for byproduct revenues.

The results of the combinations of the above alternatives were stored on magnetic tape. This magnetic tape was then used as the data input for a computer plot routine designed by the Automatic Data Processing Division of the Bureau of Mines. The plot routine generated graphical presentations of the relationships shown in figures 9 through 18.

Although the financial evaluations were performed on the basis of both 100- and 50-percent equity, only the results of the 100-percent equity evaluation are included in the study. In the 50-percent equity evaluations, the interest charge was 6 percent for an 8-year period. Generally, the 50-percent equity resulted in a price decrease of $0.01 to $0.03 per pound of recoverable copper; this difference would not be discernible on the illustrations.

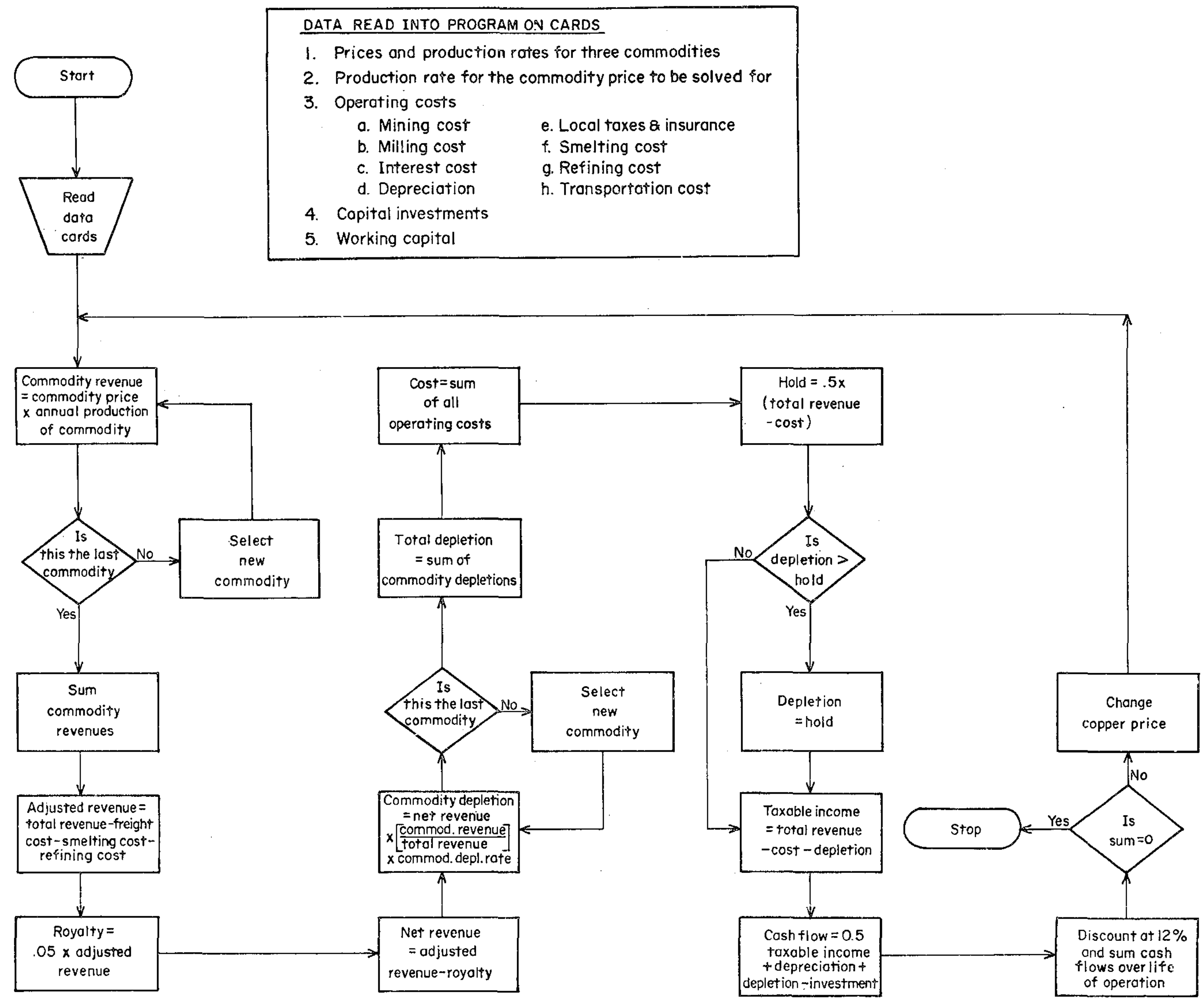

FIGURE 8. - Flow chart of the financial evaluation procedure as programed for computer usage.

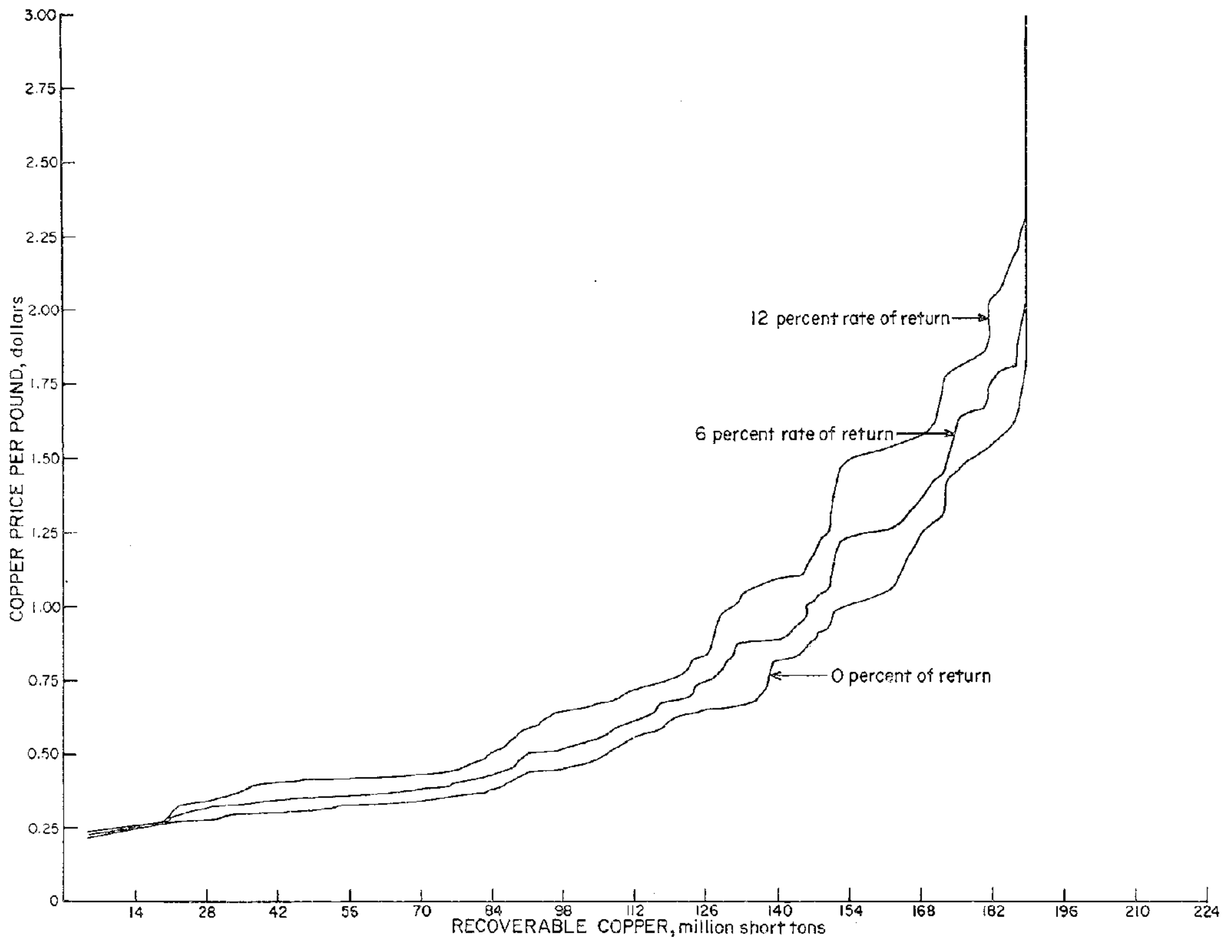

FIGURE 9. - Total domestic recoverable copper resources, price calculated using various rates of return.

Figure 9 indicates the amount of copper that is economically producible at 0-, 6-, and 12-percent discounted-cash-flow rates of return on the investment required to develop and produce a marketable product. Generally, a 12-percent return or larger is required to provide the incentive to develop a mineral deposit because of the risk involved.

At 12-percent rate of return an estimated 83 million tons of copper could be economically recovered at a copper price of $0.50. If a 0- or 6-percent rate of return were accepted the tonnage of recoverable copper would increase to 106 and 92 million tons, respectively. These estimates are based on the inclusion of byproduct revenues.

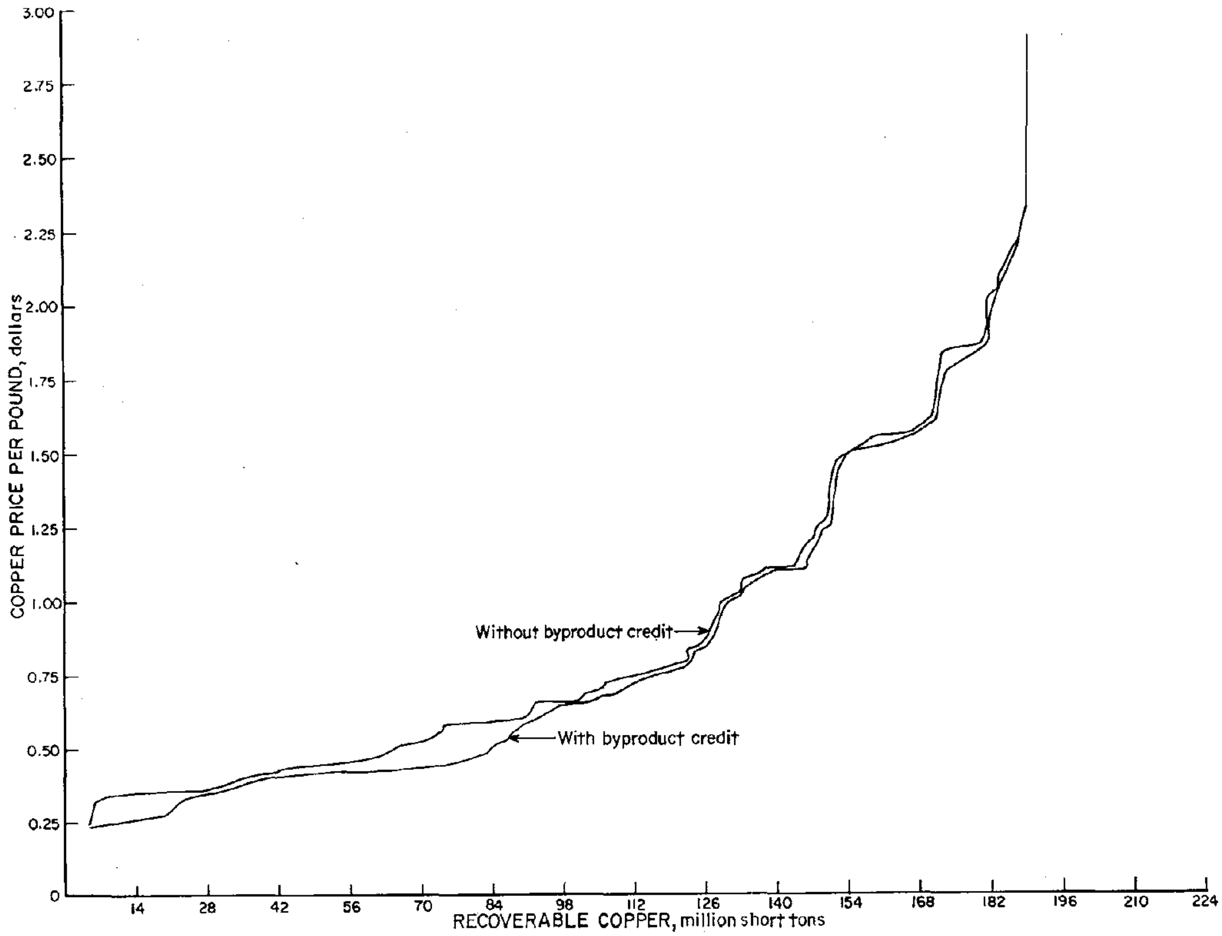

FIGURE 10. - Total domestic recoverable copper resources, price calculated with and without byproduct credit at 12-percent rate of return.

Data presented in figure 10 provide an indication of the relative importance of revenues obtained from the production of molybdenum, gold, and silver associated with the copper. The effect of the byproduct revenues is reflected in the change in the copper price required to provide a 12-percent return. The total recoverable copper that could be produced economically at a $0.50 copper price decreases from 83 million tons with credit for byproduct revenues to 65 million tons without credit for byproduct revenues. In the evaluation the prices of the molybdenum, gold, and silver were $1.70 per pound, $41 per ounce, and $1.60 per ounce, respectively.

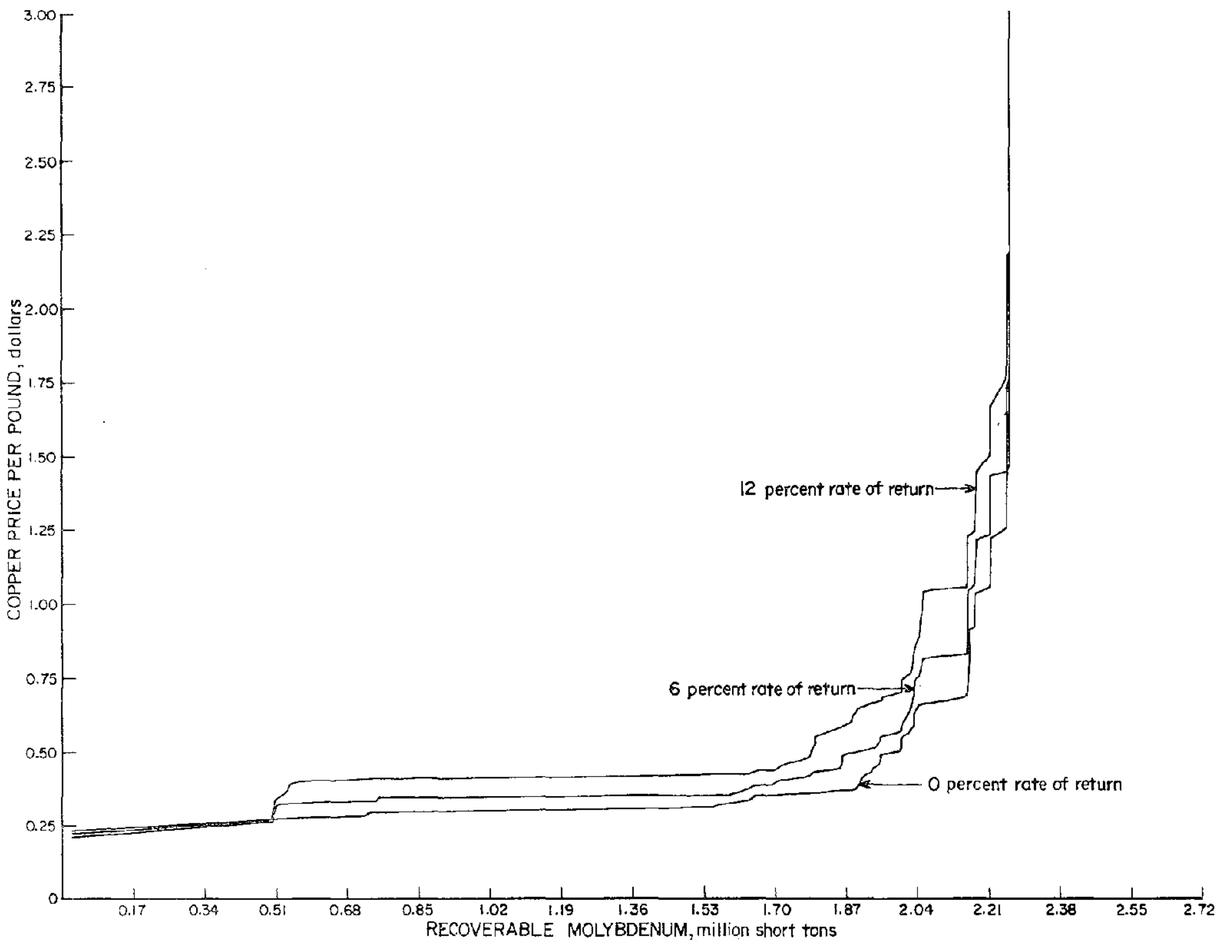

FIGURE 11. - Total molybdenum recoverable from domestic copper resources at various copper prices and rates of return.

An estimate of the total recoverable quantities of molybdenum, gold, and silver at various unit copper prices is shown in figures 11, 12, and 13 at 0-, 6-, and 12-percent rates of return. As indicated in figure 11, the total amount of molybdenum recoverable as a byproduct from the copper resources at a copper price of $0.50 is 2.0, 1.9, and 1.8 million tons at 0-, 6-, and 12-percent rates of return, respectively. It should be noted that the quantity of molybdenum produced will also vary with the market price of molybdenum.

The total recoverable quantity of byproduct gold at a $0.50 copper price is 48, 45, and 43 million troy ounces at 0-, 6-, and 12-percent rates of return, respectively (fig. 12).

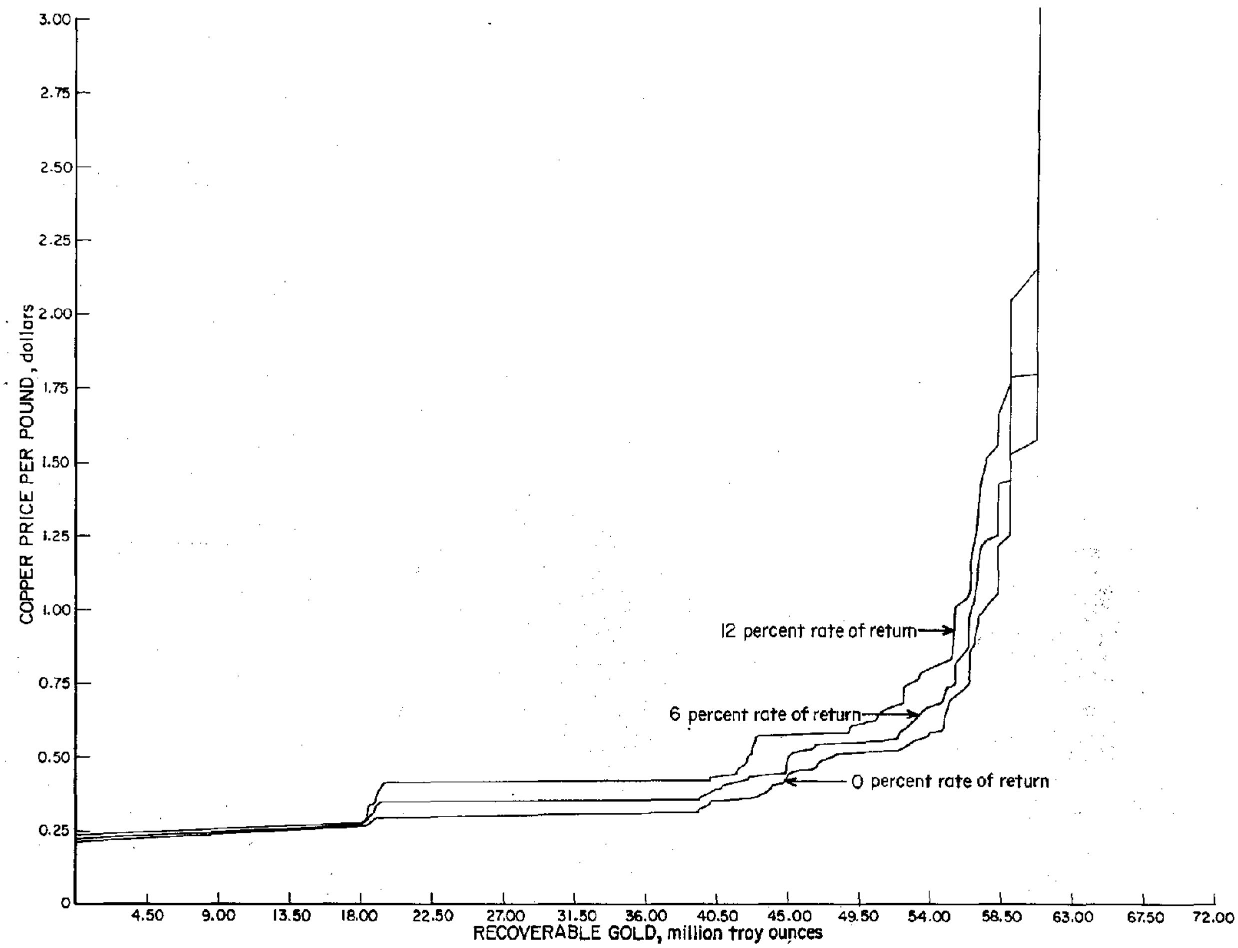

FIGURE 12. - Total gold recoverable from domestic copper resources at various copper prices and rates of return.

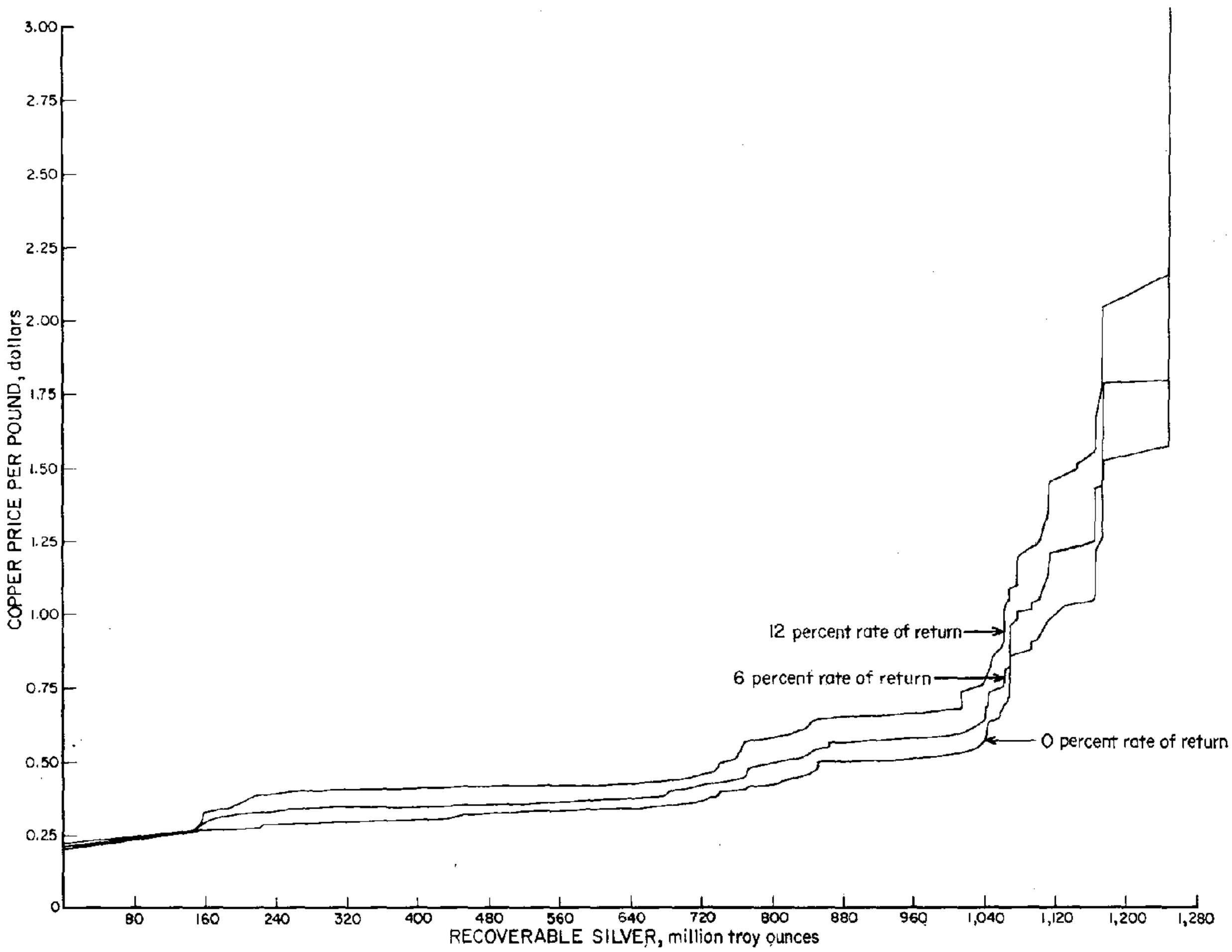

FIGURE 13. - Total silver recoverable from domestic copper resources at various copper prices and rates of return.

Byproduct silver recoverable at a $0.50 copper price is estimated at 852, 817, and 740 million troy ounces at 0-, 6-, and 12-percent rates of return, respectively (fig. 13)

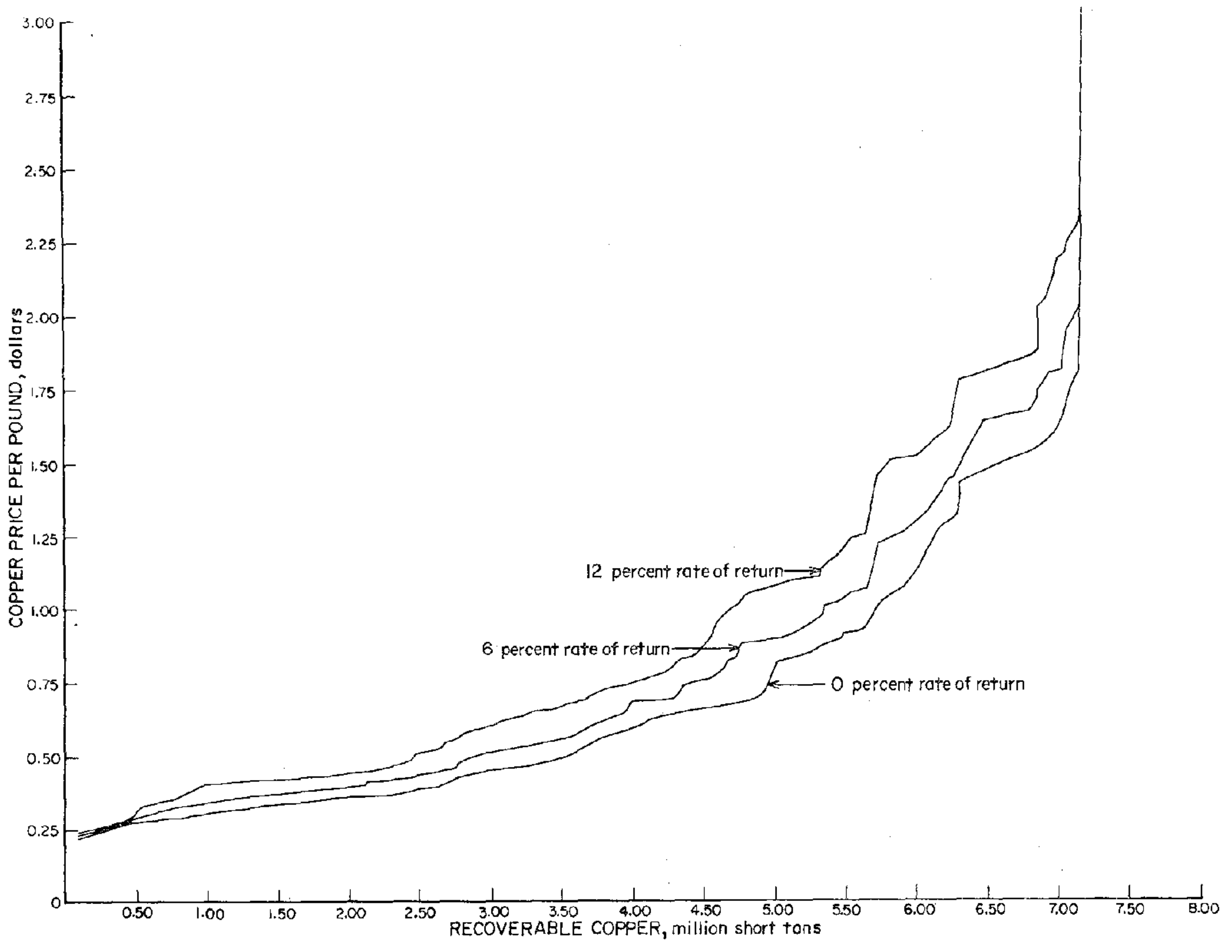

FIGURE 14. - Annual domestic copper production capacity, price calculated using various rates of return.

Figure 14 illustrates the annual mine production capacity of copper at various price levels and 0-, 6-, and 12-percent rates of return. Based on these data the expected annual mine production of recoverable copper at a price of $0.50 could be 3.6, 2.9, and 2.5 million tons at 0-, 6-, and 12-percent rates of return, respectively. Revenues include credit for byproduct production. This is based on current and projected production capacity at developed and undeveloped copper deposits. These data only indicate the potential amount of copper that could be produced at a specific price for any given year. They do not provide any indication of the duration of the production nor of the desirability of actually supplying this annual production capacity. It should be noted that an increase in production cannot be obtained immediately by increasing the price. The time required to increase production depends on factors such as the relative location of the deposit and the necessity for exploration, development, and plant construction.

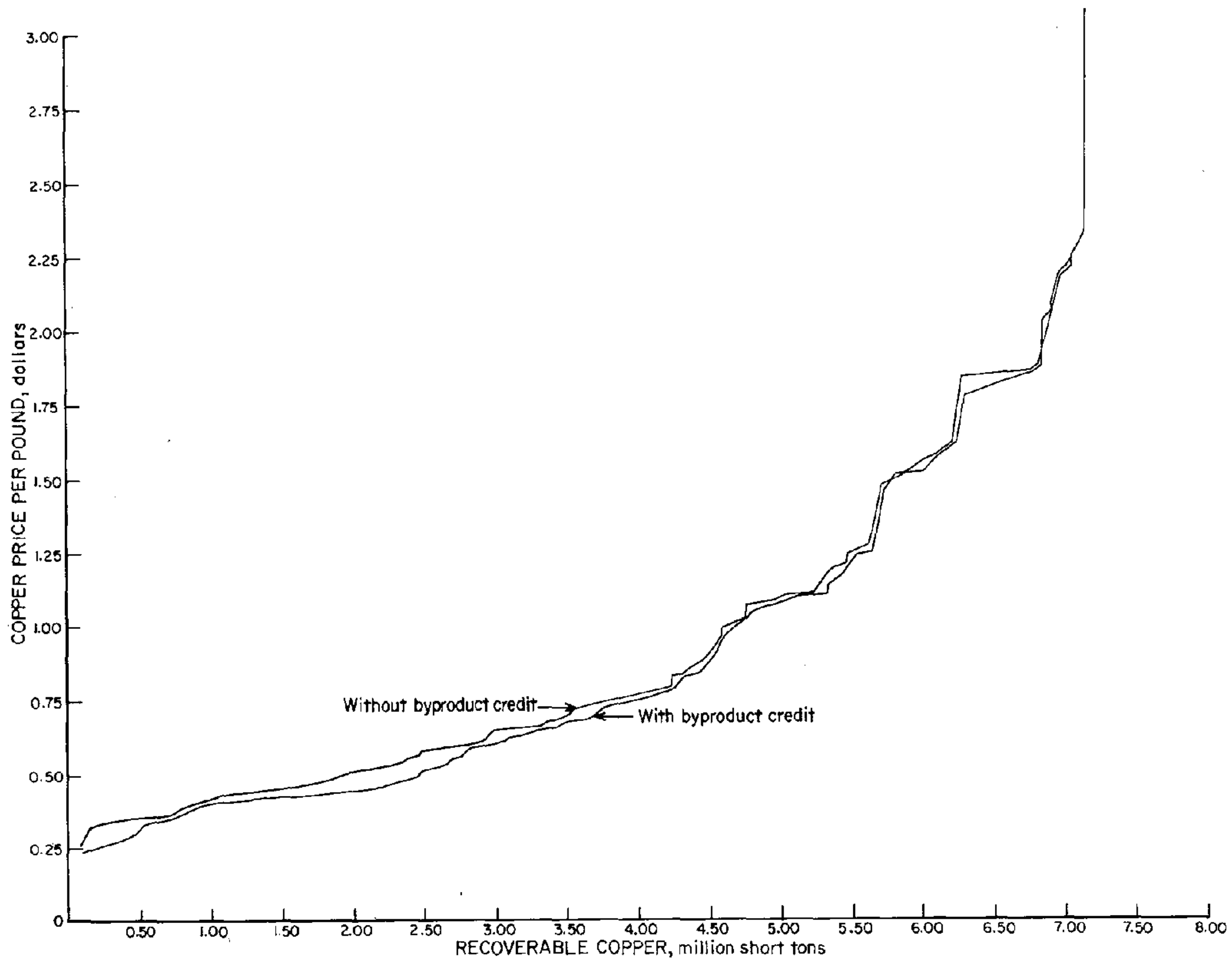

FIGURE 15. - Annual domestic copper production capacity, price calculated with and without byproduct credit at 12-percent rate of return.

Data shown in figure 15 compare the annual production capacities of recoverable copper with and without credit for byproduct revenues at a 12-percent return. The relative importance of the byproduct revenues of molybdenum, gold, and silver is indicated by the decrease from 2.5 to 2.0 million tons of copper that could economically be produced annually at a copper price of $0.50 per pound.

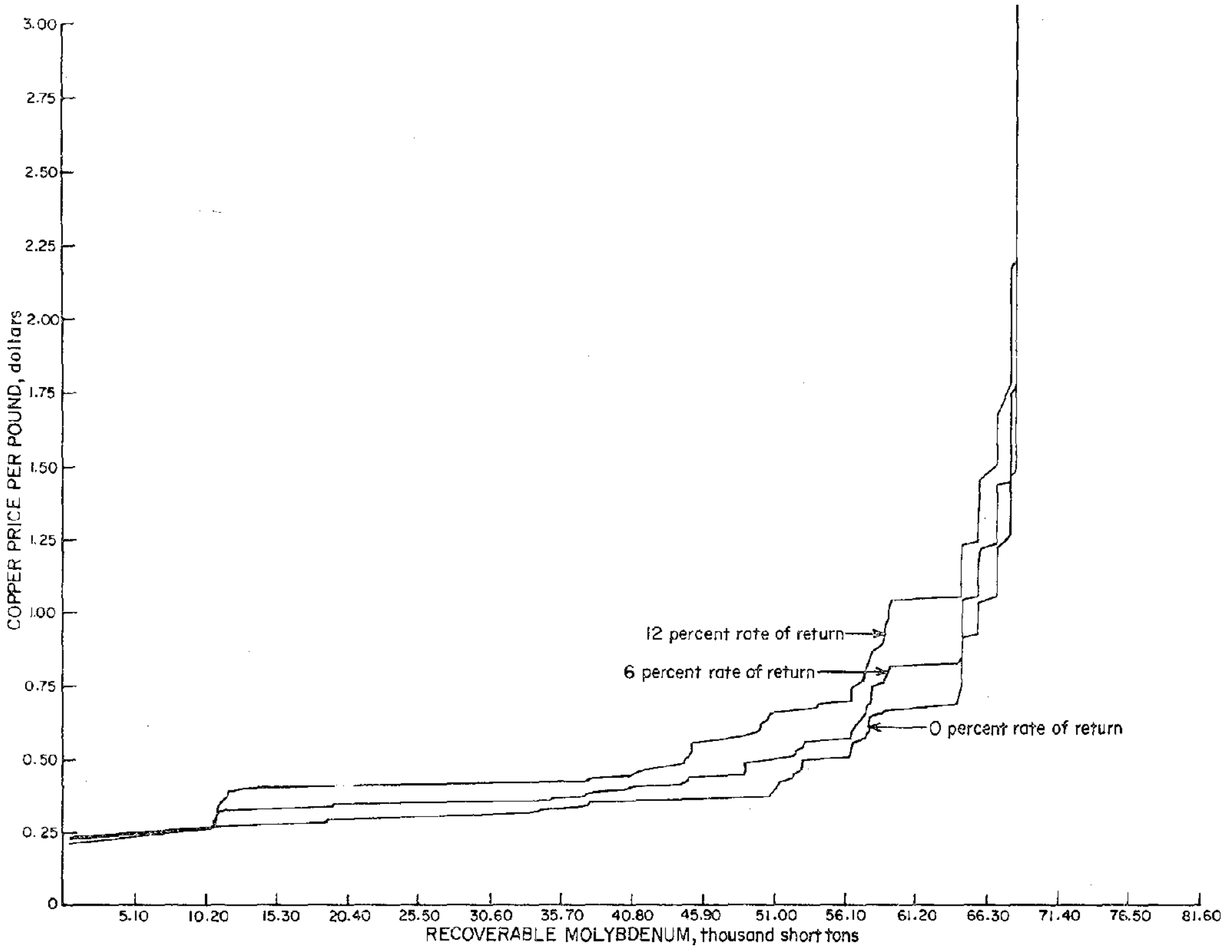

FIGURE 16. - Annual production of molybdenum recoverable from domestic copper resources at various copper prices and rates of return.

Figures 16, 17, and 18 indicate the annual production capacities of byproduct molybdenum, gold, and silver recoverable with the copper at various unit copper prices and 0-, 6-, and 12-percent return. Data in figure 16 indicate the quantity of economically recoverable molybdenum at a copper price of $0.50 per pound decreases from 57 thousand tons per year at a 0-percent rate of return to 45 thousand tons per year at a 12-percent rate of return.

At a copper price of $0.50 per pound the economically recoverable gold associated with copper resources is 1.2, 1.1, and 1.0 million troy ounces at 0-, 6-, and 12-percent rates of return, respectively.

Recoverable byproduct silver per year at a $0.50 copper price is 27, 25, and 21 million troy ounces per year at 0-, 6-, and 12-percent rates of return, respectively.

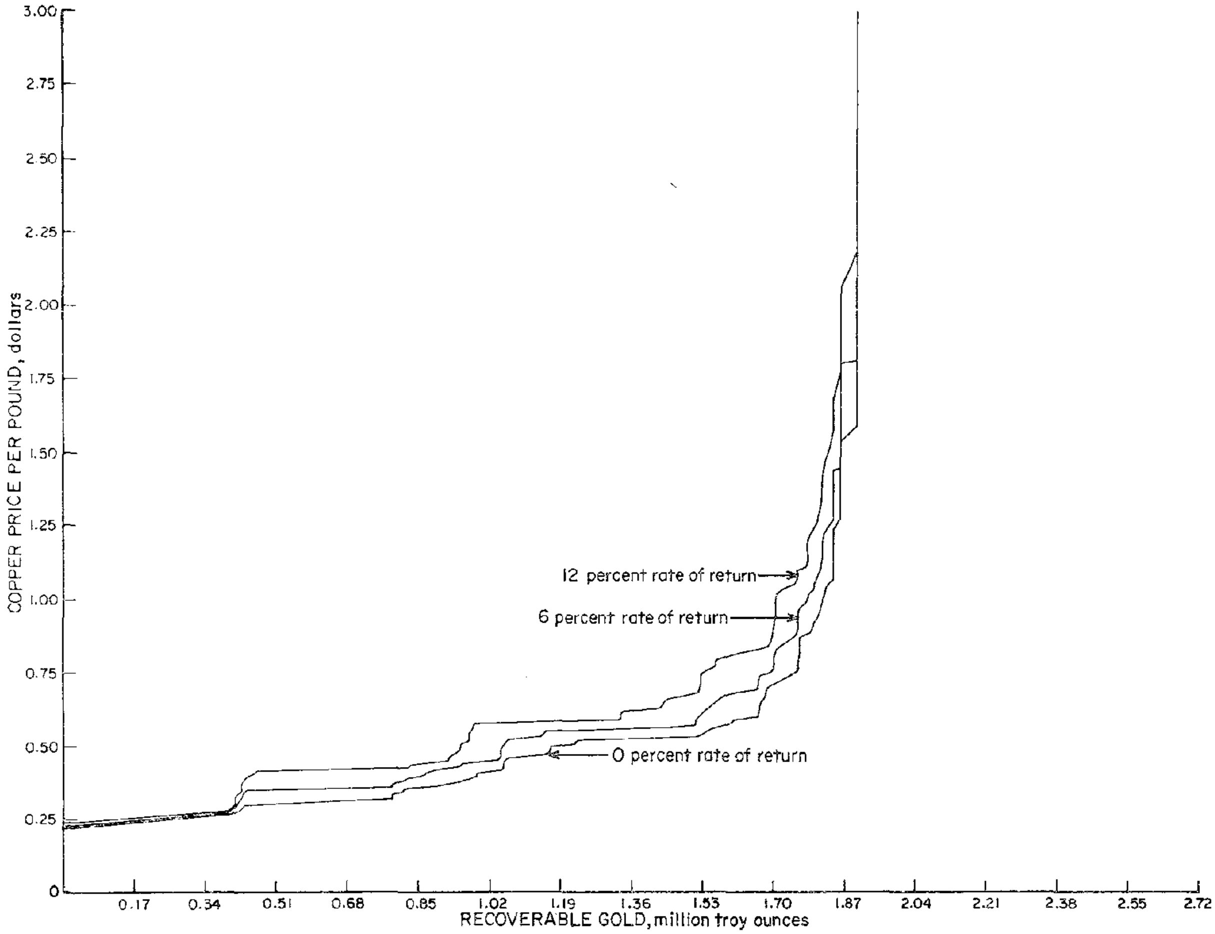

FIGURE 17. - Annual production of gold recoverable from domestic copper resources at various copper prices and rates of return.

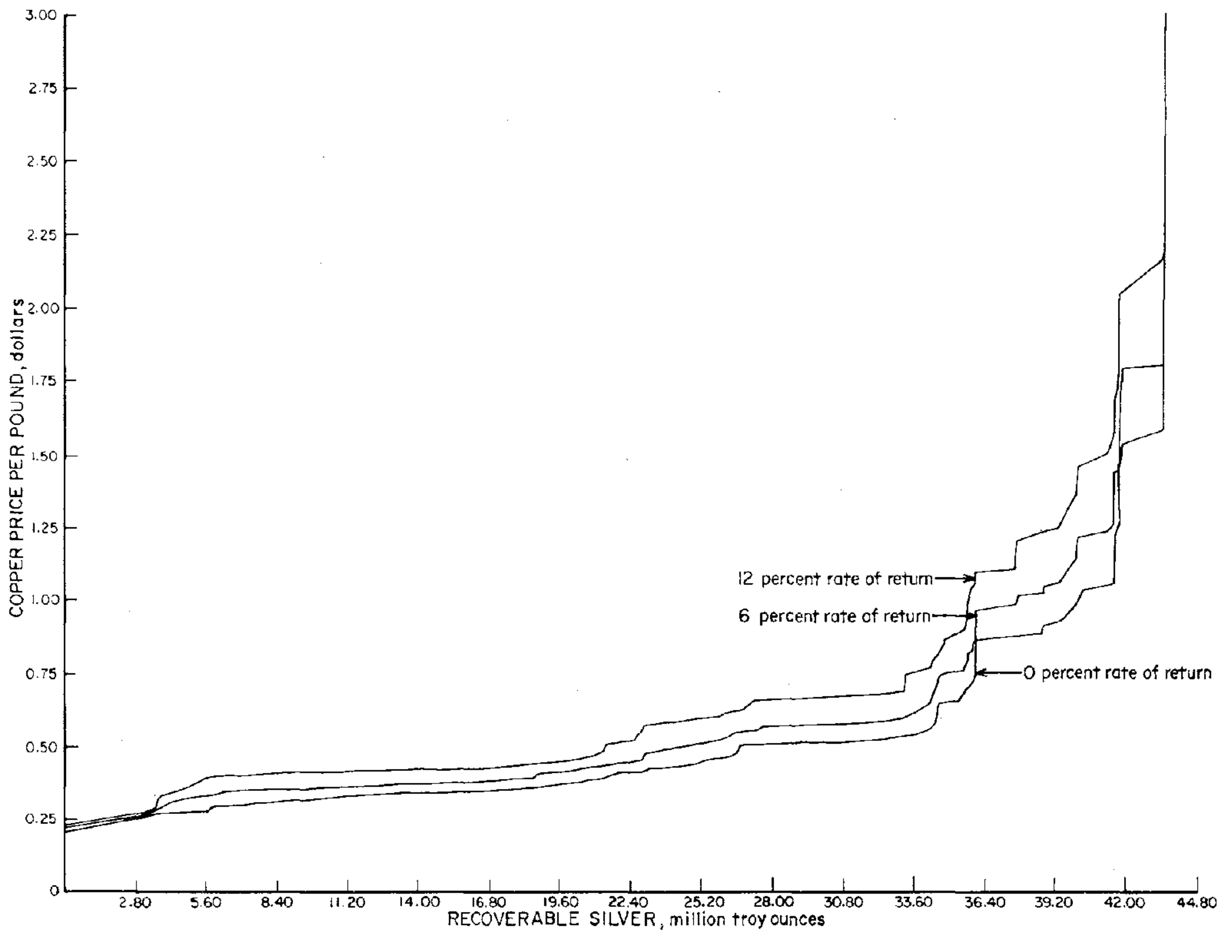

FIGURE 18. - Annual production of silver recoverable from domestic copper resources at various copper prices and rates of return.

An estimate also was made of the availability of the resource, that is, the time at which the material could be extracted and a marketable product produced. Restrictions considered were the time required to develop the deposit for production and construct the concentrating facilities. Other time delays result because overlying mineralized material of significantly different grade or mineral characteristics requiring a different mining method must be removed prior to mining underlying material.

Table 16 contains data indicating the approximate time requirements to develop some typical copper deposits. The exploration period consists of the exploration required to delineate the deposits after the initial discovery.

TABLE 16. - Historical data of approximate time required to explore, develop, and construct mining and concentrating facilities for selected copper deposits

Mining method	Exploration period, years	Mine development period, years[1]	Preproduction stripping, million tons	Milling method	Mill construction period, years[1]	Initial mill design capacity[2]
Open pit..	NA	2-1/3	NA	Flotation	2	7,500 tpd, ore
Do.....	2	1-1/3	6	...do....	1-2/3	12,000 tpd, ore
Do.....	3-1/4	1-3/4	23	...do....	1-2/3	12,000 tpd, ore
Do.....	4	2	33	...do....	1-2/3	15,000 tpd, ore
Do.....	4-1/4	4	264	...do....	3-1/4	30,000 tpd, ore
Block cave	3-1/4	3	-	...do....	2-1/3	30,000 tpd, ore
Open pit..	1-1/3	1-3/4	NA	Leach solvent.	2/3	5,000 tpy, copper

NA Not available.
[1]Mine development and mill construction normally occur simultaneously.
[2]Capacity in terms of feed except for the leach operation.

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APPENDIX A.--COST ANALYSIS OF OPEN-PIT MINING OPERATIONS

This appendix contains a brief description of the open-pit mining operations costed for this study. The various ore bodies for which costs were estimated have mining characteristics similar to those of developed deposits. Equipment selected for the study is of 1970 design and of the size now considered optimum for a particular operation. Supply consumption and equipment performance data used to make the estimates are modifications of industry experience with older and usually smaller equipment. The daily production rate for each operation includes ore, leach, and waste material. Operations were considered with the following production rates: 30,000, 40,000, 50,000, 80,000, 100,000, 150,000, and 180,000 tons per day (tpd). Capital investment and operating costs are summarized for each operation. For illustration, individual items of equipment and facilities are listed for the 40,000-tpd operation. Each operation requires the same type of equipment and facilities, but the size and quantity of the equipment and facilities vary.

Following are the data for the open-pit mining operations.

30,000-tpd Operation

General

Following is a brief description of an open-pit mining operation having a production rate of 30,000 tpd of ore, leach material, and waste. Included are tables A-1 and A-2 which contain a summary of capital investment and operation costs.

TABLE A-1. - Estimated capital requirements, 30,000-tpd open-pit mining operation

Unit	Cost
Mine lease-option cost, property acquisition	$160,000
Subtotal for depletion	160,000
Exploration, development, and engineering study	998,100
Preproduction stripping, 11,300,000 tons at $0.20 per ton	2,260,000
Subtotal for deferred expenses	3,258,100
Mine plant and buildings	926,300
Mine pit equipment	4,245,200
Subtotal for depreciation, taxes, and insurance	5,171,500
Working capital[1]	1,089,000
Total capital required	9,678,600

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE A-2. - Estimated annual operating cost, 30,000-tpd open-pit mining operation[1]

		Annual cost	Total	Cost per ton
Direct cost:				
Materials and utilities:				
Power	580 kW-hr/hr X 8,568 hr/yr X $0.007/kW-hr	$34,800	-	-
Explosives		283,800	-	-
Drill bits and steel		141,000	-	-
Fuel	1,011,000 gal X $0.16/gal	161,800	-	-
Tires		310,900	-	-
Miscellaneous operating supplies		58,100	-	-
Subtotal		-	$990,400	$0.093
Direct labor:				
452 man-hr/day	$3.50/man-hr X 357 day/yr	564,800	-	-
Supervision	15 percent of labor	84,700	-	-
Subtotal		-	649,500	.061
Maintenance:				
239 man-hr/day	$3.60/man-hr X 357 day/yr	307,200	-	-
Supervision	20 percent of labor	61,400	-	-
Maintenance supplies and parts		587,000	-	-
Subtotal		-	955,600	.089
Payroll overhead	25 percent of payroll	-	254,500	.024
Total direct cost		-	2,850,000	.267
Indirect cost:				
Administrative, technical, and clerical labor		185,700	-	.017
Payroll overhead	25 percent of administrative payroll	46,400	-	.004
Facilities maintenance and supplies	5 percent of plant facilities	46,300	-	.004
General overhead includes head office charges, exploration, and research	5 percent of direct costs	142,500	-	.013
Total indirect cost		-	420,900	.038
Fixed cost:				
Taxes and insurance	2 percent of plant cost	103,400	-	.010
Depreciation mine plant	15 years	61,800	-	.006
Depreciation mine pit equipment	10 years	424,500	-	.040
Deferred expenses	15 years	217,200	-	.020
Amortized future equipment requirements		141,500	-	.013
Total fixed cost		-	948,400	.089
Gross operating cost		-	4,219,300	.394

[1]Tonnage includes ore, waste, and leach material.

The ore deposit is in a gently dipping series of metasedimentary rocks. Sulfide ore is mainly confined to a 150-foot-thick conglomerate bed composed of chert and quartzite pebbles in a siliceous-calcareous matrix. Chalcopyrite is the main copper mineral but considerable chalcocite enrichment is present. Overlying the sulfide-ore horizon is 25 to 200 feet of mineralized calcareous shale and hornfels in which the copper minerals have been oxidized. Underlying the ore-bearing conglomerate is nearly barren sandstone.

Mining

Two rotary drills are used for drilling blastholes spaced on a 25-foot by 25-foot pattern. The average drilling rate is 325 feet per shift for an 11-inch-diameter hole. The holes are drilled to a depth of 33 feet allowing for 8 feet of subdrilling. The powder factor is 0.7 pound of AN-FO per ton of rock broken.

Material is loaded into 85-ton trucks with one 8-cubic-yard shovel, two 6-cubic-yard shovels, and one 10-cubic-yard front-end loader. The average loading rate with an 8-cubic-yard shovel is 5,630 tons per shovel-shift. The average haulage profile for ore is 3,000 feet in the pit with a climb of 175 feet and 19,000 feet of near level travel to the mill. The profile for leach material and waste is 2,500 feet in the pit with an average climb of 125 feet and 3,000 feet out of the pit with a climb of 75 feet to the leach or waste dump. The average haulage rate is 1,540 tons per truck-shift.

40,000-tpd Operation

General

Following is a brief description of an open-pit mining operation having a production rate of 40,000 tpd of ore, leach material, and waste. Included are tables A-3 and A-4 which show the equipment and facilities required. Tables A-5 and A-6 summarize the capital investment and operating costs.

TABLE A-3. - Mine pit equipment cost summary, 40,000-tpd open-pit mining operation

Item No.	Item	Quantity	Size	Unit hp	Total hp	Total cost
01100	Drill, primary.	3	Rotary electric powered quarry drill, 70,000-lb bit load.	500	1,500	$630,000
01101	Shovel.........	1	15 cu yd, electric powered........	700	700	732,000
01102	......do.......	3	6 cu yd, diesel powered...........	400	1,200	1,023,000
01103	Truck..........	13	75 ton, rear dump, diesel powered.	700	9,100	1,753,200
01104	Front-end loader.	1	Diesel powered, rubber tired, 10-cu-yd bucket.	550	550	140,000
01105	Dozer..........	1	Diesel powered, rubber tired, 63,000-lb draw bar pull.	300	300	73,000
01106	......do.......	3	Diesel powered, crawler tractor, 50,000-lb draw bar pull.	270	810	210,000
01107	Motor grader...	2	Diesel powered, 14-ft blade, 29,500-lb draw bar pull.	150	300	72,000
01108	Water truck....	2	Diesel powered, 4,000-gal capacity	150	300	56,000
01109	Service vehicle	14	Gasoline powered maintenance truck	100	1,400	56,000
01110	Utility vehicle	36	Fourteen 3/4-ton pickups, 15 1/2-ton pickups, 7 sedans.	80	2,880	108,000
	Subtotal....	-	-	-	-	4,853,200
	Contingency....	-	-	-	-	485,300
	Total.......	-	-	-	-	5,338,500

TABLE A-4. - Plant and buildings cost summary, 40,000-tpd open-pit mining operation

Item No.	Item	Quantity	Size	Total cost
02100	Transformer station	1	3,200 kV-A 69,000-volt to 4,160-volt transformers with semipermanent building.	$26,000
02101	Switch	1	Main disconnect 4,160 volt	6,000
02102	Distribution wire	28,000 ft	Main distribution overhead line, 4-single size 1-0 wires.	28,000
02103	Circuit breaker	8	Weatherproof, portable oil circuit breakers	48,000
02104	Portable cable	8,000 ft	Three conductor extra heavy duty insulation, size 1-0 wire.	32,000
02105	Coupler	8	Heavy duty electric couplers for portable cable.	3,200
02106	Pole	30	Poles for overhead distribution system, includes installation.	9,000
02107	Accessories for distribution line.	1	Cross arms, insulators, and accessories at $3,700 per mile.	5,000
02108	Mine office and change building	1	40 ft by 80 ft with 15-ft eave including utilities at $25 per sq ft.	80,000
02109	Office furniture and equipment.	1	40 ft by 80 ft at $15 per sq ft	48,000
02110	Mine service building	1	65 ft by 50 ft with 36-ft eave including utilities at $18 per sq ft.	58,500
02111	Repair and service shop	1	100 ft by 200 ft with 36-ft eave including utilities at $20 per sq ft.	400,000
02112	Warehouse	1	60 ft by 60 ft with 20-ft eave including utilities at $12 per sq ft, 1/2 charged to mine.	21,600
02113	Shop equipment and tools	1	Includes hoists, welders, and general shop tools	100,000
02114	Administration building	1	40 ft by 50 ft with 10-ft eave including utilities at $28 per sq ft, 1/2 charged to mine.	28,000
	Subtotal	-	-	893,300
	Contingency	-	-	89,300
	Total	-	-	982,600

TABLE A-5. - Estimated capital requirements, 40,000-tpd open-pit mining operation

Unit	Cost
Mine lease-option cost, property acquisition	$200,000
Subtotal for depletion	200,000
Exploration, development, and engineering study	457,600
Preproduction stripping, 6,000,000 at $0.20 per ton	1,200,000
Subtotal for deferred expenses	1,657,600
Mine plant and buildings	982,600
Mine pit equipment	5,338,500
Subtotal for depreciation, taxes, and insurance	6,321,100
Working capital[1]	1,349,600
Total capital required	9,528,300

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE A-6. - Estimated annual operating cost, 40,000-tpd open-pit mining operation[1]

	Annual cost	Total	Cost per ton
Direct cost:			
Materials and utilities:			
Power.......1,100 kW-hr/hr × 8,568 hr/yr × $0.007/kW-hr..	$66,000	-	-
Explosives..........	529,300	-	-
Drill bits and steel..........	72,000	-	-
Fuel.......1,295,600 gal × $0.16/gal..	207,300	-	-
Tires..........	293,100	-	-
Miscellaneous operating supplies..........	107,100		
Subtotal..........	-	$1,274,800	$0.090
Direct labor:			
609 man-hr/day.......$3.50/man-hr × 357 day/yr..	760,900	-	-
Supervision.......15 percent of labor..	114,100		
Subtotal..........	-	875,000	.061
Maintenance:			
216 man-hr/day.......$3.60/man-hr × 357 day/yr..	277,600	-	-
Supervision.......20 percent of labor..	55,500	-	-
Maintenance supplies and parts..........	684,400	-	-
Subtotal..........	-	1,017,500	.071
Payroll overhead.......25 percent of payroll..	-	302,000	.021
Total direct cost..........	-	3,469,300	.243
Indirect cost:			
Administrative, technical, and clerical labor..........	304,000	-	.021
Payroll overhead.......25 percent of administrative payroll..	76,000	-	.005
Facilities maintenance and supplies.......5 percent of plant facilities..	49,100	-	.004
General overhead includes head office charges, exploration, and research 5 percent of direct costs..	173,500	-	.012
Total indirect cost..........	-	602,600	.042
Fixed cost:			
Taxes and insurance.......2 percent of plant cost..	126,400	-	.009
Depreciation mine plant.......15 years..	65,500	-	.005
Depreciation mine pit equipment.......10 years..	533,900	-	.037
Deferred expenses.......15 years..	110,500	-	.008
Amortized future equipment requirements..........	178,000	-	.012
Total fixed cost..........	-	1,014,300	.071
Gross operating cost..........	-	5,086,200	.356

[1]Tonnage includes ore, waste, and leach material.

The ore body is a porphyry type in quartz monzonite and latite. The principal ore mineral is chalcopyrite. The ore body averages about 130 feet in thickness and is covered by an average of 95 feet of overburden. Cutoff grade of the ore is 0.35 percent copper and cutoff grade of leach material is 0.10 percent copper. Some molybdenum is contained in the ore.

Mining

Primary drilling is done with three rotary drill rigs capable of drilling 9- to 12.5-inch holes. Depth of the holes is 45 feet allowing for 10 feet of subdrilling. Average hole spacing with 9-inch holes is 20 feet by 24 feet; the average drilling rate is about 400 feet per shift. Approximately 15 drill shifts are required per week. Because of the presence of ground water in some areas of the pit both AN-FO and slurry are used for blasting; slurry is used in 50 percent of the holes. Blasthole loading is done on a contract basis. The powder factor is 0.35 pound of AN-FO per ton of rock broken.

The broken material is loaded into 75-ton haulage trucks with 6- and 15-cubic-yard shovels. The average loading rate is 5,740 tons per shovel-shift. The haulage rate is 1,830 tons per truck-shift over an average haulage distance of 6,400 feet of which 1,400 feet has a 10-percent grade.

50,000-tpd Operation

General

Following is a brief description of an open-pit mining operation having a production rate of 50,000 tpd of ore, leach material, and waste. Included are tables A-7 and A-8 which summarize the capital investment and operating costs.

TABLE A-7. - Estimated capital requirements, 50,000-tpd open-pit mining operation

Unit	Cost
Mine lease-option cost, property acquisition	$200,000
Subtotal for depletion	200,000
Exploration, development, and engineering study	991,200
Preproduction stripping, 5,300,000 tons at $0.20 per ton	1,060,000
Subtotal for deferred expenses	2,051,200
Mine plant and buildings	1,320,800
Mine pit equipment	4,624,000
Subtotal for depreciation, taxes, and insurance	5,944,800
Working capital[1]	1,320,900
Total capital required	9,516,900

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE A-8. - Estimated annual operating cost, 50,000-tpd open-pit mining operation[1]

	Annual cost	Total	Cost per ton
Direct cost:			
Materials and utilities:			
Power.........1,680 kW-hr/hr × 8,568 hr/yr × $0.007/kW-hr..	$100,800	-	-
Explosives..........	160,300	-	-
Drill bits and steel..........	35,300	-	-
Fuel..........1,474,300 gal × $0.16/gal..	235,900	-	-
Tires..........	520,300	-	-
Miscellaneous operating supplies..........	73,200	-	-
Subtotal..........	-	$1,125,800	$0.063
Direct labor:			
550 man-hr/day..........$3.50/man-hr × 357 day/yr..	687,200	-	-
Supervision..........15 percent of labor..	103,100	-	-
Subtotal..........	-	790,300	.044
Maintenance:			
265 man-hr/day..........$3.60/man-hr × 357 day/yr..	340,600	-	-
Supervision..........20 percent of labor..	68,100	-	-
Maintenance supplies and parts..........	781,200	-	-
Subtotal..........	-	1,189,900	.067
Payroll overhead..........25 percent of payroll..	-	299,800	.017
Total direct cost..........	-	3,405,800	.191
Indirect cost:			
Administrative, technical, and clerical labor..........	291,700	-	.016
Payroll overhead..........25 percent of administrative payroll..	72,900	-	.004
Facilities maintenance and supplies..........5 percent of plant facilities..	66,000	-	.004
General overhead includes head office charges, exploration, and research 5 percent of direct costs..	170,300	-	.009
Total indirect cost..........	-	600,900	.033
Fixed cost:			
Taxes and insurance..........2 percent of plant cost..	118,900	-	.007
Depreciation mine plant..........15 years..	88,100	-	.005
Depreciation mine pit equipment..........10 years..	462,400	-	.026
Deferred expenses..........15 years..	136,700	-	.007
Amortized future equipment requirements..........	154,100	-	.009
Total fixed cost..........	-	960,200	.054
Gross operating cost..........	-	4,966,900	.278

[1]Tonnage includes ore, waste, and leach material.

The deposit is in a gently pitching section of a faulted porphyry stock. The ore body being mined is 6,000 feet long, 1,000 feet wide, and 700 feet thick. It is overlain by from 0 to 200 feet of gravel and 0 to 300 feet of weakly mineralized porphyry. Copper values are erratically distributed in an ore zone which contains shoots of ore interspersed with lower grade material. Chalcopyrite, the predominant sulfide copper mineral, has been oxidized in the upper portion of the deposit. Three classes of ore are separated during mining; mill-grade sulfide ore containing over 0.30 percent copper, vat-leach oxide ore containing over 0.30 percent copper, and heap-leach material containing over 0.15 percent copper.

Ore is carefully sorted during mining. This is practicable because after shattering the ore is soft enough to dig from the banks with shovels or loaders. Copper distribution is carefully determined by sampling the blastholes before blasting. Changes in the relative positions of the ores of different grades during blasting is minimized by confining the face with 100 feet or more of previously shattered ore.

Mining

Rock is broken with 7-3/8-inch holes drilled on 25-foot centers to a subgrade 5 feet below 25-foot benches. The rotary-drill penetration rate is 376 feet per shift. The powder factor is 0.197 pound of AN-FO per ton of rock broken.

Rock is loaded into 85-ton trucks at a rate of 9,600 tons per shovel-shift with 9-cubic-yard shovels. Each shovel is assisted by a 6-cubic-yard front-end loader. Average haulage distance for ore is about 6,000 feet in the pit with a climb of 400 feet followed by 4,000 feet of near level road to the mill. Leach ore and waste are hauled about 4,000 feet in the pit with a climb of 250 feet followed by 7,000 feet of surface roads climbing about 100 feet onto the dumps. Average haulage rate is 1,755 tons per truck-shift.

80,000-tpd Operation

General

Following is a brief description of an open-pit mining operation having a production rate of 80,000 tpd of ore, leach material, and waste. Included are tables A-9 and A-10 which summarize the capital investment and operating costs.

TABLE A-9. - Estimated capital requirements, 80,000-tpd open-pit mining operation

Unit	Cost
Mine lease-option cost, property acquisition	$250,000
Subtotal for depletion	250,000
Exploration, development, and engineering study	2,705,800
Preproduction stripping, 46,300,000 tons at $0.20 per ton	9,260,000
Subtotal for deferred expenses	11,965,800
Mine plant and buildings	1,531,300
Mine pit equipment	12,572,800
Subtotal for depreciation, taxes, and insurance	14,104,100
Working capital[1]	2,349,100
Total capital required	28,669,000

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE A-10. - Estimated annual operating cost, 80,000-tpd open-pit mining operation[1]

	Annual cost	Total	Cost per ton
Direct cost:			
Materials and utilities:			
Power....1,600 kW-hr/hr × 8,568 hr/yr × $0.007/kW-hr..	$96,000	-	-
Explosives....	840,900	-	-
Drill bits and steel....	231,200	-	-
Fuel....2,407,500 gal × $0.16/gal..	385,200	-	-
Tires....	590,400	-	-
Miscellaneous operating supplies....	159,700		
Subtotal....	-	$2,303,400	$0.081
Direct labor:			
916 man-hr/day....$3.50/man-hr × 357 day/yr..	1,144,500	-	-
Supervision....15 percent of labor..	171,700	-	-
Subtotal....	-	1,316,200	.046
Maintenance:			
414 man-hr/day....$3.60/man-hr × 357 day/yr..	532,100	-	-
Supervision....20 percent of labor..	106,400	-	-
Maintenance supplies and parts....	1,360,400	-	-
Subtotal....	-	1,998,900	.070
Payroll overhead....25 percent of payroll..	-	488,700	.017
Total direct cost....	-	6,107,200	.214
Indirect cost:			
Administrative, technical, and clerical labor....	325,700	-	.011
Payroll overhead....25 percent of administrative payroll..	81,400	-	.003
Facilities maintenance and supplies....5 percent of plant facilities..	76,600	-	.003
General overhead includes head office charges, exploration, and research 5 percent of direct costs..	305,400	-	.011
Total indirect cost....	-	789,100	.028
Fixed cost:			
Taxes and insurance....2 percent of plant cost..	282,100	-	.010
Depreciation mine plant....15 years..	102,100	-	.004
Depreciation mine pit equipment....10 years..	1,257,300	-	.044
Deferred expenses....15 years..	797,700	-	.028
Amortized future equipment requirements....	419,100	-	.014
Total fixed cost....	-	2,858,300	.100
Gross operating cost....	-	9,754,600	.342

[1]Tonnage includes ore, waste, and leach material.

The deposit is a low-grade copper sulfide porphyry ore body within a broad zone of hydrothermal alteration in sedimentary rocks. The thickness of the ore body ranges from 200 to 700 feet; overburden averages about 200 feet in thickness. The principal ore mineral is chalcopyrite and some molybdenite is present. Cutoff grade of the ore is 0.30 percent copper and that of the leach material, 0.10 percent copper.

Mining

Primary drilling is done with four rotary drills which are capable of drilling holes ranging from 9 to 12.5 inches in diameter. Depth of the holes is 55 feet on a typical spacing of 24 feet by 18 feet with 9-inch holes. Approximately 45 drill-shifts per week are required with an average footage of 360 feet per shift.

AN-FO blasting agent is used to break the material. The overall average powder factor is about 0.36 pound per ton of material.

Rock is loaded into 85-ton trucks with 9-cubic-yard shovels at a rate of 9,100 tons per shovel-shift. Average haulage distance for ore is 1,800 feet on an 8-percent grade plus 1,200 feet of near level grade; and for leach and waste material is 1,800 feet on an 8-percent grade plus 7,800 feet of near level grade. The average haulage rate is 1,620 tons per truck-shift.

100,000-tpd Operation

General

Following is a brief description of an open-pit mining operation having a production rate of 100,000 tpd of ore, leach material, and waste. Included are tables A-11 and A-12 which summarize the capital investment and operating cost.

TABLE A-11. - Estimated capital requirements, 100,000-tpd open-pit mining operation

Unit	Cost
Mine lease-option cost, property acquisition	$250,000
Subtotal for depletion	250,000
Exploration, development, and engineering study	2,560,200
Preproduction stripping, 16,000,000 tons at $0.20 per ton	3,200,000
Subtotal for deferred expenses	5,760,200
Mine plant and buildings	1,711,200
Mine pit equipment	11,513,300
Subtotal for depreciation, taxes, and insurance	13,224,500
Working capital[1]	2,831,500
Total capital required	22,066,200

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE A-12. - Estimated annual operating cost, 100,000-tpd open-pit mining operation[1]

	Annual cost	Total	Cost per ton
Direct cost:			
Materials and utilities:			
Power.......2,995 kW-hr/hr × 8,568 hr/yr × $0.007/kW-hr..	$179,600	-	-
Explosives..........	285,700	-	-
Drill bits and steel..........	138,000	-	-
Fuel.......3,367,500 gal × $0.16/gal..	538,800	-	-
Tires..........	1,077,400	-	-
Miscellaneous operating supplies..........	109,700	-	-
Subtotal..........	-	$2,329,200	$0.065
Direct labor:			
1,180 man-hr/day.......$3.50/man-hr × 357 day/yr..	1,474,400	-	-
Supervision.......15 percent of labor..	221,200	-	-
Subtotal..........	-	1,695,600	.048
Maintenance:			
590 man-hr/day.......$3.60/man-hr × 357 day/yr..	758,300	-	-
Supervision.......20 percent of labor..	151,700	-	-
Maintenance supplies and parts..........	1,813,700	-	-
Subtotal..........	-	2,723,700	.076
Payroll overhead.......25 percent of payroll..	-	651,400	.018
Total direct cost..........	-	7,399,900	.207
Indirect cost:			
Administrative, technical, and clerical labor..........	539,100	-	.015
Payroll overhead.......25 percent of administrative payroll..	134,800	-	.004
Facilities maintenance and supplies.......5 percent of plant facilities..	85,600	-	.002
General overhead includes head office charges, exploration, and research 5 percent of direct costs..	370,000	-	.010
Total indirect cost..........	-	1,129,500	.032
Fixed cost:			
Taxes and insurance.......2 percent of plant cost..	264,500	-	.007
Depreciation mine plant.......15 years..	114,100	-	.003
Depreciation mine pit equipment.......10 years..	1,151,300	-	.032
Deferred expenses.......15 years..	384,000	-	.011
Amortized future equipment requirements..........	383,800	-	.011
Total fixed cost..........	-	2,297,700	.064
Gross operating cost..........	-	10,827,100	.303

[1]Tonnage includes ore, waste, and leach material.

The deposit contains several copper-porphyry ore bodies along a zone 5 miles long and 1 mile wide. Disseminated copper ore occurs both in monzonite porphyry stocks and in surrounding sedimentary rocks. Chalcopyrite is the predominant copper mineral but chalcocite enrichment is important. Cutoff grade for mill ore is 0.40 percent copper. Lower grade material containing above 0.20 percent copper is placed on prepared leach dumps.

Mining

Nine-inch holes are used for blasting. The average rotary drilling rate is 430 feet per shift. Hole spacing is 23 feet by 26 feet and holes are drilled to a subgrade 10 feet below the bottom of a 40-foot bench. AN-FO blasting agent is used at a rate of 0.17 pound per ton of rock broken.

Rock is loaded into 85-ton trucks with 15-cubic-yard shovels at the rate of 10,000 tons per shovel-shift. Average haulage distance for ore is about 6,000 feet in the pit with a 400-foot climb plus 1,000 feet of level haulage to a rail loadout point. Waste and leach material are hauled about 3,000 feet in the pit with a climb of 150 feet plus 7,000 feet with a climb of 150 feet to leach and waste dumps. Average tonnage hauled per truck-shift is 1,490 tons.

150,000-tpd Operation

General

Following is a brief description of an open-pit mining operation having a production rate of 150,000 tpd of ore, leach material, and waste. Included are tables A-13 and A-14 which summarize the capital investment and operating costs.

TABLE A-13. - Estimated capital requirements, 150,000-tpd open-pit mining operation

Unit	Cost
Mine lease-option cost, property acquisition	$300,000
Subtotal for depletion	300,000
Exploration, development, and engineering study	3,100,000
Preproduction stripping, 21,500,000 tons at $0.20 per ton	4,300,000
Subtotal for deferred expenses	7,400,000
Mine plant and buildings	1,691,500
Mine pit equipment	20,681,800
Subtotal for depreciation, taxes, and insurance	22,373,300
Working capital[1]	4,494,500
Total capital required	34,567,800

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE A-14. - Estimated annual operating cost, 150,000-tpd open-pit mining operation[1]

	Annual cost	Total	Cost per ton
Direct cost:			
Materials and utilities:			
Power....2,500 kW-hr/hr × 8,568 hr/yr × $0.007/kW-hr..	$149,900	-	-
Explosives....	1,755,000	-	-
Drill bits and steel....	383,500	-	-
Fuel....6,040,600 gal × $0.16/gal..	966,500	-	-
Tires....	1,796,800	-	-
Miscellaneous operating supplies....	251,400	-	-
Subtotal....	-	$5,303,100	$0.099
Direct labor:			
1,365 man-hr/day....$3.50/man-hr × 357 day/yr..	1,705,600	-	-
Supervision....15 percent of labor..	255,800	-	-
Subtotal....	-	1,961,400	.037
Maintenance:			
753 man-hr/day....$3.60/man-hr × 357 day/yr..	967,800	-	-
Supervision....20 percent of labor..	193,600	-	-
Maintenance supplies and parts....	2,427,600	-	-
Subtotal....	-	3,589,000	.067
Payroll overhead....25 percent of payroll..	-	780,700	.015
Total direct cost....	-	11,634,200	.217
Indirect cost:			
Administrative, technical, and clerical labor....	364,000	-	.007
Payroll overhead....25 percent of administrative payroll..	91,000	-	.002
Facilities maintenance and supplies....5 percent of plant facilities..	84,600	-	.002
General overhead includes head office charges, exploration, and research 5 percent of direct costs..	581,700	-	.010
Total indirect cost....	-	1,121,300	.021
Fixed cost:			
Taxes and insurance....2 percent of plant cost..	447,500	-	.008
Depreciation mine plant....15 years..	112,800	-	.002
Depreciation mine plant equipment....10 years..	2,068,200	-	.039
Deferred expenses....15 years..	493,300	-	.009
Amortized future equipment requirements....	689,400	-	.013
Total fixed cost....	-	3,811,200	.071
Gross operating cost....	-	16,566,700	.309

[1]Tonnage includes ore, waste, and leach material.

The ore body is of contact metamorphic origin. It averages 700 feet in thickness, has a lateral extent of 2,500 feet, and is overlain with about 180 feet of overburden. The principal ore mineral is chalcopyrite. Cutoff grade of the ore is 0.30 percent copper and cutoff grade of the leach material is 0.10 percent copper. Some molybdenum is recovered.

Mining

Primary drilling is done with five rotary drill rigs which are capable of drilling holes ranging from 9 to 12.5 inches in diameter. Depth of the holes is 50 feet with 10 feet of subdrilling. Hole spacing with 9-inch holes is 30 feet by 30 feet in overburden and 24 feet by 27 feet in harder rock. The average drilling rate with 9-inch holes is about 550 feet per drill-shift with approximately 47 drill-shifts required per week. AN-FO is used for blasting except in wet holes where slurry is used. About 25 percent of the holes are wet. Both AN-FO and slurry are loaded from two powder trucks. AN-FO consumption is about 0.26 pound per ton of rock broken.

The blasted material is loaded with six 15-cubic-yard shovels into 120-ton haulage trucks at an average rate of 12,800 tons per shovel-shift. The average one-way haulage distance is about 3,500 feet at near level grade, and 9,500 feet at 7-percent grade for ore and leach material. Haulage distance for the waste material is approximately 6,000 feet at near level grade and 12,000 feet at 7-percent grade. Average tonnage hauled per truck-shift is 1,340 tons.

180,000-tpd Operation

General

Following is a brief description of an open-pit mining operation having a production rate of 180,000 tpd of ore, leach material, and waste. Included are tables A-15 and A-16 which summarize the capital investment and operating costs.

TABLE A-15. - Estimated capital requirements, 180,000-tpd open-pit mining operation

Unit	Cost
Mine lease-option cost, property acquisition......................	$400,000
Subtotal for depletion..	400,000
Exploration, development, and engineering study..................	3,750,000
Preproduction stripping, 100,000,000 tons at $0.20 per ton........	20,000,000
Subtotal for deferred expenses..............................	23,750,000
Mine plant and buildings..	1,942,700
Mine pit equipment..	17,664,300
Subtotal for depreciation, taxes, and insurance.............	19,607,000
Working capital[1]..	4,501,200
Total capital required......................................	48,258,200

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE A-16. - Estimated annual operating cost, 180,000-tpd open-pit mining operation[1]

	Annual cost	Total	Cost per ton
Direct cost:			
Materials and utilities:			
Power......3,200 kW-hr/hr × 8,568 hr/yr × $0.007/kW-hr..	$191,900	-	-
Explosives..........	2,995,000	-	-
Drill bits and steel..........	459,000	-	-
Fuel......4,621,800 gal × $0.16/gal..	739,500	-	-
Tires..........	1,234,700	-	-
Miscellaneous operating supplies..........	164,700	-	-
Subtotal..........	-	$5,784,800	$0.090
Direct labor:			
1,227 man-hr/day......$3.50/man-hr × 357 day/yr..	1,533,100	-	-
Supervision......15 percent of labor..	230,000	-	-
Subtotal..........	-	1,763,100	.027
Maintenance:			
663 man-hr/day......$3.60/man-hr × 357 day/yr..	852,100	-	-
Supervision......20 percent of labor..	170,400	-	-
Maintenance supplies and parts..........	2,068,700	-	-
Subtotal..........	-	3,091,200	.048
Payroll overhead......25 percent of payroll..	-	696,400	.011
Total direct cost..........	-	11,335,500	.176
Indirect cost:			
Administrative, technical, and clerical labor..........	588,000	-	.009
Payroll overhead......25 percent of administrative payroll..	147,000	-	.002
Facilities maintenance and supplies......5 percent of plant facilities..	97,100	-	.002
General overhead includes head office charges, exploration, and research 5 percent of direct costs..	566,800	-	.009
Total indirect cost..........	-	1,398,900	.022
Fixed cost:			
Taxes and insurance......2 percent of plant cost..	392,100	-	.006
Depreciation mine plant......15 years..	129,500	-	.002
Depreciation mine pit equipment......10 years..	1,766,400	-	.027
Deferred expenses......15 years..	1,583,300	-	.025
Amortized future equipment requirements..........	588,800	-	.009
Total fixed cost..........	-	4,460,100	.069
Gross operating cost..........	-	17,194,500	.267

[1]Tonnage includes ore, waste, and leach material.

The deposit is of the copper-porphyry type. It averages about 600 feet in thickness and has a lateral extent of about 3,000 feet. Average thickness of the overburden is 300 feet. Mineralization is predominantly chalcopyrite with considerable molybdenite present.

Mining

Six rotary drills capable of drilling 9- to 12.25-inch holes are used for the primary drilling. Hole spacing is 25 feet by 25 feet and 30 feet by 30 feet depending upon the hole diameter. Depth of the holes is 60 feet allowing for subdrilling. Average penetration rate with 12.25-inch holes is 375 feet per shift. Approximately 57 drill-shifts per week are required. Both AN-FO and slurry blasting agents are used because of wet holes. About 75 percent of the holes are wet. The powder factor is 0.31 pound of AN-FO per ton of rock.

Loading of the material into 120-ton trucks is done with 15-cubic-yard shovels at a rate of 12,900 tons per shovel-shift. Overall average haulage distance for the ore is 5,000 feet at near level grade and 1,000 feet at 10-percent grade. Average haulage distance for the leach material and waste is 8,000 feet at near level grade and 2,000 feet at 10-percent grade. Average tonnage hauled per truck-shift is 2,210 tons.

APPENDIX B.--COST ANALYSIS OF UNDERGROUND MINING OPERATIONS

Included in this appendix are the cost estimates developed for this study for underground mining operations using cut-and-fill, room-and-pillar, and block-caving methods. The daily production rates for each method are as follows: cut-and-fill, 6,000 tpd; room-and-pillar, 25,000 tpd; and block-cave, 30,000 tpd. In the analyses it is assumed that the deposits are undeveloped and that production starts at their apex. Also, that all equipment and facilities are of 1970 design and of the optimum size for the particular mine.

6,000-tpd Cut-and-Fill Operation

General

Following is a brief description of a cut-and-fill mining operation having a production rate of 6,000 tpd of ore. Included are tables B-1, B-2, and B-3 which list the required equipment, facilities, and development work. Capital investment and operating costs are summarized in tables B-4 and B-5.

The tabular-shaped ore body is 18 feet in stratigraphic width and dips 50 degrees. The first 15 years of mining, for which this analysis is made, will be confined to a block 5,280 feet long and extending to a vertical depth of 3,750 feet. The host rock is lava of average firmness and hardness with only moderate fracturing. About one-fourth of the haulageways and other permanent openings require roof support. Only limited temporary support is needed during stoping.

Mining

Access to the ore body is by vertical shaft to a depth of 3,750 feet and then by incline to the ore horizon. Crosscuts are driven from the vertical shaft to the ore body at 200-foot vertical intervals. The haulage drifts are driven in the ore body at each production level parallel to the strike of the ore body. Ventilation is by an exhaust fan above the incline plus auxiliary fans above each stope. About 2,000 gpm of water is pumped from the mine.

Drilling in the cut-and-fill stopes is done by rubber-tired jumbos mounting two 3.5-inch Leyner drills. An average of 1.9 feet of drill hole is required per ton of rock broken. Penetration rate is 1.5 feet per minute for 2-inch-diameter holes. Tungsten-carbide bit life is about 190 feet and drill rod life about 340 feet. Explosive consumption is 1.40 pounds of AN-FO per ton of ore broken.

Broken ore is loaded and hauled across the filled stopes to transfer raises with 5-cubic-yard diesel-powered load-haul-dump vehicles at a rate of 70 tons per hour with an average haulage distance of 500 feet. Eleven-ton trolley motors and 10-ton ore cars are used to haul the broken ore to the shaft pocket where they are dumped with a Granby car dumper.

Development drilling is mainly in ore, and consumption of supplies is similar to that in stoping. Rail-mounted drill jumbos are used. Dynamite is used for development blasting because of ground water. Rock broken during development is loaded directly into rail cars with rocker shovels. Sixteen-ton skips are used for rock hoisting. Mill sands are used for stope filling.

TABLE B-1. - Underground plant and equipment cost summary, 6,000-tpd underground cut-and-fill mining operation

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost: Material	Cost: Labor	Total cost
01100	Pump (drainage).....	12	Vertical 8-stage 13-1/4-in bowl (3 spares).	600	5,400	$219,000	$21,900	$240,900
01101	Drainage lines......	16,000 ft	10-in pipe with victaulic couplings.	-	-	177,700	177,700	355,400
01102	Compressed air line.	8,000 ft	.........do..........	-	-	93,200	93,200	186,400
01103	.........do.........	5,000 ft	8-in pipe with victaulic couplings.	-	-	44,700	44,700	89,400
01104	.........do.........	15,000 ft	6-in pipe with victaulic couplings.	-	-	88,800	88,800	177,600
01105	Drill and culinary waterline.	28,000 ft	4-in pipe with victaulic couplings.	-	-	87,200	87,200	174,400
01106	Blowers............	12	Portable in workings (2 spares).	15	150	9,600	1,000	10,600
01107	Electric distribution system.	-	Cables, transformers, etc.	-	-	440,000	340,000	780,000
01108	Telephone..........	-	Throughout mine and surface.	10	10	15,000	15,000	30,000
01109	Ore haulage locomotive.	3	11-ton, 250-volt dc trolley type.	-	-	123,000	6,000	129,000
01110	Ore car............	28	200 cu ft, Granby type.	-	-	114,800	5,700	120,500
01111	Supply trucks.......	10	Flat trucks..........	-	-	13,100	700	13,800
01112	Trolley power source	3	Rectifier type.......	150	450	143,000	28,600	171,600
01113	Granby dump ramp....	12	Retractable, air powered.	-	-	30,000	3,000	33,000
01114	Development locomotives.	6	6-ton battery type...	-	-	168,000	8,400	176,400
01115	Development cars....	18	85 cu ft, Granby type.	-	-	44,200	2,200	46,400
01116	Battery charger.....	3	Rectifier type.......	150	450	80,000	16,000	96,000
01117	Jumbo (development).	6	2 drills, 3-1/2-in pistons.	-	-	90,000	4,500	94,500
01118	Loading machine.....	6	Overshot type, air power.	-	-	69,600	3,500	73,100
01119	Stoper.............	40	31-in feed, 79 lb....	-	-	62,400	-	62,400
01120	Hoist..............	14	1,200-lb rope pull...	-	-	27,600	1,400	29,000
01121	Scraper hoist.......	30	2-drum, 2,000-lb rope pull.	-	-	120,000	6,000	126,000
01122	Jumbo (stoping).....	12	2 drills, 3-1/2-in pistons, rubber tired.	-	-	232,000	11,600	243,600
01123	Load-haul-dump vehicle.	8	5-cu-yd diesel powered (2 spares).	195	1,170	488,000	-	488,000
01124	Sand fill distribution pipe.	23,000 ft	10-in pipe with victaulic couplings.	-	-	256,000	256,000	512,000
01125	Shop tools.........	-	Hoists, welders, general shop tools.	-	-	50,000	-	50,000
	Total direct cost.	-	-	-	-	3,286,900	1,223,100	4,510,000
	Field indirect......	-	-	-	-	-	-	611,600
	Total construction	-	-	-	-	-	-	5,121,600
	Engineering.........	-	-	-	-	-	-	256,100
	Administration and overhead.	-	-	-	-	-	-	256,100
	Subtotal..........	-	-	-	-	-	-	5,633,800
	Contingency.........	-	-	-	-	-	-	563,400
	Subtotal..........	-	-	-	-	-	-	6,197,200
	Fee................	-	-	-	-	-	-	309,900
	Total.............	-	-	-	-	-	-	6,507,100

TABLE B-2. - Surface plant and equipment cost summary, 6,000-tpd underground cut-and-fill mining operation

Item No.	Item	Quantity	Size	Unit hp	Total hp	Total cost
	Ore hoisting shaft					
02100	Excavation and foundation	-	For headframe and hoist installation.......	-	-	$450,000
02101	Headframe................	1	150-ft-high steel..........................	-	-	670,000
02102	Ore bin..................	1	4,000-ton concrete.........................	-	-	219,000
02103	Hoist building...........	1	50 ft by 170 ft with 38-ft eave............	-	-	234,000
02104	Ore hoist................	1	14-ft-diam double drum with motor-generator set and flywheel.	4,000	4,000	950,000
02105	Ore skips and cable......	-	16-ton skips, 2-1/4-in.cable...............	-	-	77,000
02106	Auxiliary hoist, cage, and cable.	1	6-ft by 6-ft by 10-ft counter weighted cage, 1-1/4-in cable.	180	180	139,000
	Service shaft (incline)					
02107	Excavation and foundation	-	For headframe and hoist installation.......	-	-	122,000
02108	Headframe................	1	100-ft-high steel..........................	-	-	182,000
02109	Hoist building...........	1	40 ft by 40 ft with 25-ft eave.............	-	-	51,000
02110	Supply hoist.............	-	8-ft single drum with motor-generator set..	400	400	247,500
02111	Cage and cable...........	-	8 ft by 6 ft by 30 ft, 1-1/4-in cable......	-	-	43,400
02112	Ventilation fan..........	5	5-ft axialvane (1 spare) including housing.	200	800	147,000
02113	Transformer station......	2	7,000 kV-A, 69,000-volt to 2,200-volt, semipermanent building.	-	-	123,000
02114	Switch...................	2	Main disconnect 2,200 volts................	-	-	12,000
02115	Distribution wire........	4,000 ft	Overhead line size 1-0 wire................	-	-	4,000
02116	...........do............	24,000 ft	Overhead line size 4 wire..................	-	-	10,800
02117	Poles....................	24	For distribution system....................	-	-	7,200
02118	Accessories for distribution, wire line.	-	Cross arms, insulators, etc., at $3,700 per mile.	-	-	4,900
02119	Standby powerplant.......	1	5,000 kV-A, diesel powered.................	7,000	7,000	244,800
02120	Standby powerplant building.	1	40 ft by 80 ft with 20-ft eave including 25-ton bridge crane at $18 per sq ft.	-	-	57,600
02121	Compressor...............	3	4,500 cfm with motor.......................	700	2,100	231,000
02122	Compressor building......	1	48 ft by 130 ft with 30-ft eave including 25-ton bridge crane at $18 per sq ft.	-	-	112,300
02123	Receiver.................	3	10 ft diam by 20 ft........................	-	-	7,500
02124	Air line.................	3,000 ft	10-in pipe, victaulic couplings............	-	-	42,000
02125	Mine office lamp room and change room.	1	60 ft by 100 ft with 20-ft eave including utilities at $25 per sq ft.	-	-	150,000
02126	Office furniture and equipment.	1	30 ft by 40 ft at $15 per sq ft............	-	-	18,000
02127	Machine shop and equipment repair shop.	1	60 ft by 250 ft with 20-ft eave including utilities at $18 per sq ft.	-	-	270,000
02128	Shop equipment and tools.	-	Includes hoists, welders, and general shop tools.	-	-	100,000
02129	Timber framing shed......	1	30 ft by 60 ft with 15-ft eave including utilities and equipment at $12 per sq ft.	-	-	21,600
02130	Warehouse................	1	50 ft by 80 ft with 10-ft eave including utilities at $12 per sq ft.	-	-	48,000
02131	Explosives magazine......	1	15 ft by 20 ft with 10-ft eave, buried and fenced at $18 per sq ft.	-	-	5,400
02132	Tank for sandfill........	15	10 ft diam by 10 ft with agitator (1 spare)	2	28	33,000
02133	Pump for sandfill........	8	8 in by 6 in, centrifugal, abrasive resistant (1 spare).	300	2,100	95,100
02134	Pipe for sandfill........	20,000 ft	6-in with welded joints (buried)...........	-	-	248,000
02135	Hydrocyclone for sandfill	7	12-in diam.................................	-	-	15,400
02136	Pump.....................	8	5 in by 4 in, centrifugal, abrasive resistant (1 spare).	20	140	28,500
02137	Administration building..	1	40 ft by 40 ft with 10-ft eave including utilities at $28 per sq ft, 1/2 charged to mine.	-	-	22,400
02138	Service vehicle..........	11	Crane, forklift, trucks, dozer, grader, and front-end loader.	-	-	364,000
02139	Utility vehicle..........	12	Eight 1/2-ton pickups, 3 sedans, 1 station wagon.	80	880	36,000
	Subtotal..............	-	-	-	19,028	5,844,400
	Contingency.............	-	-	-	-	584,400
	Total[1]...............	-	-	-	-	6,428,800

[1]The indirect costs of the surface facilities have been allowed for in the estimated capital requirements by increasing the amount allocated to exploration, development, and engineering study.

TABLE B-3. - Development cost summary, 6,000-tpd underground cut-and-fill mining operation

Item	Quantity	Size	Cost		Total cost
			Material	Labor	
Ore hoisting shaft.	1	19-ft diam concrete lined.	$1,660,000	$2,030,000	$3,690,000
Service shaft	1	8 ft by 12 ft concrete lined.	1,015,000	1,465,000	2,480,000
Underground levels.	-	8-ft by 12-ft drifts and crosscuts plus underground shops--total equivalent footage 18,300 ft.	488,000	1,525,000	2,013,000
Pump rooms and sumps.	3	20-ft by 20-ft by 30-ft rooms, 85,000-gal sumps, two 18,000-gal settling sumps.	60,900	132,800	193,700
Preproduction stope preparation.	4	1,320-ft by 18-ft block with 340-ft interval between levels (includes access and ventilation raises, vehicle ramp, and ore chutes).	486,000	1,534,000	2,020,000
Subtotal...	-	-	3,709,900	6,686,800	10,396,700
Contingency..	-	-	-	-	1,039,700
Total[1].....	-	-	-	-	11,436,400

[1]The indirect development costs have been allowed for in the estimated capital requirements by increasing the amount allocated to exploration, development, and engineering study.

TABLE B-4. - Estimated capital requirements, 6,000-tpd underground cut-and-fill mining operation

Unit	Cost
Mine lease-option cost, property acquisition......................	$250,000
Subtotal for depletion......................................	250,000
Exploration, development, and engineering study (facilities which were used for both exploration and ore production are included in mine development)......................................	3,319,300
Mine development and stope preparation............................	11,436,400
Subtotal for deferred expenses...............................	14,755,700
Surface mine plant and equipment..................................	6,428,800
Underground plant and equipment...................................	6,507,100
Subtotal for depreciation, taxes, and insurance..............	12,935,900
Working capital[1]..	3,980,100
Total capital required......................................	31,921,700

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE B-5. - Estimated annual operating cost, 6,000-tpd underground cut-and-fill mining operation

	Annual cost	Total	Cost per ton
Direct cost:			
Materials and utilities:			
Power....3,720 kW-hr/hr × 8,568 hr/yr × $0.007/kW-hr..	$223,100	-	-
Explosives....	663,100	-	-
Drill steel and bits....	666,000	-	-
Wood, steel, cement, and rock bolt roof supports....	835,000	-	-
Diesel fuel....264,000 gal × $0.16/gal..	42,200	-	-
Tires....	60,500	-	-
Rail, trolley, pipe, structural steel....	228,000	-	-
Hoisting cables....	63,400	-	-
Miscellaneous supplies....	67,000	-	-
Subtotal....	-	$2,848,300	$1.330
Direct labor:			
2,484 man-hr/day....$3.85/man-hr × 357 day/yr..	3,414,100	-	-
Supervision....15 percent of labor..	512,100	-	-
Subtotal....	-	3,926,100	1.833
Maintenance (mine openings and equipment):			
812 man-hr/day....$3.90/man-hr × 357 day/yr..	1,130,500	-	-
Supervision....20 percent of labor..	226,100	-	-
Maintenance supplies and parts....	2,138,000	-	-
Subtotal....	-	3,494,600	1.631
Payroll overhead....25 percent of payroll..	-	1,320,700	.617
Total direct cost....	-	11,589,700	5.411
Indirect cost:			
Administrative, technical, and clerical labor....	196,000	-	.091
Payroll overhead....25 percent of administrative payroll..	49,000	-	.023
Surface buildings maintenance and supplies....5 percent of plant facilities..	321,400	-	.150
General overhead includes head office charges, exploration, and research 5 percent of direct costs..	579,500	-	.271
Total indirect cost....	-	1,145,900	.535
Fixed cost:			
Taxes and insurance....2 percent of plant cost..	258,700	-	.121
Depreciation mine plant and equipment....15 years..	783,900	-	.366
Depreciation shorter lived equipment....7.8-year average..	150,900	-	.070
Deferred expenses....15 years..	983,700	-	.459
Amortized future equipment requirements....	72,400	-	.034
Total fixed cost....	-	2,249,600	1.050
Gross operating cost....	-	14,985,200	6.996

25,000-tpd Room-and-Pillar Operation

General

Following is a brief description of a room-and-pillar mining operation having a production rate of 25,000 tpd of ore. Included are tables B-6, B-7, and B-8 which list the required equipment, facilities, and development work. Capital investment and operating costs are summarized in tables B-9 and B-10.

The ore deposit is a series of mineralized narrow sandstone and shale beds containing copper as chalcocite. Their average total stratigraphic thickness is 14 feet and their dip from 0 to 25 degrees. Proven reserves for 15 years of production occupy an area of about 6 square miles. The ground is competent over a width of 20 feet and the hanging wall can be adequately supported by roof bolts set at 5-foot centers. Firmer, more massive sandstone underlies the ore horizon.

Mining

A two-level mining system is used. The main incline is located about 40 feet below the base of the ore zone. Haulage drifts connect with the incline at 1/4-mile intervals as measured along the incline. The incline and drifts are 20 feet wide and 12 feet high, thus providing sufficient room for the conveyor-belt ore-transportation system and equipment roadways. Access points to the ore are established at 1/4-mile intervals along the haulage drifts. A ramp provides vehicle access between the levels.

The production level is developed by a network of drifts and inclines on 1/4-mile centers. The inclines extend down the dip from surface portals. The development drifts overlie the lower haulage drifts. These divide the deposit into 1/4-mile square blocks for mining. Each block has a crusher and ramp. The crusher, a bin, and a feeder installed in a large raise are used to reduce the ore to minus 8-inch size and to transfer it to a conveyor belt in an underlying haulage drift.

Ventilation is maintained by exhaust fans set in the portals of the production-level inclines, which are bratticed to pull air from the lower level through the active mine faces. Underground shops, pump stations, drainage lines, and utility lines are located on the lower level.

Mining procedure is to divide the 1/4-mile square blocks into 200-foot sections which are mined successively starting at the up-dip side of the block. Rooms 20 feet wide with intervening 20-foot pillars are advanced and connected to previous workings. On the retreat, pillars are reduced one-half by mining 20-foot windows, leaving permanent 20- by 20-foot pillars. Thus, final recovery is approximately 75 percent.

Development and stope drilling is done with self-contained drill jumbos using portable electric air compressors; each jumbo has two 3.5-inch Leyner drills having a 14-foot travel. Holes are drilled with 3.0-foot burden. Penetration rate is 3.0 feet per minute for 2-inch-diameter holes. Tungsten carbide bit life is 400 feet and drill rod life 730 feet. Explosive consumption is 0.76 pound AN-FO per ton of rock broken. Stoper drills are used for roof bolting with 6-foot bolts being installed at a rate of 35 per machine-shift. Broken ore is loaded and trammed with 5-cubic-yard diesel-powered load-haul-dump vehicles at a rate of 74 tph over an average haulage distance of 1,500 feet.

TABLE B-6. - Underground plant and equipment cost summary, 25,000-tpd underground room-and-pillar mining operation

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost: Material	Cost: Labor	Total cost
01100	Pump	10	Vertical 8-stage, 13-1/4-in bowl (1 spare).	600	5,400	$181,700	$18,200	$199,900
01101	Drainage line	2	16,000-ft, 10-in line victaulic couplings.	-	-	357,500	35,800	393,300
01102	Drill and culinary waterline	16,000 ft	6-in pipe with victaulic couplings	-	-	69,000	6,900	75,900
01103	do	30,000 ft	4-in pipe with victaulic couplings	-	-	93,600	9,400	103,000
01104	Electrical transmission cable.	49,800 ft	3 conductor extra heavy insulation size 1-0 wire.	-	-	199,000	19,900	218,900
01105	Transformer	10	1,500 kV-A 4,160 volt	-	-	60,000	6,000	66,000
01106	Fan	9	5-ft axialvane (1 spare)	200	1,600	164,500	16,500	181,000
01107	Blower	24	In workings (4 spares)	15	300	19,200	1,900	21,100
01108	Grizzly	4	40 ft by 10 ft, 5-1/2 to 6-1/2 in tapered openings.	-	-	17,600	2,800	20,400
01109	Pan feeder	4	48 in by 50 ft	40	160	105,600	16,900	122,500
01110	Jaw crusher	4	30 in by 42 in	-	-	312,000	49,900	361,900
01111	Crusher motor	4	-	100	400	33,000	5,300	38,300
01112	Belt feeder	4	30 in by 30 ft	5	20	70,400	11,300	81,700
01113	Belt conveyor	12	48 in by 1,320 ft on +10° slope	500	6,000	2,328,000	372,500	2,700,500
01114	do	6	48 in by 1,320 ft on 0° slope	200	1,200	876,000	140,200	1,016,200
01115	Telephone	1	Throughout mine and surface	10	10	15,000	15,000	30,000
01116	Public address	1	In principal working places	10	10	20,000	20,000	40,000
01117	Drill jumbo	30	With two 3-1/2-in drills, 14-ft feed (4 spares).	-	-	840,000	-	840,000
01118	Stoper	20	31-in feed, 79 lb (4 spares)	-	-	26,400	-	26,400
01119	Load-haul-dump vehicle	30	5 cu yd, diesel powered (5 spares)	195	4,875	1,830,000	-	1,830,000
01120	Compressor	30	600 cfm, electric powered (4 spares)	150	3,900	660,000	-	660,000
01121	do	14	250 cfm, electric powered (4 spares)	75	750	173,600	-	173,600
01122	Bulldozer	7	13,700-lb draw bar pull, diesel powered (1 spare).	65	390	140,000	-	140,000
01123	Shop tools	-	Hoists, welders, general shop tools.	-	-	100,000	-	100,000
	Total direct cost	-	-	-	-	8,692,100	748,500	9,440,600
	Field indirect	-	-	-	-	-	-	374,300
	Total construction	-	-	-	-	-	-	9,814,900
	Engineering	-	-	-	-	-	-	490,700
	Administration and overhead	-	-	-	-	-	-	490,700
	Subtotal	-	-	-	-	-	-	10,796,300
	Contingency	-	-	-	-	-	-	1,079,600
	Subtotal	-	-	-	-	-	-	11,875,900
	Fee	-	-	-	-	-	-	593,800
	Total	-	-	-	-	-	-	12,469,700

TABLE B-7. - Surface plant and equipment cost summary, 25,000-tpd underground room-and-pillar mining operation

Item No.	Item	Quantity	Size	Unit hp	Total hp	Total cost
02100	Transformer station.	1	15,000 kV-A, 69,000-volt to 4,160-volt semipermanent building.	-	-	$66,500
02101	Switch............	1	Main disconnect 4,160 volt............	-	-	6,000
02102	Distribution wire.	60,000 ft	Overhead line size 1-0 wire...........	-	-	60,000
02103	........do........	10,000 ft	Overhead line size 4 wire.............	-	-	4,500
02104	Transformer.......	2	1,500 kV-A, 4,160 volt to 440 volt....	-	-	13,200
02105	Poles.............	62	For distribution system...............	-	-	18,600
02106	Accessories for distribution wire line.	-	Cross arms insulators, etc., at $3,700 per mile.	-	-	13,000
02107	Standby powerplant	1	5,000 kV-A, diesel powered............	7,000	7,000	244,800
02108	Standby powerplant building.	-	40 ft by 80 ft with 30-ft eave including 25-ton bridge crane and utilities at $18 per sq ft.	-	-	57,600
02109	Mine and engineering office building.	1	80 ft by 100 ft with 10-ft eave including utilities at $25 per sq ft.	-	-	200,000
02110	Office furniture and equipment.	1	80 ft by 100 ft at $15 per sq ft......	-	-	120,000
02111	Changehouse and lamp room.	1	65 ft by 250 ft with 25-ft eave including utilities and furnishings at $25 per sq ft.	-	-	406,300
02112	Machine shop......	1	60 ft by 160 ft with 30-ft eave including 25- and 15-ton bridge cranes and utilities at $18 per sq ft.	-	-	172,800
02113	Shop equipment and tools.	1	Includes hoists, welders, compressor, and general shop tools.	-	-	120,000
02114	Drill repair shop.	1	25 ft by 40 ft with 10-ft eave including equipment and utilities at $18 per sq ft.	-	-	18,000
02115	Blacksmith shop...	1	40 ft by 45 ft with 20-ft eave including equipment and utilities at $18 per sq ft.	-	-	32,400
02116	Vehicle repair shop.	1	60 ft by 210 ft with 30-ft eave including equipment at $22 per sq ft.	-	-	277,200
02117	Electric equipment repair shop.	1	70 ft by 220 ft with 20-ft eave including equipment at $18 per sq ft.	-	-	277,200
02118	Carpenter shop....	1	40 ft by 50 ft with 20-ft eave including equipment at $18 per sq ft.	-	-	36,000
02119	Tool shed.........	1	30-ft by 60-ft shed with 15-ft eave including equipment at $12 per sq ft.	-	-	21,600
02120	Warehouse.........	1	60 ft by 110 ft with 10-ft eave at $12 per sq ft.	-	-	79,200
02121	Ammonium nitrate storage.	1	30 ft by 50 ft with 10-ft eave buried and fenced at $18 per sq ft.	-	-	27,000
02122	Dynamite magazine.	1	30 ft by 50 ft with 10-ft eave buried and fenced at $18 per sq ft.	-	-	27,000
02123	Service vehicle...	20	Cranes, forklifts, trucks, dozer, grader, and front-end loader.	-	-	610,000
02124	Utility vehicle...	24	Twenty 1/2-ton pickups, 3 sedans, 1 station wagon.	-	-	76,000
	Subtotal.......	-	-	-	-	2,984,900
	Contingency.......	-	-	-	-	298,500
	Total[1]........	-	-	-	-	3,283,400

[1]The indirect costs of the surface facilities have been allowed for in the estimated capital requirements by increasing the amount allocated to exploration, development, and engineering study.

TABLE B-8. - Development cost summary, 25,000-tpd underground room-and-pillar mining operation[1]

Item	Quantity	Size	Cost		Total cost
			Material	Labor	
Haulage level incline.	16,000 ft	12-ft by 20-ft incline for conveyor haulage and vehicle access.	$498,000	$1,546,100	$2,044,100
Haulage level drifts and ramps to ore level.	8,300 ft	12-ft by 20-ft drifts for conveyor haulage and vehicle access.	215,300	668,300	883,600
Underground shops, pump rooms, sumps, etc.	-	Shops 2,000 tons, transformer station 1,500 tons, pump rooms 6,000 tons, sumps 32,000 tons.	64,600	200,800	265,400
Crusher rooms.....	4	26,000 tons, total excavation.	40,500	125,800	166,300
Ore level workings	21,120 ft	14-ft by 20-ft drifts in ore to develop 4 blocks 1/4 mile by 1/4 mile (will produce 492,800 tons of ore).	767,600	2,383,500	3,151,100
Subtotal.....	-	-	1,586,000	4,924,500	6,510,500
Contingency.......	-	-	-	-	651,100
Total[2].......	-	-	-	-	7,161,600

[1]Includes all of main haulage incline, pump rooms, and sumps but only portion of haulage drifts and ore level needed to reach 25,000-tpd production rate. Further development to be done as required and classified as expense.

[2]The indirect development costs have been allowed for in the estimated capital requirements by increasing the amount allowed to exploration, development, and engineering study.

TABLE B-9. - Estimated capital requirements, 25,000-tpd underground room-and-pillar mining operation

Unit	Cost
Mine lease-option cost, property acquisition......................	$700,000
Subtotal for depletion..	700,000
Exploration, development, and engineering study (facilities which were used for both exploration and subsequent ore production are included in mine development).....................	5,672,800
Mine development and stope preparation............................	7,161,600
Subtotal for deferred expenses................................	12,834,400
Surface mine plant and equipment..................................	3,283,400
Underground plant and equipment...................................	12,469,700
Subtotal for depreciation, taxes, and insurance..............	15,753,100
Working capital[1]..	8,575,300
Total investment..	37,862,800

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE B-10. - Estimated annual operating cost, 25,000-tpd underground room-and-pillar mining operation

	Annual cost	Total	Cost per ton
Direct cost:			
Materials and utilities:			
Power........8,030 kW-hr/hr x 8,568 hr/yr x $0.007/kW-hr..	$481,600	-	-
Explosives........	1,485,200	-	-
Drill steel and bits........	1,294,900	-	-
Timber and rock bolt roof supports........	990,100	-	-
Diesel fuel........872,500 gal x $0.16/gal..	139,600	-	-
Tires........	208,500	-	-
Conveyor belting........	421,900	-	-
Miscellaneous supplies........	250,000	-	-
Subtotal........	-	$5,271,800	$0.591
Direct labor:			
3,480 man-hr/day........$3.85/man-hr x 357 day/yr..	4,783,100	-	-
Supervision........15 percent of labor..	717,500	-	-
Subtotal........	-	5,500,600	.616
Maintenance (mine openings and equipment):			
2,256 man-hr/day........$3.90/man-hr x 357 day/yr..	3,141,000	-	-
Supervision........20 percent of labor..	628,200	-	-
Maintenance supplies and parts........	7,207,200	-	-
Subtotal........	-	10,976,400	1.230
Payroll overhead........25 percent of payroll..	-	2,317,400	.260
Total direct cost........	-	24,066,200	2.697
Indirect cost:			
Administrative, technical, and clerical labor........	750,000	-	.084
Payroll overhead........25 percent of administrative payroll..	187,500	-	.021
Surface facilities maintenance and supplies...5 percent of plant facilities..	164,200	-	.018
General overhead includes head office charges, exploration, and research 5 percent of direct costs..	1,203,300	-	.135
Total indirect cost........	-	2,305,000	.258
Fixed cost:			
Taxes and insurance........2 percent of plant cost..	315,100	-	.035
Depreciation mine plant and equipment........15 years..	733,000	-	.082
Depreciation shorter lived equipment........9.1-year average..	522,900	-	.059
Deferred expenses........15 years..	855,600	-	.096
Amortized future equipment requirements........	205,700	-	.023
Total fixed cost........	-	2,632,300	.295
Gross operating cost........	-	29,003,500	3.250

30,000-tpd Block-Caving Operation

General

Following is a brief description of a block-cave mining operation having a production rate of 30,000 tpd of ore. Included are tables B-11, B-12, and B-13 which list the required equipment, facilities, and development work. Capital investment and operating costs are summarized in tables B-14 and B-15.

The segment of the ore body evaluated in this study is about 3,000 feet long, 1,000 feet wide, and 700 feet thick, and contains adequate ore for 15 years of production. The remainder of the deposit contains much larger reserves. Copper content is 0.78 percent and occurs as chalcopyrite disseminated in altered quartz monzonite. The ore is relatively soft and is closely fractured. It caves easily when undercut and crushes to small fragments while caving to the drawpoints. Artificial support is needed to maintain all mine openings.

Mining

A conventional undercut block-caving method with gravity ore collection is used. All production is from a single level 1,400 feet below the surface. This production level consists of a grizzly level located approximately 60 feet above a haulage level. Drifts on the grizzly level also connect the workings to the shaft and are used for access and for supply handling. Ventilation air is circulated between two special ventilation shafts and the two ore-hoisting shafts. About 3,000 gpm of drain water are pumped from the mine. Broken ore is pulled from the undercut through finger raises and grizzlies into transfer raises which empty on the haulage level. The average production rate for ore pulling and secondary blasting is 266 tons per man-shift. Twenty-three-ton trolley motors and 15-ton ore cars are used to haul ore to the shaft pockets where they are dumped with a rotary car dumper. Twenty-ton skips are used for hoisting. The ore hauling and hoisting rate is 243 tons per man-shift.

Mainline haulageways are driven with conventional drill jumbos, rocker shovels, and battery locomotives. About 93 percent of the haulageways are supported by 12- by 12-inch timber and about 7 percent by steel and concrete. Ninety-pound rail is used for permanent track. The rate of advance for completed 11- by 12-foot drift is about 1.0 foot per man-shift.

Raises and drifts required for ore gathering and undercutting are driven with hand-held drills and electric-powered scrapers. Heavy steel and concrete ground support is needed for the raises and grizzly drifts. Light timber is used for temporary ground support while making the undercut. Preparation of a typical 100- by 160-foot block requires about 2,000 man-shifts of face labor and about 1,400 man-shifts of maintenance, support, and supervisory labor.

TABLE B-11. - Underground plant and equipment cost summary, 30,000-tpd underground block-cave mining operation

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost		Total cost
						Material	Labor	
01100	Pump (drainage).....	4	Vertical 8-stage 13-1/4-in bowl (1 spare).	600	1,800	$73,000	$7,300	$80,300
01101	Drainage lines......	4,800 ft	10-in pipe with victaulic couplings.	-	-	53,500	53,500	107,000
01102	Pump (culinary water).	2	Vertical 9-stage 12-in bowl (1 spare).	-	-	11,600	1,200	12,800
01103	Storage tank (culinary water).	1	20,000 gal...........	-	-	9,400	3,700	13,100
01104	Chlorinator (culinary water).	1	Complete unit........	-	-	1,300	200	1,500
01105	Pump line (culinary water).	1,600 ft	6-in pipe with victaulic couplings.	-	-	6,900	6,900	13,800
01106	Compressed air line.	19,000 ft	10-in pipe with victaulic couplings.	-	-	221,400	221,400	442,800
01107	.........do.........	12,000 ft	4-in pipe with victaulic couplings.	-	-	37,400	37,400	74,800
01108	Drill and culinary..	31,000 ft	4-in pipe with victaulic couplings.	-	-	96,700	96,700	193,400
01109	Fan.................	2	5-ft axialvane........	200	400	41,100	4,100	45,200
01110	Blowers.............	50	In workings (10 spares).	15	600	40,000	4,000	44,000
01111	Electric distribution system.	-	Cables, transformers, etc.	-	-	824,400	618,600	1,443,000
01112	Telephone...........	-	Throughout mine and surface.	10	10	15,000	15,000	30,000
01113	Public address......	-	In principal working places.	10	10	20,000	20,000	40,000
01114	Radio phone.........	-	On moving vehicles...	10	10	86,600	43,400	130,000
01115	Ore haulage locomotive.	9	23-ton, 275-volt dc trolley type.	-	-	479,000	24,000	503,000
01116	Ore car.............	135	15-ton box type......	-	-	1,000,000	50,000	1,050,000
01117	Supply truck........	45	Flat trucks..........	-	-	59,000	3,000	62,000
01118	Trolley power source	4	Rectifier type.......	670	2,700	370,000	74,000	444,000
01119	Rotary tipple.......	2	Three 15-ton car.....	40	80	126,200	12,300	138,500
01120	Development locomotive.	8	8-ton, battery type..	-	-	244,000	12,200	256,200
01121	Mine car............	90	5-ton, A-bottom......	-	-	241,200	12,000	253,200
01122	Battery charger.....	2	Rectifier type.......	670	1,340	185,000	37,000	222,000
01123	Drill jumbo.........	8	4 drills with 3-1/2-in pistons.	-	-	305,600	15,300	320,900
01124	Loading machine.....	8	Overshot type, air power.	-	-	174,400	8,700	183,100
01125	Concrete placing equipment.	6	Complete units.......	-	-	600,000	30,000	630,000
01126	Stoper..............	32	31-in feed, 79 lb....	-	-	42,300	-	42,300
01127	Jackdrill with feedleg.	28	72-in feed travel, 113 lb.	-	-	49,700	-	49,700
01128	Hoist...............	12	1,200-lb rope pull...	-	-	23,700	1,200	24,900
01129	Scraper hoist.......	4	2-drum, 2,000-lb rope pull.	-	-	16,000	800	16,800
	Total direct cost.	-	-	-	-	5,454,400	1,413,900	6,868,300
	Field indirect......	-	-	-	-	-	-	707,000
	Total construction	-	-	-	-	-	-	7,575,300
	Engineering.........	-	-	-	-	-	-	378,800
	Administration and overhead.	-	-	-	-	-	-	378,800
	Subtotal..........	-	-	-	-	-	-	8,332,900
	Contingency.........	-	-	-	-	-	-	833,300
	Subtotal..........	-	-	-	-	-	-	9,166,200
	Fee.................	-	-	-	-	-	-	458,300
	Total.............	-	-	-	-	-	-	9,624,500

TABLE B-12. - Surface plant and equipment cost summary, 30,000-tpd underground block-cave mining operation

Item No.	Item	Quantity	Size	Unit hp	Total hp	Total cost
	Ore hoisting shaft (2)					
02100	Excavation and foundation.....	2	For headframe and hoist installation...........	-	-	$1,154,000
02101	Headframe....................	2	178-ft-high steel..............................	-	-	1,716,000
02102	Ore bin......................	2	5,000-ton concrete.............................	-	-	500,000
02103	Hoist building...............	1	60 ft by 270 ft with 45-ft eave................	-	-	382,800
02104	Ore hoist....................	2	15-ft-diam double drum with motor-generator set and flywheel.	6,000	12,000	2,420,000
02105	Ore skips and cable..........	4	20-ton skips, 2-1/2-in cable...................	-	-	167,600
02106	Auxiliary hoist, cage, and cable.	2	7-ft 10-in by 7-ft 10-in by 10-ft 0-in counter weighted cage, 1-1/4-in cable.	250	500	388,600
	Supply shaft					
02107	Excavation and foundation.....	1	For headframe and hoist installation...........	-	-	475,000
02108	Headframe....................	1	178-ft-high steel..............................	-	-	858,000
02109	Ore bin......................	1	400-ton concrete...............................	-	-	135,000
02110	Hoist building...............	1	40 ft by 90 ft with 30-ft eave.................	-	-	93,500
02111	Supply hoist.................	1	15-ft-diam double drum with motor-generator set.	1,750	1,750	506,000
02112	Cage and cable...............	2	14-ft by 8-ft by 20-ft cage, 2-1/2-in cable.....	-	-	55,600
	Ventilation shaft (2)					
02113	Excavation and foundation.....	2	For headframe and hoist installation...........	-	-	358,000
02114	Headframe....................	2	125-ft-high steel..............................	-	-	616,000
02115	Ore bin......................	2	400-ton concrete...............................	-	-	270,000
02116	Hoist building...............	2	30 ft by 60 ft with 20-ft eave.................	-	-	50,600
02117	Hoist cage and cable..........	2	7-ft 10-in by 7-ft 10-in by 10-ft 0-in cage, 1-1/4-in cable.	250	500	388,600
02118	Ventilation fan..............	3	5-ft axialvane (1 spare).......................	200	400	88,200
02119	Transformer station..........	3	7,000 kV-A, 69,000-volt to 2,200-volt, semi-permanent building.	-	-	184,500
02120	Switch.......................	3	Main disconnect 2,200 volts....................	-	-	18,000
02121	Distribution wire............	4,000 ft	Overhead line size 1-0 wire....................	-	-	4,000
02122	..............do.............	24,000 ft	Overhead line size 4 wire......................	-	-	10,800
02123	Poles........................	24	For distribution system........................	-	-	7,200
02124	Accessories for distribution, wire line.	-	Cross arms, insulators, etc., at $3,700 per mile	-	-	4,900
02125	Standby powerplant...........	1	5,000 kV-A, diesel powered.....................	7,000	7,000	244,800
02126	Standby powerplant building...	1	40 ft by 80 ft with 20-ft eave, including 25-ton bridge crane at $18 per sq ft.	-	-	57,600
02127	Compressor...................	4	4,500 cfm with motor...........................	700	2,800	307,900
02128	Compressor building..........	1	48 ft by 162 ft with 30-ft eave, including 25-ton bridge crane at $18 per sq ft.	-	-	140,000
02129	Receiver.....................	4	10 ft diam by 20 ft............................	-	-	10,000
02130	Air line.....................	10,000 ft	10-in pipe, victaulic couplings................	-	-	140,000
02131	Mine and engineering office building.	1	80 ft by 100 ft with 10-ft eave, including utilities at $25 per sq ft.	-	-	200,000
02132	Office furniture and equipment	1	80 ft by 100 ft at $15 per sq ft...............	-	-	120,000
02133	Changehouse, lamp room, and first-aid building.	1	60 ft by 250 ft with 25-ft eave, including utilities and furnishings at $25 per sq ft.	-	-	375,000
02134	Machine shop.................	1	100 ft by 160 ft with 30-ft eave, including 25- and 15-ton bridge cranes at $18 per sq ft.	-	-	288,000
02135	Shop equipment and tools......	1	Includes hoists, welders, and general shop tools	-	-	100,000
02136	Drill repair shop............	1	25 ft by 35 ft with 10-ft eave, including equipment at $18 per sq ft.	-	-	15,800
02137	Blacksmith shop..............	1	30 ft by 50 ft with 20-ft eave, including equipment at $18 per sq ft.	-	-	27,000
02138	Truck repair shop............	1	40 ft by 40 ft with 30-ft eave, including equipment at $22 per sq ft.	-	-	35,200
02139	Electrical equipment repair shop.	1	60 ft by 80 ft with 20-ft eave, including equipment at $18 per sq ft.	-	-	86,400
02140	Carpenter and paint shop......	1	40 ft by 50 ft with 20-ft eave, including equipment at $18 per sq ft.	-	-	36,000
02141	Timber framing shed...........	1	40-ft by 90-ft shed with 15-ft eave, including equipment at $12 per sq ft.	-	-	43,200
02142	Timber treatment plant........	1	30-ft by 75-ft shed with 20-ft eave, including equipment at $60 per sq ft.	-	-	135,000
02143	Warehouse....................	1	60 ft by 110 ft with 10-ft eave, at $12 per sq ft.	-	-	79,200
02144	Powder magazine..............	1	30 ft by 50 ft with 10-ft eave, buried and fenced at $18 per sq ft.	-	-	27,000
02145	Concrete mixer...............	2	1-1/4-cu-yd paver..............................	100	200	70,000
02146	Batch truck..................	3	8-cu-yd rear dump..............................	200	600	45,000
02147	Transporting hole............	1	1,400 ft of 10-in rotary hole..................	-	-	3,000
02148	Pipe.........................	1,400 ft	8-in casing plus fittings......................	-	-	20,000
02149	Service vehicle..............	20	Cranes, forklifts, trucks, dozer, grader, and front-end loader.	-	-	610,000
02150	Utility vehicle..............	24	Twenty 1/2-ton pickups, 3 sedans, 1 station wagon	-	-	76,000
	Subtotal................	-	-	-	-	14,145,000
	Contingency..................	-	-	-	-	1,414,500
	Total..................	-	-	-	-	15,559,500

TABLE B-13. - Development cost summary, 30,000-tpd underground block-cave mining operation

Item	Quantity	Size	Cost		Total cost
			Material	Labor	
Ore hoisting shaft.	2	24-ft diam concrete lined.	$1,878,600	$2,292,700	$4,171,300
Supply shaft.	1	..........do...........	773,500	950,800	1,724,300
Ventilation shaft.	2	16-ft diam concrete lined.	813,200	1,303,400	2,116,600
Underground levels.	-	11-ft by 12-ft drifts and crosscuts plus underground shops--total equivalent footage 52,000 ft.	3,501,200	7,060,900	10,562,100
Ventilation stations.	2	20-ft by 20-ft by 12-ft rooms and 100 ft of 11-ft by 12-ft drift, and doors.	19,800	41,500	61,300
Pump rooms and sumps.	2	20-ft by 20-ft by 30-ft rooms, 85,000-gal sumps, two 18,000-gal settling sumps.	40,600	88,500	129,100
Culinary water development.	-	2,000-ft drilling, 20-ft by 15-ft by 20-ft pump room, 25,000-gal sump.	15,700	32,900	48,600
Preproduction stope preparation.	16	90-ft by 160-ft blocks with 600-ft back.	2,304,000	2,166,400	4,470,400
Subtotal...	-	-	9,346,600	13,937,100	23,283,700
Contingency..	-	-	-	-	2,328,400
Total......	-	-	-	-	25,612,100

TABLE B-14. - Estimated capital requirements, 30,000-tpd underground block-cave mining operation

Unit	Cost
Mine lease-option cost, property acquisition.....................	$500,000
Subtotal for depletion...	500,000
Exploration, development, and engineering study (facilities which were used for both exploration and subsequent ore production are included in mine development)....................	4,878,100
Mine development and stope preparation.........................	25,612,100
Subtotal for deferred expenses..............................	30,490,200
Surface mine plant and equipment................................	15,559,500
Underground plant and equipment................................	9,624,500
Subtotal for depreciation, taxes, and insurance..............	25,184,000
Working capital[1]...	6,708,700
Total capital required..	62,882,900

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE B-15. - Estimated annual operating cost, 30,000-tpd underground block-cave mining operation

	Annual cost	Total	Cost per ton
Direct cost:			
Materials and utilities:			
Power......................5,740 kW-hr/hr X 8,568 hr/yr X $0.007/kW-hr..	$344,300	-	-
Explosives..	405,900	-	-
Drill steel and bits..	151,700	-	-
Wood, steel, and rock bolt roof supports..................................	719,000	-	-
Cement, sand, and gravel..	322,500	-	-
Rail, trolley, pipe, structural steel..................................	408,300	-	-
Hoisting cables..	75,000	-	-
Miscellaneous supplies..	30,000	-	-
Subtotal..	-	$2,456,700	$0.229
Direct labor:			
3,256 man-hr/day..............................$3.85/man-hr x 357 day/yr..	4,475,200	-	-
Supervision.......................................15 percent of labor..	671,300	-	-
Subtotal..	-	5,146,500	.481
Maintenance (mine openings and equipment):			
2,854 man-hr/day..............................$3.90/man-hr X 357 day/yr..	3,973,600	-	-
Supervision.......................................20 percent of labor..	794,700	-	-
Maintenance supplies and parts..	4,840,000	-	-
Subtotal..	-	9,608,300	.897
Payroll overhead..................................25 percent of payroll..	-	2,478,700	.231
Total direct cost..	-	19,690,200	1.838
Indirect cost:			
Administrative, technical, and clerical labor..................................	560,000	-	.052
Payroll overhead......................25 percent of administrative payroll..	140,000	-	.013
Surface facilities maintenance and supplies...5 percent of plant facilities..	495,000	-	.046
General overhead includes head office charges, exploration, and research 5 percent of direct costs..	984,500	-	.092
Total indirect cost..	-	2,179,500	.204
Fixed cost:			
Taxes and insurance................................2 percent of plant cost..	503,700	-	.047
Depreciation mine plant and equipment.............................15 years..	1,564,400	-	.146
Depreciation shorter lived equipment.....................7.8-year average..	220,300	-	.020
Deferred expenses..15 years..	2,032,700	-	.190
Amortized future equipment requirements..................................	105,700	-	.010
Total fixed cost..	-	4,426,800	.413
Gross operating cost..	-	26,296,500	2.455

APPENDIX C.--COST ANALYSIS OF COPPER CONCENTRATORS

Copper sulfide concentrators with designed production capacities of 5,000, 6,000, 15,000, 23,000, 40,000, and 72,000 tpd were costed for the study. All the concentrators employ similar process flowsheets with minor variations. The major differences are in the 5,000-tpd concentrator, which does not have a molybdenum recovery circuit, and the 6,000-tpd concentrator, which was designed to process native copper ore. Detailed equipment lists were prepared for each operation so as to provide a basis for the estimation of the capital investments. However, to avoid repetition, the equipment lists and flow diagrams for only the 15,000-tpd concentrator are included in this publication. Tables containing a summary of capital investment, operating costs, and utility requirements are included for each of the six concentrators.

Data pertaining to each of the concentrators follow.

5,000-tpd Concentrator

A summary of the capital investment for a 5,000-tpd concentrator is listed in table C-1. Operating costs are summarized in table C-2, and C-3 contains an estimate of the plant utility requirements.

These costs are based on a flow diagram similar to that shown for the 15,000-tpd concentrator in this appendix. There are minor differences in the arrangement of the materials-handling system and general plant arrangement. The major difference is that the 5,000-tpd concentrator does not have a byproduct molybdenum recovery circuit.

TABLE C-1. - Estimated capital requirements, 5,000-tpd copper concentrator

Unit	Cost
Crushing section:	
Primary crushing	$2,490,900
Secondary and tertiary crushing	2,292,200
Grinding section	3,026,700
Flotation section	1,545,000
Copper filter section	331,200
Lime preparation section	207,600
Tailings disposal section	1,574,500
Subtotal	11,468,100
General facilities and utilities	1,146,800
Subtotal for depreciation, taxes, and insurance	12,614,900
Working capital[1]	797,100
Total capital required	13,412,000

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE C-2. - Estimated annual operating cost, 5,000-tpd copper concentrator

	Annual cost	Total	Cost per ton
Direct cost:			
Materials and utilities:			
Power.......................3,990 kW-hr/hr x 8,568 hr/yr x $0.007/kW-hr..	$239,300	-	-
Natural gas.......................3 Mscf/hr x 8,568 hr/yr x $0.43/Mscf..	11,100	-	-
Balls and grinding and crushing surfaces at $0.1530/ton x 5,000 tpd x 357 day/yr..........	273,100	-	-
Reagents..........	171,400	-	-
Miscellaneous operating supplies..................7.5 percent of power..	17,900	-	-
Subtotal..........	-	$712,800	$0.399
Direct labor:			
260 man-hr/day..............................$3.46/man-hr x 357 day/yr..	321,200	-	-
Supervision..15 percent of labor..	48,200	-	-
Subtotal..........	-	369,400	.207
Maintenance:			
Labor.......................300 man-hr/day--$3.65/man-hr x 357 day/yr..	390,900	-	-
Supervision..20 percent of labor..	78,200	-	-
Maintenance supplies and parts..........	390,900	-	-
Subtotal..........	-	860,000	.482
Payroll overhead..................................25 percent of payroll..	-	209,600	.117
Total direct cost..........	-	2,151,800	1.205
Indirect cost:			
Administrative, technical, and clerical labor..........	148,000	-	.083
Payroll overhead.....................25 percent of administrative payroll..	37,000	-	.021
Facilities maintenance and supplies..........5 percent of plant facilities..	63,300	-	.035
General overhead includes head office charges, and research 5 percent of direct costs..	107,600	-	.060
Total indirect cost..........	-	355,900	.199
Fixed cost:			
Taxes and insurance.............................2 percent of plant cost..	278,400	-	.156
Depreciation..15 years..	841,000	-	.471
Total fixed cost..........	-	1,119,400	.627
Gross operating cost..........	-	3,627,100	2.031

TABLE C-3. - Plant utility requirements, 5,000-tpd copper concentrator

Unit	Power, kW-hr/hr	New water (from own wells), gpm	Recirculated water, gpm	Natural gas, Mscf/hr
Crushing section..........	930	-	30	-
Concentrator..............	2,720	800	2,800	-
Lime preparation section..	20	20	-	-
Subtotal.............	3,670	820	2,830	0
Lighting and cranes.......	30	-	-	-
Fresh water...............	100	-	-	-
Recirculated water........	50	-	-	-
Sanitary water............	30	-	-	-
General facilities........	60	50	-	3
Miscellaneous and contingency.............	50	100	-	-
Subtotal.............	320	150	0	3
Total................	3,990	970	2,830	3

6,000-tpd Concentrator

A summary of the estimated capital investment required for a 6,000-tpd copper concentrator is listed in table C-4. Table C-5 contains the summary of operating costs and table C-6 lists the utility requirements for the plant.

This concentrator is designed to process native copper ores and therefore contains a jigging circuit. This is the primary difference from the 15,000-tpd concentrator.

TABLE C-4. - Estimated capital requirements, 6,000-tpd copper concentrator, native copper conglomerate ore

Unit	Cost
Crushing section:	
Primary crushing..	$1,370,700
Secondary and tertiary crushing.................................	2,503,600
Jigging section...	6,514,900
Grinding section..	3,165,900
Flotation section...	1,021,000
Lime preparation section..	352,500
Tailings disposal section...	1,497,600
Subtotal..	16,426,200
General facilities and utilities....................................	1,642,600
Subtotal for depreciation, taxes, and insurance.............	18,068,800
Working capital[1]...	973,800
Total capital required..	19,042,600

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE C-5. - Estimated annual operating cost, 6,000-tpd copper concentrator, native copper conglomerate ore

	Annual cost	Total	Cost per ton
Direct cost:			
Materials and utilities:			
Power..5,290 kW-hr/hr X 8,568 hr/yr X $0.009/kW-hr..	$407,900	-	-
Natural gas..5 Mscf/hr X 8,568 hr/yr X $0.70/Mscf..	30,000	-	-
Rods, balls, mill liners, and crushing surfaces at $0.3700/ton X 6,000 tpd X 357 day/yr.............	792,500	-	-
Reagents..	114,000	-	-
Miscellaneous operating supplies..................	7,300	-	-
Subtotal...................................	-	$1,351,700	$0.631
Direct labor:			
274 man-hr/day..........$3.46/man-hr X 357 day/yr..	338,500	-	-
Supervision..................15 percent of labor..	50,800	-	-
Subtotal...................................	-	389,300	.182
Maintenance:			
Labor...234 man-hr/day--$3.65/man-hr X 357 day/yr..	304,900	-	-
Supervision..................20 percent of labor..	61,000	-	-
Maintenance supplies and parts....................	304,900	-	-
Subtotal...................................	-	670,800	.313
Payroll overhead..............25 percent of payroll..	-	188,800	.088
Total direct cost..........................	-	2,600,600	1.214
Indirect cost:			
Administrative, technical, and clerical labor........	89,000	-	.042
Payroll overhead 25 percent of administrative payroll..	22,300	-	.010
Facilities maintenance and supplies 5 percent of plant facilities..	87,000	-	.040
General overhead includes head office charges, and research............5 percent of direct costs..	130,000	-	.061
Total indirect cost........................	-	328,300	.153
Fixed cost:			
Taxes and insurance.........2 percent of plant cost..	382,800	-	.179
Depreciation............................15 years..	1,204,600	-	.562
Total fixed cost...........................	-	1,587,400	.741
Gross operating cost.......................	-	4,516,300	2.108

TABLE C-6. - Plant utility requirements, 6,000-tpd copper concentrator, native copper conglomerate ore

Unit	Power, kW-hr/hr	New water (from own wells), gpm	Recirculated water, gpm	Natural gas, Mscf/hr
Crushing section................	800	-	50	-
Concentrator....................	3,730	1,950	1,950	-
Lime preparation section........	50	50	-	-
Subtotal..................	4,580	2,000	2,000	0
Lighting and cranes.............	50	-	-	-
Fresh water.....................	250	-	-	-
Recirculated water..............	160	-	-	-
Sanitary water..................	50	-	-	-
General facilities..............	100	300	-	5
Miscellaneous and contingency...	100	300	-	-
Subtotal..................	710	600	0	5
Total.....................	5,290	2,600	2,000	5

15,000-tpd Concentrator

Following is a brief description of the flow of material through a copper concentrator. All concentrators analyzed in this appendix employ similar equipment to crush, grind, concentrate, and produce a copper and molybdenum concentrate.

Mine-run ore is delivered to a primary crusher (fig. C-1, table C-7) having a maximum capacity of 1,400 tons per hour. The crushed ore, the major portion of which is sized to minus 4-inch, is conveyed to a storage bin from which it is fed to the secondary and tertiary crushing plant.

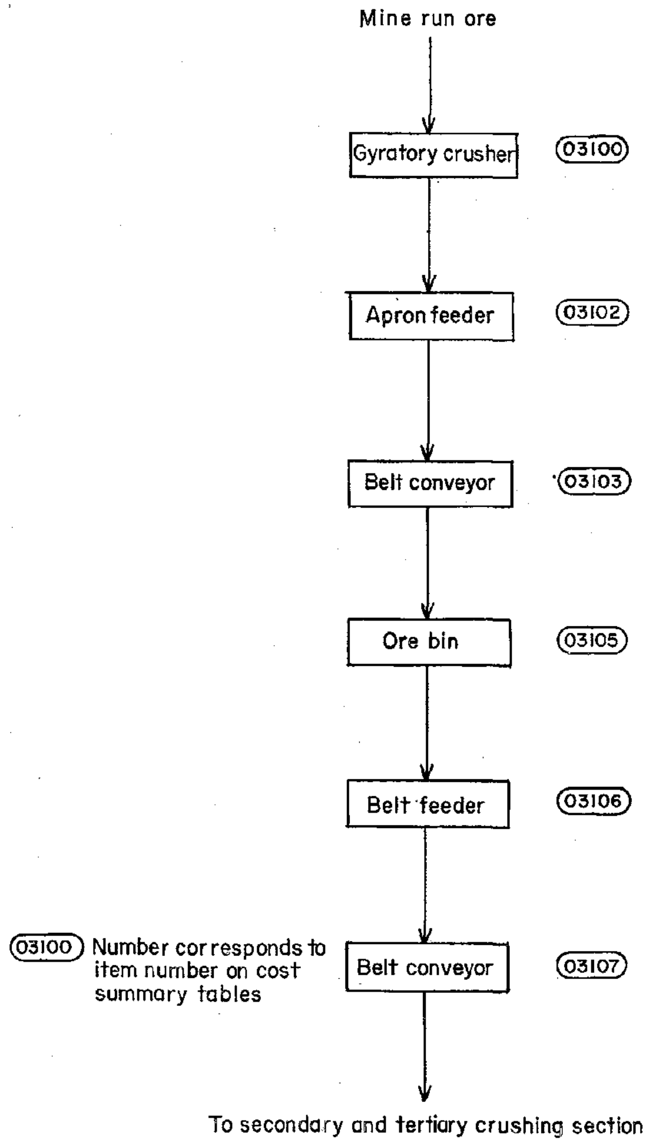

FIGURE C-1. - Flow diagram of primary crushing section, 15,000-tpd copper concentrator.

TABLE C-7. - Cost summary, primary crushing, conveying, and intermediate storage section, 15,000-tpd copper concentrator

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost: Material	Cost: Labor	Total cost
03100	Gyratory crusher	1	48 in by 74 in	-	-	$264,000	$42,200	$306,200
03101	Crusher motor	1	-	400	400	50,000	8,000	58,000
03102	Apron feeder	1	72 in by 16 ft	30	30	38,000	6,100	44,100
03103	Belt conveyor	1	48 in by 202 ft	70	70	32,900	5,300	38,200
03104	Magnet	1	48 in by 54 in	-	-	6,500	200	6,700
03105	Coarse ore bin	1	4,000 ton	-	-	79,500	119,300	198,800
03106	Belt feeder	4	42 in by 10 ft	2	8	51,600	8,300	59,900
03107	Belt conveyor	1	48 in by 123 ft	50	50	23,000	3,700	26,700
03108	Magnet	1	48 in by 54 in	6	6	6,500	200	6,700
03109	Dust collector	1	27,000 cfm, wet type	50	50	16,100	2,600	18,700
03110	do	1	10,000 cfm, wet type	20	20	9,400	1,500	10,900
03111	Bridge crane	1	75-ton, 5-ton auxiliary, 55-ft span.	85	85	103,500	16,600	120,100
03112	Pump	3	4 in by 2 in, rubber lined, centrifugal.	7.5	22.5	3,900	600	4,500
	Subtotal	-	-	-	742	684,900	214,600	899,500
	Excavation	-	-	-	-	19,500	110,600	130,100
	Concrete	-	-	-	-	118,400	128,200	246,600
	Buildings	-	-	-	-	229,700	64,800	294,500
	Piping	-	-	-	-	131,300	53,600	184,900
	Electrical	-	-	-	-	138,100	108,500	246,600
	Painting	-	-	-	-	5,800	4,500	10,300
	Instrumentation	-	-	-	-	9,200	3,100	12,300
	Insulation	-	-	-	-	1,200	200	1,400
	Subtotal	-	-	-	-	653,200	473,500	1,126,700
	Total direct costs	-	-	-	-	1,338,100	688,100	2,026,200
	Field indirect	-	-	-	-	-	-	344,100
	Total construction	-	-	-	-	-	-	2,370,300
	Engineering	-	-	-	-	-	-	118,500
	Administration and overhead.	-	-	-	-	-	-	118,500
	Subtotal	-	-	-	-	-	-	2,607,300
	Contingency	-	-	-	-	-	-	260,700
	Subtotal	-	-	-	-	-	-	2,868,000
	Fee	-	-	-	-	-	-	143,400
	Total	-	-	-	-	-	-	3,011,400

Feed to the secondary and tertiary crushing section (fig. C-2, table C-8) is sized by screening into three products. These products are plus 1-3/4-inch, plus 5/8-inch minus 1-3/4-inch, and minus 5/8-inch material. Plus 1-3/4-inch material is reduced in the secondary crusher, combined with the plus 5/8-inch minus 1-3/4-inch material, and transferred to the tertiary crushers which reduce the material to minus 5/8-inch. A screen prior to the tertiary crusher sizes the material allowing the minus 5/8-inch material to bypass the tertiary crushers. The minus 5/8-inch products, the bypass material at the secondary crusher, the bypass material at the tertiary crusher, and the tertiary crusher product are conveyed to the fine ore storage bin.

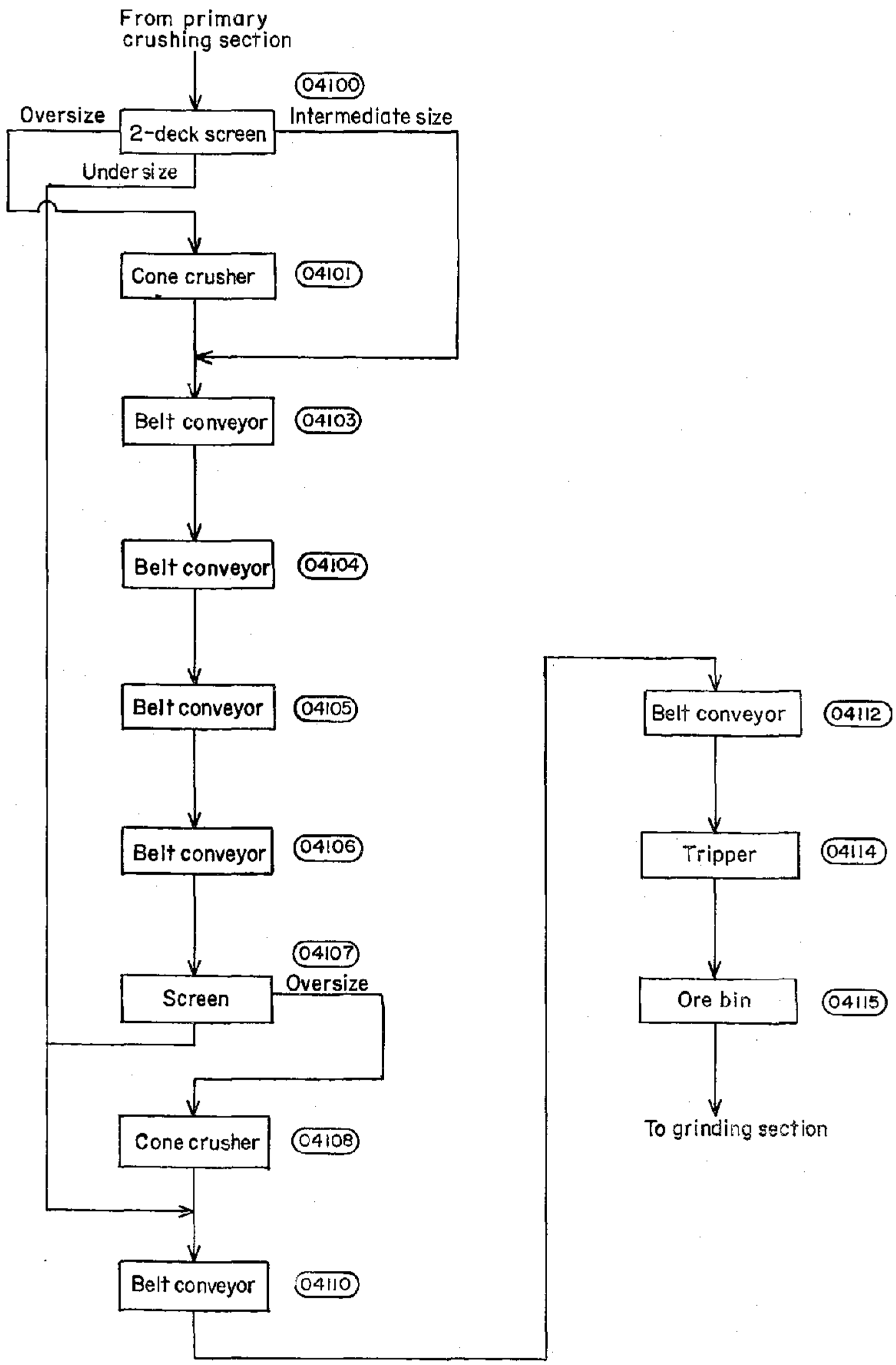

FIGURE C-2. - Flow diagram of secondary and tertiary crushing section, 15,000-tpd copper concentrator.

TABLE C-8. - Cost summary, secondary and tertiary crushing section, 15,000-tpd copper concentrator

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost: Material	Cost: Labor	Total cost
04100	Screen..............	1	6 ft by 14 ft, double deck............	25	25	$17,000	$2,700	$19,700
04101	Cone crusher.........	1	7-ft std............................	-	-	97,500	15,600	113,100
04102	Crusher motor........	1	-	300	300	16,500	2,600	19,100
04103	Belt conveyor........	1	48 in by 156 ft......................	75	75	26,700	4,300	31,000
04104	.........do..........	1	48 in by 24 ft.......................	15	15	9,800	1,600	11,400
04105	.........do..........	1	48 in by 219 ft......................	75	75	35,700	5,700	41,400
04106	.........do..........	1	48 in by 24 ft.......................	7	7	9,700	1,600	11,300
04107	Screen..............	2	6 ft by 12 ft, single deck............	15	30	19,200	3,100	22,300
04108	Cone crusher.........	2	7 ft shorthead........................	-	-	209,400	33,500	242,900
04109	Crusher motor........	2	-	300	600	33,000	5,300	38,300
04110	Belt conveyor........	1	48 in by 356 ft......................	30	30	49,300	7,900	57,200
04111	Magnet..............	1	48 in by 54 in........................	-	-	6,500	200	6,700
04112	Belt conveyor........	1	48 in by 493 ft......................	120	120	68,000	10,900	78,900
04113	Belt conveyor scale..	1	48 in................................	.5	.5	6,400	1,000	7,400
04114	Tripper (traveling)..	1	48 in................................	3	3	12,000	1,900	13,900
04115	Fine ore bin.........	1	20,000 tons..........................	-	-	216,000	324,000	540,000
04116	Dust collector.......	2	27,000 cfm, wet type..................	50	100	32,200	5,200	37,400
04117	.........do..........	1	13,800 cfm, wet type..................	20	20	9,400	1,500	10,900
04118	Pump................	3	4 in by 2 in, rubber lined, centrifugal	7.5	22.5	3,900	600	4,500
04119	Bridge crane.........	1	30 ton, 5-ton auxiliary, 43-ft span....	25	25	52,000	8,300	60,300
	Subtotal..........	-	-	-	1,448	930,200	437,500	1,367,700
	Excavation...........	-	-	-	-	26,500	150,200	176,700
	Concrete.............	-	-	-	-	160,800	174,100	334,900
	Buildings............	-	-	-	-	312,000	88,000	400,000
	Piping..............	-	-	-	-	178,300	72,900	251,200
	Electrical...........	-	-	-	-	187,500	147,400	334,900
	Painting.............	-	-	-	-	7,800	6,200	14,000
	Instrumentation......	-	-	-	-	12,600	4,200	16,800
	Insulation...........	-	-	-	-	1,600	200	1,800
	Subtotal..........	-	-	-	-	887,100	643,200	1,530,300
	Total direct costs	-	-	-	-	1,817,300	1,080,700	2,898,000
	Field indirect.......	-	-	-	-	-	-	540,400
	Total construction	-	-	-	-	-	-	3,438,400
	Engineering..........	-	-	-	-	-	-	171,900
	Administration and overhead.	-	-	-	-	-	-	171,900
	Subtotal..........	-	-	-	-	-	-	3,782,200
	Contingency..........	-	-	-	-	-	-	378,200
	Subtotal..........	-	-	-	-	-	-	4,160,400
	Fee.................	-	-	-	-	-	-	208,000
	Total............	-	-	-	-	-	-	4,368,400

Crushed ore is transported to the grinding section (fig. C-3, table C-9) where it is wet ground in rod mills operating in open circuit and in ball mills grinding in closed circuit with hydrocyclones. Ore in the cyclone overflow to the flotation cells is 90 percent minus 65 mesh.

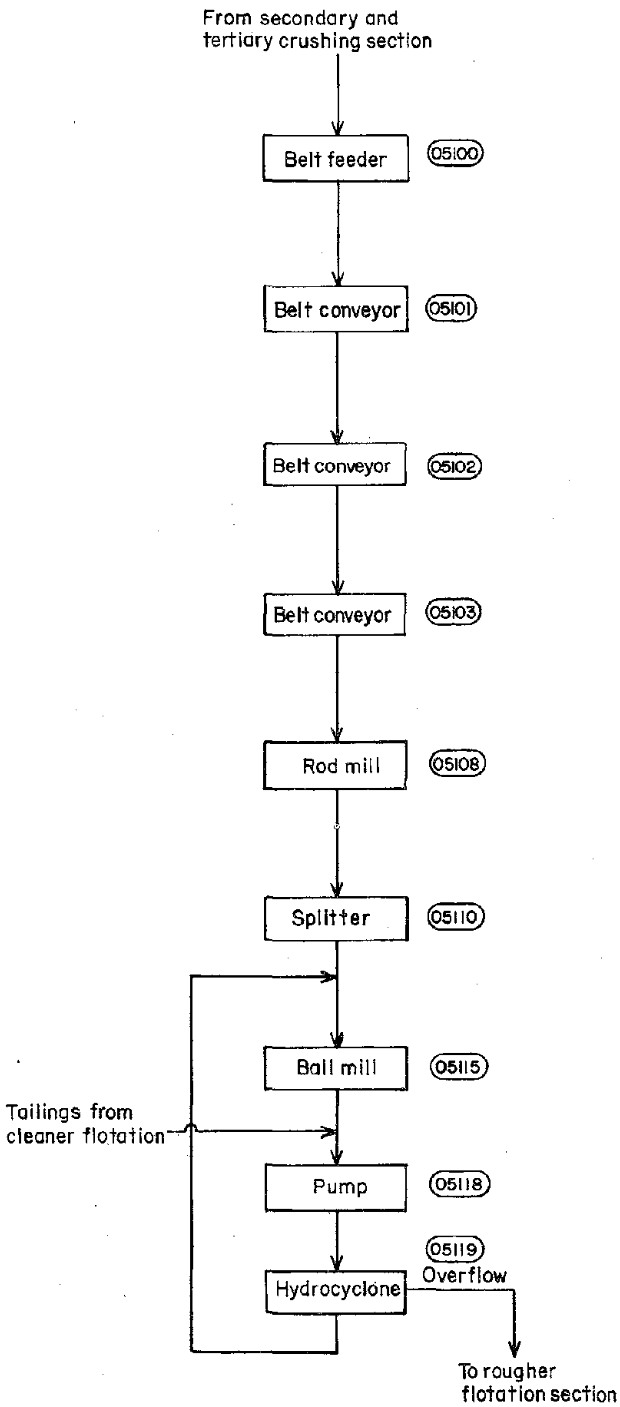

FIGURE C-3. - Flow diagram of grinding section, 15,000-tpd copper concentrator.

TABLE C-9. - Cost summary, grinding section, 15,000-tpd copper concentrator

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost: Material	Cost: Labor	Total cost
05100	Belt feeder	14	36 in by 31 ft	3	42	$72,200	$11,600	$83,800
05101	Belt conveyor	2	24 in by 56 ft	2	4	16,600	2,700	19,300
05102	do	2	24 in by 78 ft	3	6	17,800	2,800	20,600
05103	do	2	30 in by 26 ft	5	10	11,200	1,800	13,000
05104	Belt scale	2	30 in	.5	1	8,400	1,300	9,700
05105	Dust collector	2	13,800 cfm, wet type	20	40	18,800	3,000	21,800
05106	Pump	2	4 in by 2 in, rubber lined, centrifugal.	7.5	15.0	2,600	400	3,000
05107	Rod mill scoop box	2	-	-	-	8,400	1,300	9,700
05108	Rod mill	2	12.5 ft by 16 ft	-	-	430,000	86,000	516,000
05109	Rod mill motor	2	-	1,250	2,500	84,000	13,400	97,400
05110	Rod mill disk box and splitter	2	-	-	-	8,000	1,300	9,300
05111	Rod mill rod charger	2	-	-	-	13,000	2,100	15,100
05112	Rod mill rod storage rack	2	-	-	-	1,300	200	1,500
05113	Rod mill disk sampler	2	-	.25	.5	3,200	500	3,700
05114	Rod mill charge	-	270 tons	-	-	45,000	-	45,000
05115	Ball mill	4	12.5 ft by 14 ft	-	-	775,000	155,000	930,000
05116	Ball mill motor	4	-	1,250	5,000	168,000	26,800	194,800
05117	Ball mill charge	-	420 tons	-	-	104,000	-	104,000
05118	Slurry pump	8	10 in by 8 in	40	320	37,000	5,900	42,900
05119	Hydrocyclone	16	20 in	-	-	36,200	5,800	42,000
05120	Pump	2	3 in, rubber lined, centrifugal	7.5	15	2,400	400	2,800
05121	Bridge crane	1	30-ton, 5-ton auxiliary, 43-ft span.	25	25	52,000	8,300	60,300
	Subtotal	-	-	-	7,979	1,915,100	330,600	2,245,700
	Excavation	-	-	-	-	54,600	309,300	363,900
	Concrete	-	-	-	-	330,900	358,500	689,400
	Buildings	-	-	-	-	642,300	181,200	823,500
	Piping	-	-	-	-	367,100	150,000	517,100
	Electrical	-	-	-	-	386,100	303,400	689,500
	Painting	-	-	-	-	16,100	12,600	28,700
	Instrumentation	-	-	-	-	25,900	8,600	34,500
	Insulation	-	-	-	-	3,400	500	3,900
	Subtotal	-	-	-	-	1,826,400	1,324,100	3,150,500
	Total direct costs	-	-	-	-	3,741,500	1,654,700	5,396,200
	Field indirect	-	-	-	-	-	-	827,400
	Total construction	-	-	-	-	-	-	6,223,600
	Engineering	-	-	-	-	-	-	311,200
	Administration and overhead	-	-	-	-	-	-	311,200
	Subtotal	-	-	-	-	-	-	6,846,000
	Contingency	-	-	-	-	-	-	684,600
	Subtotal	-	-	-	-	-	-	7,530,600
	Fee	-	-	-	-	-	-	376,500
	Total	-	-	-	-	-	-	7,907,100

The flotation section (figs. C-4 and C-5, table C-10) is composed of rougher, cleaner, and recleaner units in which the material is upgraded to produce a copper-molybdenum concentrate. Waste (tailings) is pumped to the tailings-disposal section and the concentrate is pumped to the byproduct-molybdenum recovery section.

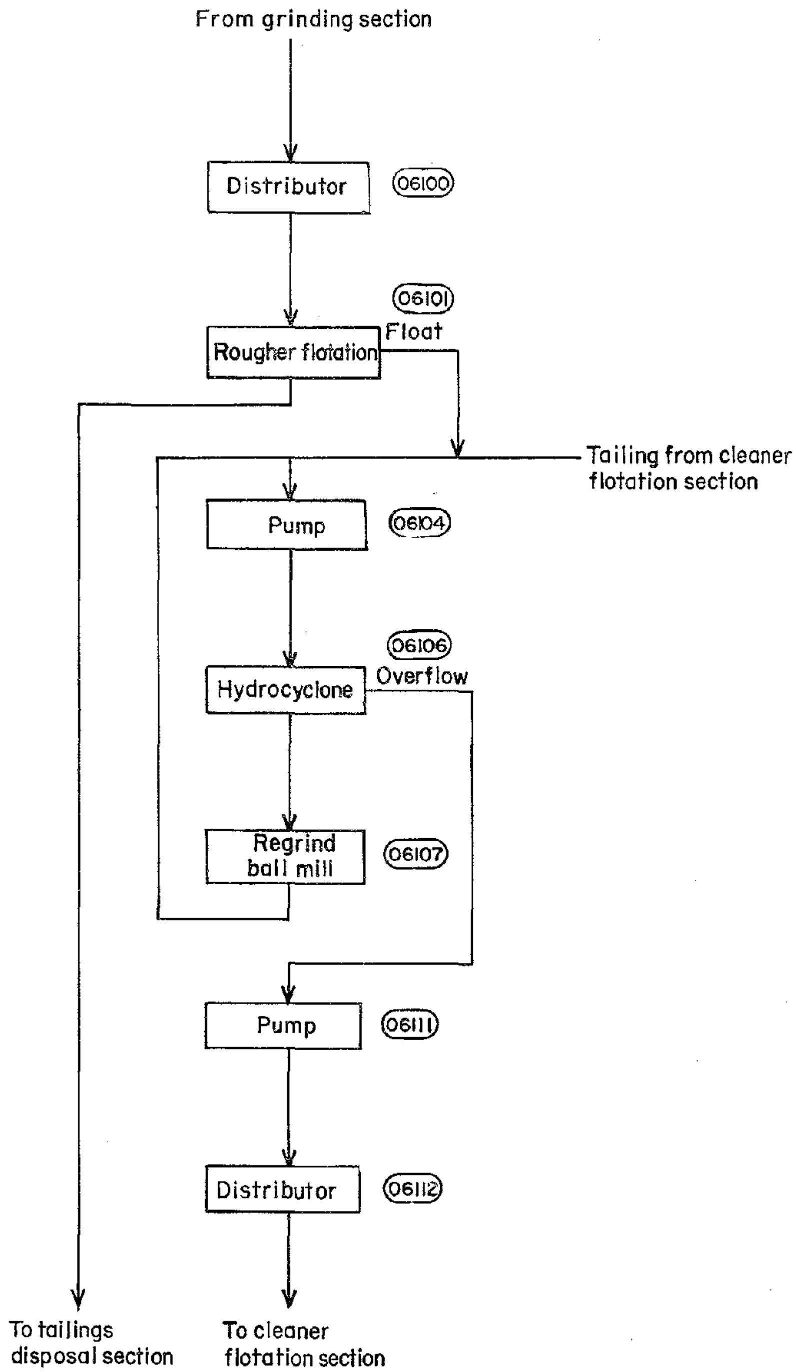

FIGURE C-4. - Flow diagram of rougher flotation section, 15,000-tpd copper concentrator.

TABLE C-10. - Cost summary, flotation section, 15,000-tpd copper concentrator

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost: Material	Cost: Labor	Total cost
06100	Pulp distributor...	2	8-ft diam.............	1	2	$21,000	$3,400	$24,400
06101	Rougher flotation unit.	180	2 sections of 90 cells, 40 cu ft.	3.75	675	270,000	43,200	313,200
06102	Flotation launderer	1,260 ft	12 in.................	-	-	52,900	8,500	61,400
06103	Sampler............	4	-	.25	1	6,400	1,000	7,400
06104	Pump...............	4	5 in by 6 in, rubber lined, centrifugal.	25	100	14,000	2,200	16,200
06105	........do.........	1	3 in, rubber lined, centrifugal.	15	15	3,000	500	3,500
06106	Hydrocyclone.......	6	10 in..................	-	-	12,600	2,000	14,600
06107	Regrind ball mill..	2	8.5 ft by 12 ft........	-	-	170,000	34,000	204,000
06108	Regrind ball mill motor.	2	-	300	600	33,000	5,300	38,300
06109	Ball mill charge...	-	70 tons................	-	-	17,400	-	17,400
06110	Sampler............	2	-	.25	.5	3,200	500	3,700
06111	Pump...............	4	5 in by 6 in, rubber lined, centrifugal.	25	100	14,000	2,200	16,200
06112	Pulp distributor...	2	6-ft diam.............	1	2	9,400	1,500	10,900
06113	Cleaner flotation unit.	40	2 sections of 20 cells, 40 cu ft.	3.75	150	60,000	9,600	69,600
06114	Flotation launderer	280 ft	12 in.................	-	-	11,800	1,900	13,700
06115	Sampler............	2	-	.25	.50	3,200	500	3,700
06116	Pump...............	4	5 in by 6 in, rubber lined, centrifugal.	25	100	14,000	2,200	16,200
06117	Recleaner flotation unit.	8	2 sections of 4 cells, 40 cu ft.	3.75	30	12,000	1,900	13,900
06118	Flotation launderer	56 ft	12 in.................	-	-	2,400	400	2,800
06119	Sampler............	4	-	.25	1	6,400	1,000	7,400
06120	Thickener..........	2	50 ft by 12 ft.........	3	6	84,800	13,600	98,400
06121	Pump...............	2	6 in, diaphragm........	3	6	6,800	1,100	7,900
06122	........do.........	2	2 in, rubber lined, centrifugal.	7.5	15	3,000	500	3,500
06123	Bridge crane.......	1	10-ton, 60-ft span.....	20	20	19,000	3,000	22,000
06124	........do.........	1	5-ton, 30-ft span......	15	15	14,000	2,200	16,200
	Subtotal........	-	-	-	1,839	864,300	142,200	1,006,500

TABLE C-10. - Cost summary, flotation section, 15,000-tpd copper concentrator--Continued

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost		Total cost
						Material	Labor	
	Excavation.........	-	-	-	-	$24,600	$139,600	$164,200
	Concrete...........	-	-	-	-	149,400	161,800	311,200
	Buildings..........	-	-	-	-	289,900	81,800	371,700
	Piping.............	-	-	-	-	165,700	67,700	233,400
	Electrical.........	-	-	-	-	174,200	136,900	311,100
	Painting...........	-	-	-	-	7,300	5,700	13,000
	Instrumentation....	-	-	-	-	11,700	3,900	15,600
	Insulation.........	-	-	-	-	1,500	200	1,700
	Subtotal........	-	-	-	-	824,300	597,600	1,421,900
	Total direct costs.	-	-	-	-	1,688,600	739,800	2,428,400
	Field indirect.....	-	-	-	-	-	-	369,900
	Total construction.	-	-	-	-	-	-	2,798,300
	Engineering........	-	-	-	-	-	-	139,900
	Administration and overhead.	-	-	-	-	-	-	139,900
	Subtotal........	-	-	-	-	-	-	3,078,100
	Contingency........	-	-	-	-	-	-	307,800
	Subtotal........	-	-	-	-	-	-	3,385,900
	Fee................	-	-	-	-	-	-	169,300
	Total..........	-	-	-	-	-	-	3,555,200

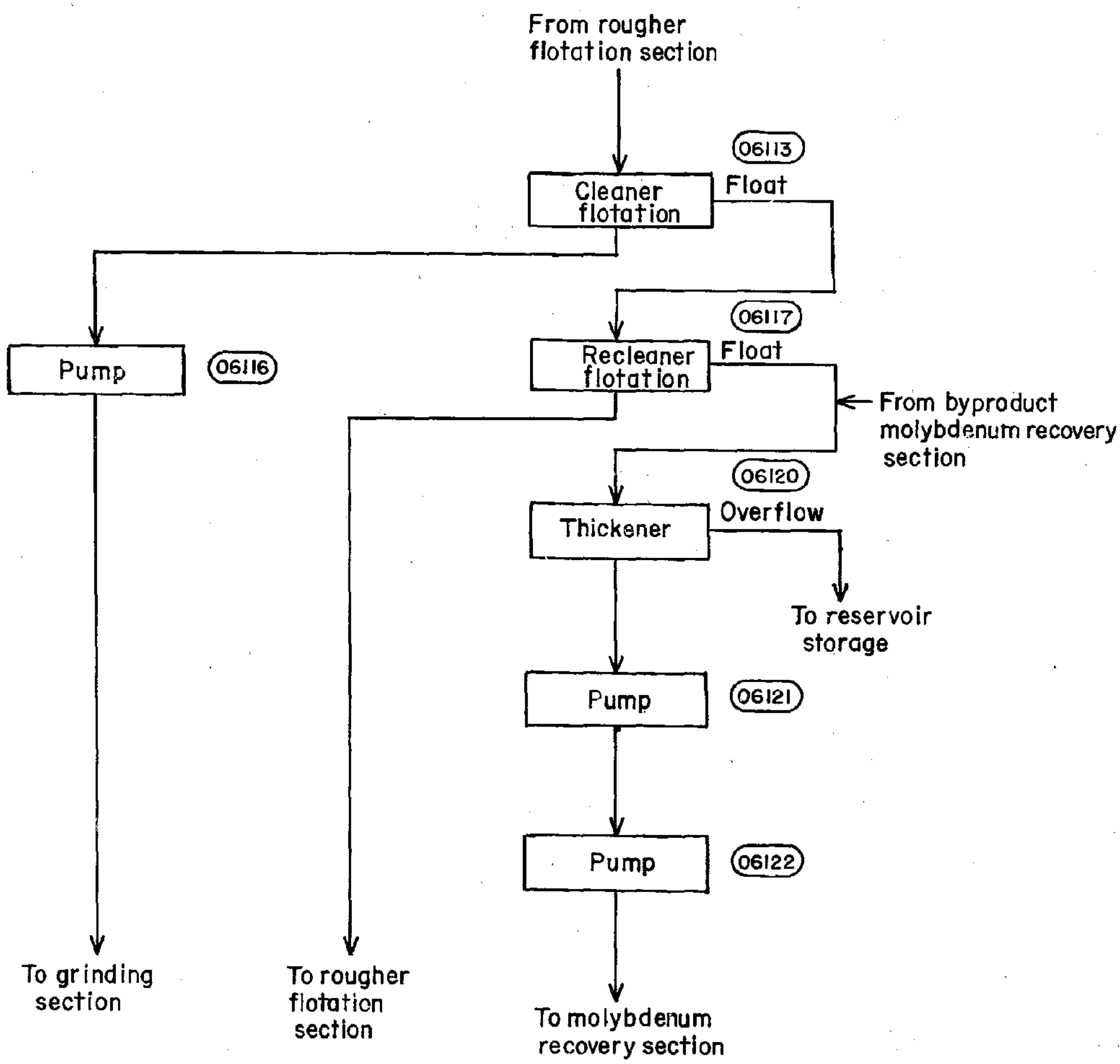

FIGURE C-5. - Flow diagram of cleaner flotation section, 15,000-tpd copper concentrator.

In the byproduct-molybdenum recovery section (fig. C-6, table C-11) the concentrate is separated into copper and molybdenum concentrates. The molybdenum concentrate is dewatered, dried, and prepared for marketing. The copper concentrate is transferred to the copper-filter section.

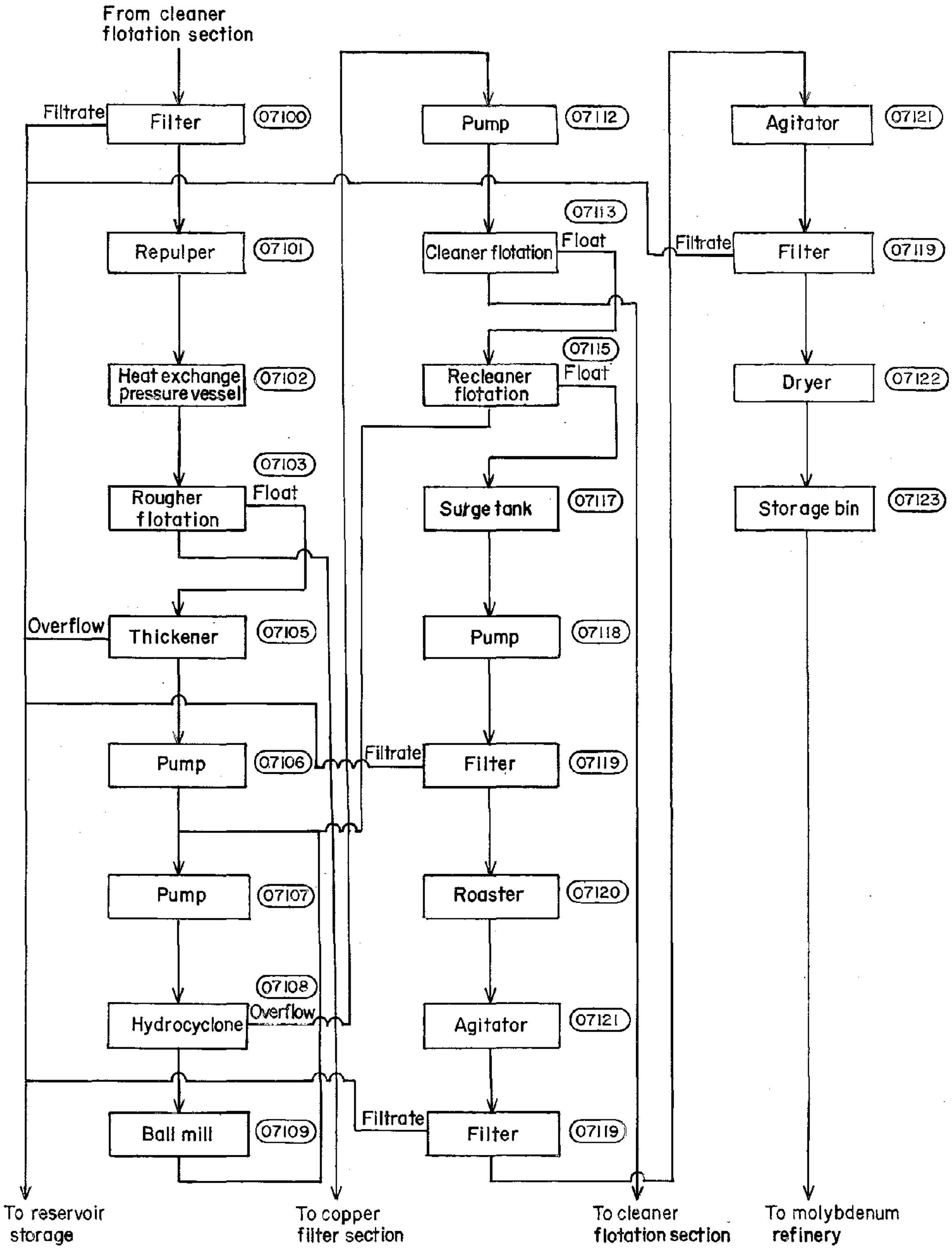

FIGURE C-6. - Flow diagram of byproduct molybdenum recovery section, 15,000-tpd copper concentrator.

TABLE C-11. - Cost summary, byproduct molybdenum recovery section, 15,000-tpd copper concentrator

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost: Material	Cost: Labor	Total cost
07100	Filter............	1	8.5 ft by 7 ft.....	3	3	$19,100	$3,100	$22,200
07101	Repulper...........	1	10 ft by 10 ft.....	5	5	3,600	600	4,200
07102	Heat exchanger, pressure vessel, and boiler.	1	-	-	-	93,900	15,000	108,900
07103	Rougher flotation unit.	12	40-cu-ft cells.....	3.75	45	18,000	2,900	20,900
07104	Flotation launderer	84 ft	12 in.............	-	-	3,500	600	4,100
07105	Thickener..........	1	40 ft by 10 ft.....	10	10	31,400	5,000	36,400
07106	Pump...............	1	6 in, diaphragm....	3	3	3,400	500	3,900
07107	........do.........	1	2 in, rubber lined, centrifugal.	7.5	7.5	1,500	200	1,700
07108	Hydrocyclone.......	3	6 in...............	-	-	2,100	300	2,400
07109	Ball mill..........	1	5 ft by 8 ft.......	-	-	24,400	4,900	29,300
07110	Ball mill motor....	1	-	75	75	7,000	1,100	8,100
07111	Ball mill charge...	1	14-ton.............	-	-	3,500	-	3,500
07112	Pump...............	1	2 in, rubber lined, centrifugal.	7.5	7.5	1,500	200	1,700
07113	Cleaner flotation unit.	10	18-cu-ft cells.....	3.75	37.5	15,000	2,400	17,400
07114	Flotation launderer	60 ft	12 in..............	-	-	2,400	400	2,800
07115	Recleaner flotation unit.	10	12-cu-ft cells.....	3	30	12,000	1,900	13,900
07116	Flotation launderer	47 ft	12 in..............	-	-	2,000	300	2,300
07117	Surge tank.........	1	10 ft by 10 ft.....	-	-	1,900	300	2,200
07118	Pump...............	1	2 in, rubber lined, centrifugal.	7.5	7.5	1,500	200	1,700
07119	Filter.............	3	3 ft by 2 ft.......	.75	2.25	7,200	1,200	8,400
07120	Roaster............	1	8.75-ft diam, 10 hearth.	30	30	87,000	13,900	100,900
07121	Agitator and wash tank.	2	5 ft by 5 ft.......	3	6	2,800	400	3,200
07122	Dryer..............	1	4-ft diam, 4 hearth	3	3	30,000	4,800	34,800
07123	Storage bin........	1	75-ton.............	-	-	7,300	11,000	18,300
	Subtotal........	-	-	-	272	382,000	71,200	453,200
	Excavation.........	-	-	-	-	10,900	61,700	72,600
	Concrete...........	-	-	-	-	66,000	71,500	137,500
	Buildings..........	-	-	-	-	128,100	36,100	164,200
	Piping.............	-	-	-	-	73,200	29,900	103,100
	Electrical.........	-	-	-	-	77,000	60,500	137,500
	Painting...........	-	-	-	-	3,200	2,500	5,700
	Instrumentation....	-	-	-	-	5,200	1,700	6,900
	Insulation.........	-	-	-	-	700	100	800
	Subtotal........	-	-	-	-	364,300	264,000	628,300
	Total direct costs.	-	-	-	-	746,300	335,200	1,081,500
	Field indirect.....	-	-	-	-	-	-	167,600
	Total construction.	-	-	-	-	-	-	1,249,100
	Engineering........	-	-	-	-	-	-	62,500
	Administration and overhead.	-	-	-	-	-	-	62,500
	Subtotal........	-	-	-	-	-	-	1,374,100
	Contingency........	-	-	-	-	-	-	137,400
	Subtotal........	-	-	-	-	-	-	1,511,500
	Fee................	-	-	-	-	-	-	75,600
	Total..........	-	-	-	-	-	-	1,587,100

The copper concentrate, transferred to the copper-filter section (fig. C-7, table C-12), is dewatered and prepared for shipment to a smelter.

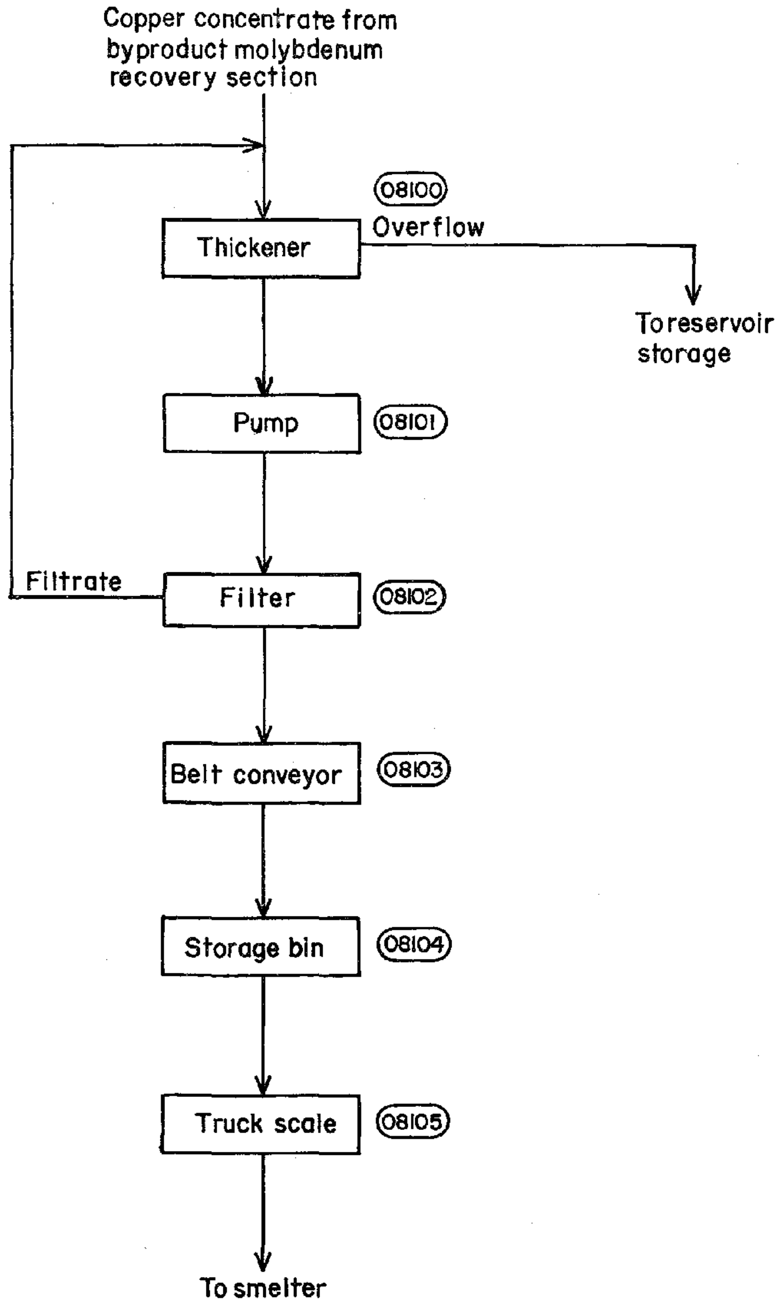

FIGURE C-7. - Flow diagram of copper filter section, 15,000-tpd copper concentrator.

TABLE C-12. - Cost summary, copper filter section, 15,000-tpd copper concentrator

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost		Total cost
						Material	Labor	
08100	Thickener	1	60 ft by 12 ft.	3	3	$50,800	$8,100	$58,900
08101	Pump	1	2 in, diaphragm	2	2	1,900	300	2,200
08102	Filter	1	8.5 ft by 7 ft.	3	3	19,100	3,100	22,200
08103	Belt conveyor	1	24 in by 100 ft	10	10	9,700	1,600	11,300
08104	Storage bin	1	600-ton	-	-	26,000	39,000	65,000
08105	Truck scale	1	200-ton	-	-	18,800	3,000	21,800
	Subtotal	-	-	-	18	126,300	55,100	181,400
	Excavation	-	-	-	-	3,600	20,400	24,000
	Concrete	-	-	-	-	21,800	23,600	45,400
	Buildings	-	-	-	-	42,400	11,900	54,300
	Piping	-	-	-	-	24,200	9,900	34,100
	Electrical	-	-	-	-	25,500	20,000	45,500
	Painting	-	-	-	-	1,100	800	1,900
	Instrumentation	-	-	-	-	1,700	600	2,300
	Insulation	-	-	-	-	200	100	300
	Subtotal	-	-	-	-	120,500	87,300	207,800
	Total direct costs	-	-	-	-	246,800	142,400	389,200
	Field indirect	-	-	-	-	-	-	71,200
	Total construction	-	-	-	-	-	-	460,400
	Engineering	-	-	-	-	-	-	23,000
	Administration and overhead	-	-	-	-	-	-	23,000
	Subtotal	-	-	-	-	-	-	506,400
	Contingency	-	-	-	-	-	-	50,600
	Subtotal	-	-	-	-	-	-	557,000
	Fee	-	-	-	-	-	-	27,900
	Total	-	-	-	-	-	-	584,900

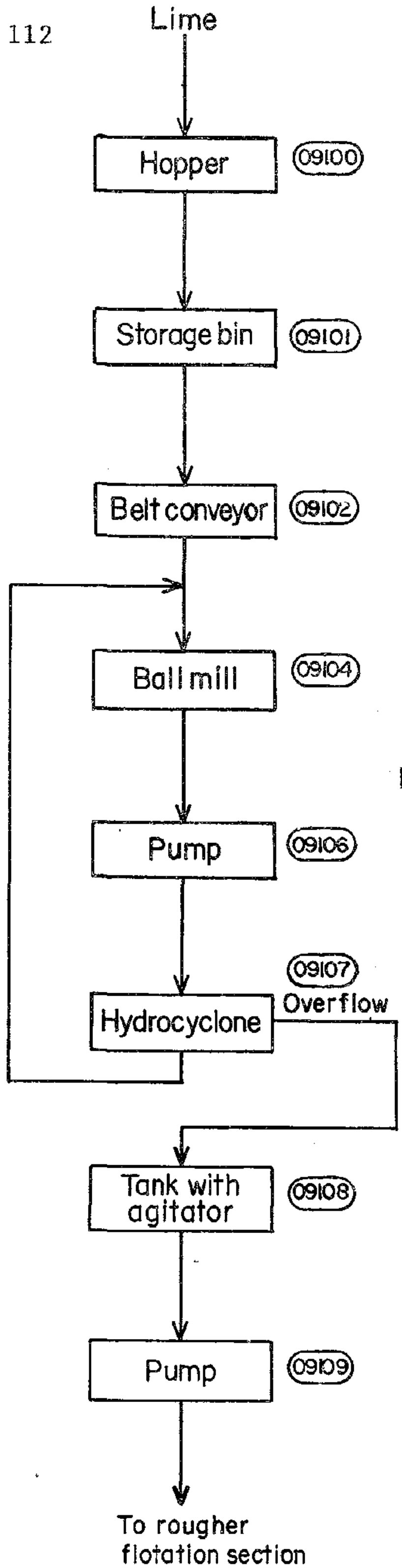

FIGURE C-8. - Flow diagram of lime preparation section, 15,000-tpd copper concentrator.

The lime preparation section is used to pulverize and slurry lime needed for the pH control of solutions. Figure C-8 is a flow diagram of the procedure and table C-13 contains a list of the equipment.

TABLE C-13. - Cost summary, lime preparation section, 15,000-tpd copper concentrator

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost: Material	Cost: Labor	Total cost
09100	Hopper	1	50-ton	-	-	$4,000	$6,000	$10,000
09101	Storage bin	1	150-ton	-	-	10,500	15,800	26,300
09102	Belt conveyor	1	24 in by 100 ft	10	10	9,700	1,600	11,300
09103	Belt conveyor scale	1	24 in	-	-	4,200	700	4,900
09104	Ball mill	1	3 ft by 5 ft	-	-	7,200	1,400	8,600
09105	Ball mill motor	1	-	20	20	1,200	200	1,400
09106	Pump	1	3 in, rubber lined, centrifugal.	5	5	1,300	200	1,500
09107	Hydrocyclone	1	10 in	-	-	2,100	300	2,400
09108	Tank with agitator	2	20-ft diam by 20 ft.	5	10	23,000	3,700	26,700
09109	Pump	1	4 in by 6 in, rubber lined, centrifugal.	7.5	7.5	3,400	500	3,900
	Subtotal	-	-	-	53	66,600	30,400	97,000
	Excavation	-	-	-	-	1,900	10,800	12,700
	Concrete	-	-	-	-	11,500	12,500	24,000
	Buildings	-	-	-	-	22,300	6,300	28,600
	Piping	-	-	-	-	12,800	5,200	18,000
	Electrical	-	-	-	-	13,400	10,600	24,000
	Painting	-	-	-	-	600	400	1,000
	Instrumentation	-	-	-	-	900	300	1,200
	Insulation	-	-	-	-	100	100	200
	Subtotal	-	-	-	-	63,500	46,200	109,700
	Total direct costs	-	-	-	-	130,100	76,600	206,700
	Field indirect	-	-	-	-	-	-	38,300
	Total construction	-	-	-	-	-	-	245,000
	Engineering	-	-	-	-	-	-	12,300
	Administration and overhead	-	-	-	-	-	-	12,300
	Subtotal	-	-	-	-	-	-	269,600
	Contingency	-	-	-	-	-	-	27,000
	Subtotal	-	-	-	-	-	-	296,600
	Fee	-	-	-	-	-	-	14,800
	Total	-	-	-	-	-	-	311,400

TABLE C-15. - Estimated capital requirements, 15,000-tpd copper concentrator

Unit	Cost
Crushing section:	
Primary crushing	$3,011,400
Secondary and tertiary crushing	4,368,400
Grinding section	7,907,100
Flotation section	3,555,200
Byproduct molybdenum recovery section	1,587,100
Copper filter section	584,900
Lime preparation section	311,400
Tailings-disposal section	3,548,300
Subtotal	24,873,800
General facilities and utilities	2,487,400
Subtotal for depreciation, taxes, and insurance	27,361,200
Working capital[1]	1,695,000
Total capital required	29,056,200

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE C-16. - Estimated annual operating cost, 15,000-tpd copper concentrator

	Annual cost	Total	Cost per ton
Direct cost:			
Materials and utilities:			
Power..12,700 kW-hr/hr × 8,568 hr/yr × $0.007/kW-hr	$761,700	-	-
Natural gas..25 Mscf/hr × 8,568 hr/yr × $0.43/Mscf	92,100	-	-
Rods, balls, and grinding and crushing surfaces at $0.134/ton × 15,000 tpd × 357 day/yr	717,600	-	-
Reagents	471,200	-	-
Miscellaneous operating supplies 7.5 percent of power	57,100	-	-
Subtotal	-	$2,099,700	$0.392
Direct labor:			
643 man-hr/day..........$3.46/man-hr × 357 day/yr	794,100	-	-
Supervision..................15 percent of labor	119,200	-	-
Subtotal	-	913,300	.171
Maintenance:			
312 man-hr/day..........$3.65/man-hr × 357 day/yr	406,600	-	-
Supervision..................20 percent of labor	81,300	-	-
Maintenance supplies and parts	406,600	-	-
Subtotal	-	894,500	.167
Payroll overhead..............25 percent of payroll	-	350,400	.065
Total direct cost	-	4,257,900	.795
Indirect cost:			
Administrative, technical, and clerical labor	304,000	-	.057
Payroll overhead 25 percent of administrative payroll	76,000	-	.014
Facilities maintenance and supplies 5 percent of plant facilities	136,400	-	.025
General overhead includes head office charges, and research............5 percent of direct costs	212,900	-	.040
Total indirect cost	-	729,300	.136
Fixed cost:			
Taxes and insurance.........2 percent of plant cost	600,000	-	.112
Depreciation..............................15 years	1,824,100	-	.341
Total fixed cost	-	2,424,100	.453
Gross operating cost	-	7,411,300	1.384

TABLE C-17. - Plant utility requirements, 15,000-tpd copper concentrator

Unit	Power, kW-hr/hr	New water (from own wells), gpm	Recirculated water, gpm	Natural gas, Mscf/hr
Crushing section..........	900	300	-	-
Concentrator.............	8,900	2,000	4,500	-
Byproduct molybdenum recovery section.........	200	-	-	15
Lime preparation section..	30	-	-	-
Subtotal............	10,030	2,300	4,500	15
Lighting and cranes.......	150	-	-	-
Fresh water...............	1,200	-	-	-
Recirculated water........	1,100	-	-	-
Sanitary water............	50	30	-	-
General facilities........	120	70	-	10
Miscellaneous and contingency.............	50	-	-	-
Subtotal............	2,670	100	0	10
Total...............	12,700	2,400	4,500	25

TABLE C-18. - Estimated capital requirements, 23,000-tpd copper concentrator

Unit	Cost
Crushing section:	
Primary crushing..	$4,172,900
Secondary and tertiary crushing.............................	5,877,700
Grinding section..	19,746,300
Flotation section...	7,221,300
Byproduct molybdenum recovery section.......................	1,509,700
Copper filter section.......................................	546,100
Lime preparation section....................................	396,800
Tailings-disposal section...................................	4,533,300
Subtotal..	44,004,100
General facilities and utilities............................	4,400,400
Subtotal for depreciation, taxes, and insurance.............	48,404,500
Working capital[1]...	2,699,300
Total capital required......................................	51,103,800

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE C-19. - Estimated annual operating cost, 23,000-tpd copper concentrator

	Annual cost	Total	Cost per ton
Direct cost:			
Materials and utilities:			
Power........16,700 kW-hr/hr × 8,568 hr/yr × $0.007/kW-hr..	$1,001,600	-	-
Natural gas........30 Mscf/hr × 8,568 hr/yr × $0.43/Mscf..	110,500	-	-
Rods, balls, and grinding and crushing surfaces at $0.198/ton × 23,000 tpd × 357 day/yr........	1,625,800	-	-
Reagents........	583,000	-	-
Miscellaneous operating supplies........7.5 percent of power..	75,100	-	-
Subtotal........	-	$3,396,000	$0.414
Direct labor:			
774 man-hr/day........$3.46/man-hr × 357 day/yr..	956,100	-	-
Supervision........15 percent of labor..	143,400	-	-
Subtotal........	-	1,099,500	.134
Maintenance:			
567 man-hr/day........$3.65/man-hr × 357 day/yr..	738,800	-	-
Supervision........20 percent of labor..	147,800	-	-
Maintenance supplies and parts........	738,800	-	-
Subtotal........	-	1,625,400	.198
Payroll overhead........25 percent of payroll..	-	496,500	.060
Total direct cost........	-	6,617,400	.806
Indirect cost:			
Administrative, technical, and clerical labor........	325,700	-	.040
Payroll overhead........25 percent of administrative payroll..	81,400	-	.010
Facilities maintenance and supplies........5 percent of plant facilities..	234,400	-	.029
General overhead includes head office charges, and research 5 percent of direct costs..	330,900	-	.040
Total indirect cost........	-	972,400	.118
Fixed cost:			
Taxes and insurance........2 percent of plant cost..	1,031,400	-	.126
Depreciation........15 years..	3,227,000	-	.393
Total fixed cost........	-	4,258,400	.519
Gross operating cost........	-	11,848,200	1.443

TABLE C-20. - Plant utility requirements, 23,000-tpd copper concentrator

Unit	Power, kW-hr/hr	New water (from own wells), gpm	Recirculated water, gpm	Natural gas, Mscf/hr
Crushing section..........	1,300	-	200	-
Concentrator..............	11,500	2,300	11,600	-
Byproduct molybdenum recovery section.........	200	1,000	-	20
Lime preparation section..	100	100	-	-
Subtotal.............	13,100	3,400	11,800	20
Lighting and cranes.......	200	-	-	-
Fresh water...............	1,500	-	-	-
Recirculated water........	1,500	-	-	-
Sanitary water............	100	-	-	-
General facilities........	200	100	-	10
Miscellaneous and contingency..............	100	200	-	-
Subtotal.............	3,600	300	0	10
Total................	16,700	3,700	11,800	30

40,000-tpd Concentrator

A summary of the capital cost requirements for a 40,000-tpd copper concentrator is contained in table C-21. Operating costs, direct and indirect, are summarized in table C-22. Plant utility requirements for power, water, and fuel are shown in table C-23.

These detailed costs are based on a flow diagram similar to that of the 15,000-tpd concentrator. There are variations owing to differences in the materials-handling system and general plant layout, but metallurgically the design is similar. A copper and molybdenum concentrate is produced.

TABLE C-21. - Estimated capital requirements, 40,000-tpd copper concentrator

Unit	Cost
Crushing section:	
Primary crushing..	$4,152,000
Secondary and tertiary crushing..................................	12,268,300
Grinding section..	29,139,100
Flotation section...	15,004,200
Byproduct molybdenum recovery section.............................	1,526,400
Copper filter section...	957,900
Lime preparation section..	1,023,100
Tailings-disposal section...	4,908,800
Subtotal..	68,979,800
General facilities and utilities..................................	6,898,000
Subtotal for depreciation, taxes, and insurance...............	75,877,800
Working capital[1]..	3,864,300
Total capital required..	79,742,100

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE C-22. - Estimated annual operating cost, 40,000-tpd copper concentrator

	Annual cost	Total	Cost per ton
Direct cost:			
Materials and utilities:			
Power....34,700 kW-hr/hr × 8,568 hr/yr × $0.007/kW-hr..	$2,081,200	-	-
Natural gas....20 Mscf/hr × 8,568 hr/yr × $0.43/Mscf..	73,700	-	-
Rods, balls, and grinding and crushing surfaces at $0.149/ton × 40,000 tpd × 357 day/yr....	2,127,700	-	-
Reagents....	1,116,700	-	-
Miscellaneous operating supplies....7.5 percent of power..	156,100	-	-
Subtotal....	-	$5,555,400	$0.389
Direct labor:			
1,243 man-hr/day....$3.46/man-hr × 357 day/yr..	1,535,400	-	-
Supervision....15 percent of labor..	230,300	-	-
Subtotal....	-	1,765,700	.124
Maintenance:			
835 man-hr/day....$3.65/man-hr × 357 day/yr..	1,088,000	-	-
Supervision....20 percent of labor..	217,600	-	-
Maintenance supplies and parts....	1,088,000	-	-
Subtotal....	-	2,393,600	.168
Payroll overhead....25 percent of payroll..	-	767,800	.054
Total direct cost....	-	10,482,500	.734
Indirect cost:			
Administrative, technical, and clerical labor....	364,000	-	.025
Payroll overhead....25 percent of administrative payroll..	91,000	-	.006
Facilities maintenance and supplies....5 percent of plant facilities..	362,600	-	.025
General overhead includes head office charges, and research 5 percent of direct costs..	524,100	-	.037
Total indirect cost....	-	1,341,700	.094
Fixed cost:			
Taxes and insurance....2 percent of plant cost..	1,595,400	-	.112
Depreciation....15 years..	5,058,500	-	.354
Total fixed cost....	-	6,653,900	.466
Gross operating cost....	-	18,478,100	1.294

TABLE C-23. - Plant utility requirements, 40,000-tpd copper concentrator

Unit	Power, kW-hr/hr	New water (from own wells), gpm	Recirculated water, gpm	Natural gas, Mscf/hr
Crushing section..........	2,600	-	100	-
Concentrator..............	26,600	4,300	12,800	-
Byproduct molybdenum recovery section.........	400	-	-	-
Lime preparation section..	300	-	-	-
Subtotal.............	29,900	4,300	12,900	0
Lighting and cranes.......	400	-	-	-
Fresh water...............	2,600	-	-	-
Recirculated water........	1,000	-	-	-
Sanitary water............	200	100	-	-
General facilities........	400	-	-	20
Miscellaneous and contingency..............	200	300	-	-
Subtotal.............	4,800	400	0	20
Total...............	34,700	4,700	12,900	20

72,000-tpd Concentrator

Estimated capital and operating costs for a 72,000-tpd copper concentrator producing a copper and molybdenum concentrate are shown in tables C-24 and C-25. The costs are based on a flow diagram similar to that of the 15,000-tpd concentrator with minor variations owing to mineral characteristics, plant layout, and materials-handling system.

Table C-26 contains utility requirements for water, power, and fuel.

TABLE C-24. - Estimated capital requirements, 72,000-tpd copper concentrator

Unit	Cost
Crushing section:	
Primary crushing..	$12,842,800
Secondary and tertiary crushing...........................	17,149,300
Grinding section..	34,920,300
Flotation section...	13,406,200
Byproduct molybdenum recovery section.....................	12,579,000
Copper filter section.....................................	1,228,700
Lime preparation section..................................	1,365,300
Tailings-disposal section.................................	10,359,300
Subtotal..	103,850,900
General facilities and utilities..........................	10,385,100
Subtotal for depreciation, taxes, and insurance............	114,236,000
Working capital[1]..	6,446,300
Total capital required...................................	120,682,300

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE C-25. - Estimated annual operating cost, 72,000-tpd copper concentrator

	Annual cost	Total	Cost per ton
Direct cost:			
Materials and utilities:			
Power			
45,800 kW-hr/hr x 8,568 hr/yr x $0.007/kW-hr..	$2,746,900	-	-
Natural gas..70 Mscf/hr x 8,568 hr/yr x $0.43/Mscf..	257,900	-	-
Balls and grinding and crushing surfaces at			
$0.167/ton x 72,000 tpd x 357 day/yr............	4,292,600	-	-
Reagents..	2,270,600	-	-
Miscellaneous operating supplies			
7.5 percent of power..	206,000	-	-
Subtotal..................................	-	$9,774,000	$0.380
Direct labor:			
1,784 man-hr/day.......$3.46/man-hr x 357 day/yr..	2,203,600	-	-
Supervision..................15 percent of labor..	330,500	-	-
Subtotal..................................	-	2,534,100	.099
Maintenance:			
1,263 man-hr/day.......$3.65/man-hr x 357 day/yr..	1,645,800	-	-
Supervision..................20 percent of labor..	329,200	-	-
Maintenance supplies and parts...................	1,645,800	-	-
Subtotal..................................	-	3,620,800	.141
Payroll overhead.............25 percent of payroll..	-	1,127,300	.044
Total direct cost..........................	-	17,056,200	.664
Indirect cost:			
Administrative, technical, and clerical labor.......	588,000	-	.023
Payroll overhead			
25 percent of administrative payroll..	147,000	-	.006
Facilities maintenance and supplies			
5 percent of plant facilities..	553,400	-	.022
General overhead includes head office charges,			
and research...........5 percent of direct costs..	852,800	-	.033
Total indirect cost........................	-	2,141,200	.084
Fixed cost:			
Taxes and insurance........2 percent of plant cost..	2,435,100	-	.095
Depreciation...........................15 years..	7,615,700	-	.296
Total fixed cost...........................	-	10,050,800	.391
Gross operating cost.......................	-	29,248,200	1.139

TABLE C-26. - Plant utility requirements, 72,000-tpd copper concentrator

Unit	Power, kW-hr/hr	New water (from own wells), gpm	Recirculated water, gpm	Natural gas, Mscf/hr
Crushing section................	3,200	-	300	-
Concentrator....................	36,800	9,600	46,300	-
Byproduct molybdenum recovery				
section.......................	2,000	3,000	-	50
Lime preparation section........	300	200	-	-
Subtotal..................	42,300	12,800	46,600	50
Lighting and cranes.............	300	-	-	-
Fresh water.....................	1,400	-	-	-
Recirculated water..............	600	-	-	-
Sanitary water..................	300	-	-	-
General facilities..............	600	500	-	20
Miscellaneous and contingency...	300	500	-	-
Subtotal..................	3,500	1,000	0	20
Total.....................	45,800	13,800	46,600	70

APPENDIX D.--COST ANALYSIS OF COPPER-LEACH OPERATIONS

The cost of producing copper from leachable ore is analyzed in this appendix. Costs were estimated for the forming of a leach dump, circulating the solution through the leach material to dissolve the leachable copper, and for recovering the copper from the leach solution. Two methods, cementation and solvent extraction-electrowinning, were considered for recovery of copper from the leach solution. Included for each operation are plant descriptions, flow diagrams, equipment lists, and capital and operating cost summaries.

Data pertaining to each operation follow.

Dump Formation and Solution Circulation

The cost of operating a leach dump that receives 2,000 tpd of leach ore, circulates 3,000 gpm of acid solution through the dump, pumps copper-containing solution to a cementation plant 10,000 feet distant, and returns depleted solution to the dump is analyzed in this section. The leach-dump area is underlain by impervious hardpan upon which the leach solution flows naturally to a collecting reservoir. Most of the acid needed for dissolving the copper minerals is self-generated by the ore which contains about 15 percent pyrite. The leach ore is a byproduct material from open-pit mining of a commercial ore body. Mining costs of the leach material are charged to commercial ore production because they would be incurred no matter what the disposition of the leach ore. Dozers, charged to the leach operation, are used to distribute leach ore evenly over the heaps, which are about 300 feet square. Lifts of 25 feet are used until a final height of 200 feet is reached. Upon completion of each lift a network of pipe is laid on the leach heap and a leaching solution is distributed to the leach heap for about 6 months. The pipe is then moved to a similar adjoining heap while another 25-foot lift of leach ore is bedded for subsequent leaching.

Figure D-1 is a flow diagram of the solution-circulating section and table D-1 lists the equipment required to prepare the material and apply the solution.

Estimated total capital requirement, including facilities, utilities, and working capital, is $1.07 million (table D-2).

Estimated annual operating costs, direct, indirect, and fixed, of $201,200 or $0.282 per ton of ore bedded are detailed in table D-3.

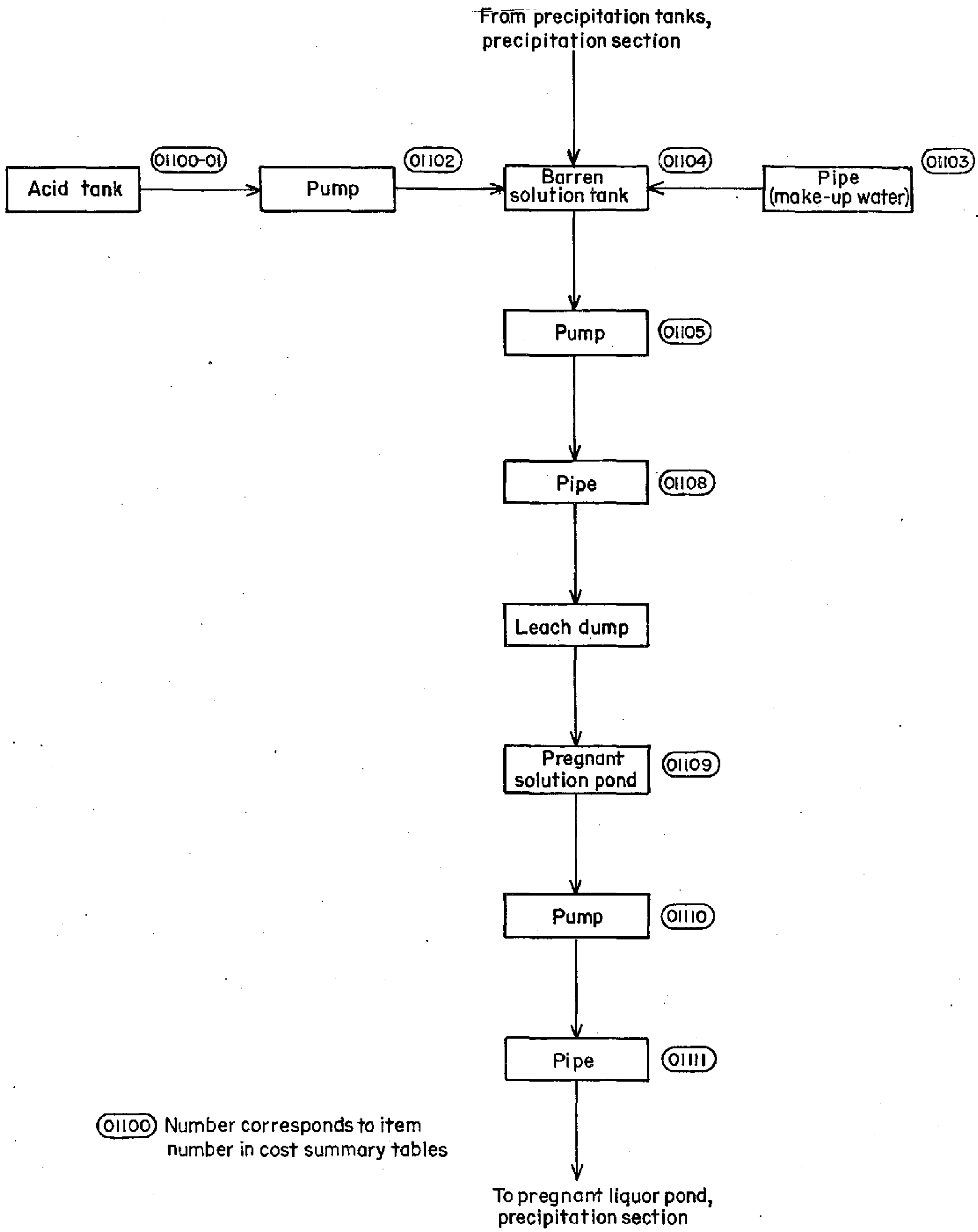

FIGURE D-1. - Flow diagram of solution circulating section, 3,000-gpm solution circulated, copper-leach operation.

TABLE D-1. - Cost summary, 2,000-tpd ore bedded, 3,000-gpm solution circulated, dump leaching section of copper-leach operation

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost: Material	Cost: Labor	Total cost
01100	Tank	1	10,000 gal, stainless steel	-	-	$12,000	$1,900	$13,900
01101	....do....	1	4,000 gal, stainless steel	-	-	7,000	1,100	8,100
01102	Pump	3	5-in stainless steel vertical slurry pump.	1- 30 2- 50	130	26,000	4,200	30,200
01103	Pipe	5,500 ft	4-in diam, galvanized steel	-	-	10,600	4,300	14,900
01104	Barren solution tank	1	12 ft by 12 ft by 6 ft	-	-	2,300	2,300	4,600
01105	Pump	4	6-in stainless steel vertical slurry pump.	2-275 2-100	750	44,200	7,100	51,300
01106	Pipe	10,000 ft	14-in diam, epoxy-lined asbestos cement.	-	-	70,400	35,200	105,600
01107	....do....	2,500 ft	10-in diam, epoxy-lined asbestos cement.	-	-	10,900	5,500	16,400
01108	....do....	32,000 ft	8-in diam, epoxy-lined acid asbestos	-	-	107,200	53,600	160,800
01109	Pregnant solution collecting pond.	1	50 ft by 100 ft clay lined pond, 50 ft by 15 ft high concrete dam.	-	-	3,600	3,900	7,500
01110	Pump	2	8-in stainless steel vertical slurry pump.	1-125 1-200	325	29,000	2,100	31,100
01111	Pipe	10,500 ft	12-in diam, epoxy-lined asbestos cement.	-	-	58,500	23,900	82,400
01112	Office and warehouse (share with precipitation section).	1/2	20 ft by 40 ft with 10-ft eave including utilities at $25 per sq ft.	-	-	7,800	2,200	10,000
01113	Yard, storage area, and fire protection (share with precipitation section).	1/2	Extension of plant road	-	-	11,700	3,300	15,000
01114	Dozer	1	Diesel-powered crawler tractor with 67,000-lb draw bar pull.	385	385	100,000	-	100,000
01115	Truck (share with precipitation section).	1/2	20-ton flatbed, diesel powered	150	150	7,500	-	7,500
01116	Truck	1	1/2-ton pickup	80	80	3,000	-	3,000
	Total direct cost	-	-	-	1,820	511,700	150,600	662,300
	Field indirect	-	-	-	-	-	-	75,300
	Total construction	-	-	-	-	-	-	737,600
	Engineering	-	-	-	-	-	-	36,900
	Administration and overhead	-	-	-	-	-	-	36,900
	Subtotal	-	-	-	-	-	-	811,400
	Contingency	-	-	-	-	-	-	81,100
	Subtotal	-	-	-	-	-	-	892,500
	Fee	-	-	-	-	-	-	44,600
	Total	-	-	-	-	-	-	937,100

TABLE D-2. - Estimated capital requirements, 2,000-tpd ore bedded, 3,000-gpm solution circulated, dump leaching section of copper-leach operation

Unit	Cost
Copper ore bedding and solution section	$937,100
Subtotal	937,100
General facilities and utilities	93,700
Subtotal for depreciation, taxes, and insurance	1,030,800
Working capital[1]	40,800
Total	1,071,600

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE D-3. - Estimated annual operating cost, 2,000-tpd ore bedded, 3,000-gpm solution circulated, dump leaching section of copper-leach operation

	Annual cost	Total	Cost per ton ore
Direct cost:			
Materials and utilities:			
Power....370 kW-hr/hr × 8,760 hr/yr × $0.007/kW-hr..	$22,700	-	-
Sulfuric acid....0.6 ton acid/ton copper × 2,560 tons × $12.50/ton..	19,200	-	-
Diesel fuel....15,600 gal/yr × $0.16/gal..	2,500	-	-
Miscellaneous operating supplies....	2,300	-	-
Subtotal....	-	$46,700	$0.065
Direct labor:			
12 man-hr/day....$3.50/man-hr × 357 day/yr..	15,000	-	-
Supervision....1 metallurgist 1/2 time..	7,000	-	-
Subtotal....	-	22,000	.031
Maintenance (by plant crew and charged pro rata):			
3 man-hr/day....$3.60/man-hr × 357 day/yr..	3,900	-	-
Supervision....20 percent of labor..	800	-	-
Equipment maintenance supplies and parts....	9,000	-	-
Subtotal....	-	13,700	.019
Payroll overhead....25 percent of payroll..	-	6,700	.009
Total direct cost....	-	89,100	.125
Indirect cost:			
Administrative, technical, and clerical labor....	6,100	-	.009
Payroll overhead....25 percent of administrative payroll..	1,500	-	.002
Buildings and facilities maintenance and supplies 5 percent of plant facilities..	4,700	-	.029
General overhead includes head office charges, exploration, and research 5 percent of direct costs..	4,500	-	.006
Total indirect cost....	-	16,800	.024
Fixed cost:			
Taxes and insurance....2 percent of plant cost..	19,600	-	.027
Depreciation....15 years..	55,200	-	.077
Depreciation....10 years..	15,400	-	.022
Amortized future equipment requirements....	5,100	-	.007
Total fixed cost....	-	95,300	.133
Gross operating cost....	-	201,200	.282

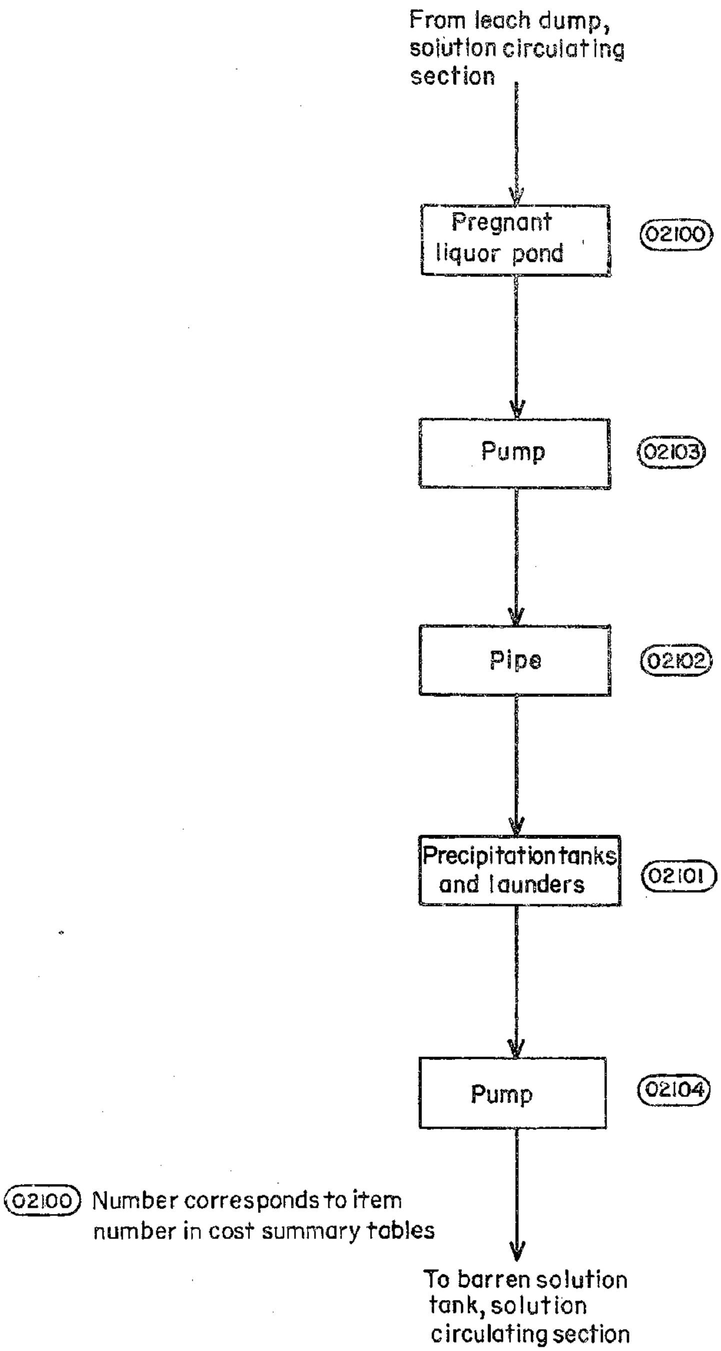

FIGURE D-2. - Flow diagram of copper precipitation section, 3,000-gpm solution treated, copper-leach operation.

Cementation

The cost of producing 3,000 tpy of cement copper from leach solutions circulating at 3,000 gpm is analyzed in this section. The solution is circulated through tanks and launders containing the scrap iron which precipitates copper from the acid solution. A mobile crane equipped with a magnet or clamshell and a front-end loader are used to recharge the precipitation tanks with scrap iron and remove the precipitated copper. The copper is dewatered and shipped to a smelter.

Figure D-2 is a flow diagram of this section of a copper-leach operation and table D-4 contains a listing of the equipment.

The total estimated capital investment, including facilities, utilities, and working capital, is \$0.73 million (table D-5).

The total estimated annual operating cost (table D-6), including direct, indirect, and fixed costs, is \$307,700 or \$0.051 per pound of recoverable copper.

Solvent Extraction and Electrowinning

The cost of producing 7,000 tpy of electrolytic copper from leach-dump solutions circulating at 3,000 gpm using solvent extraction and electrowinning methods is analyzed in this section. This method uses an organic solution containing 8 percent LIX64N (a patented General Mills Chemical, Inc., trade name) and 92 percent kerosene. The LIX64N solution has a much stronger affinity for copper than does SO_4 when in weak sulfuric acid solution, but a much weaker affinity for copper than SO_4 when in strong sulfuric acid solution.

TABLE D-4. - Cost summary, copper precipitation section, 3,000-gpm solution treated, 3,000-tpy copper produced, copper-leach operation

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost		Total cost
						Material	Labor	
02100	Pregnant liquor pond.......	1	100 ft by 300 ft by 25 ft deep, concrete with clay lining.	-	-	$42,300	$25,700	$68,000
02101	Precipitating tanks and launders.	1	385-cu-yd reinforced concrete at $200 per cu yd, 267-cu-yd concrete pads at $125 per cu yd, 109-cu-yd miscellaneous concrete at $150 per cu yd.	-	-	60,900	65,900	126,800
02102	Pipe......................	1,000 ft	14-in diam, epoxy-lined asbestos cement.	-	-	7,000	3,500	10,500
02103	Pump......................	3	4-in stainless steel vertical slurry..	25	75	21,000	3,400	24,400
02104	...........do............	2	2-in stainless steel, vertical high pressure.	10	20	8,400	1,300	9,700
02105	Front-end loader..........	1	Rubber tired, 2-cu-yd bucket diesel powered.	100	100	27,000	-	27,000
02106	Crane.....................	1	Mobile, rubber tired, diesel powered, 30-ton, 60-ft boom.	125	125	80,000	-	80,000
02107	Magnet....................	1	For crane, 5-ft diam, 4,000-lb lifting capacity with 20-kV-A diesel generator.	45	45	12,300	-	12,300
02108	Clamshell bucket..........	1	3/4 cu yd (for crane)................	-	-	2,500	-	2,500
02109	Truck.....................	1	20-ton flatbed......................	150	150	15,000	-	15,000
02110	...........do............	1	1/2-ton pickup......................	80	80	3,000	-	3,000
02111	Office and warehouse (share with solution section).	1/2	20 ft by 40 ft with 10-ft eave including utilities at $25 per sq ft.	-	-	7,800	2,200	10,000
02112	Yard, storage area, and fire protection (share with solution section).	1/2	Extension of plant road and fire protection system, 20,000-sq-ft yard storage.	-	-	11,700	3,300	15,000
	Total direct cost.....	-	-	-	570	298,900	105,300	404,200
	Field indirect............	-	-	-	-	-	-	52,700
	Total construction....	-	-	-	-	-	-	456,900
	Engineering...............	-	-	-	-	-	-	22,800
	Administration and overhead	-	-	-	-	-	-	22,800
	Subtotal............	-	-	-	-	-	-	502,500
	Contingency...............	-	-	-	-	-	-	50,300
	Subtotal............	-	-	-	-	-	-	552,800
	Fee.......................	-	-	-	-	-	-	27,600
	Total................	-	-	-	-	-	-	580,400

TABLE D-5. - Estimated capital requirements, copper precipitation section, 3,000-gpm solution treated, 3,000-tpy copper produced, copper-leach operation

Unit	Cost
Copper precipitation section	$580,400
Subtotal	580,400
General facilities and utilities	58,000
Subtotal for depreciation, taxes, and insurance	638,400
Working capital[1]	89,900
Total capital required	728,300

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE D-6. - Estimated annual operating cost, copper precipitation section, 3,000-gpm solution treated, 3,000-tpy copper produced, copper-leach operation

	Annual cost	Total	Cost per pound copper
Direct cost:			
Materials and utilities:			
Power....50 kW-hr/hr X 8,760 hr/yr X $0.007/kW-hr..	$3,100	-	-
Scrap iron 1.7 ton scrap/ton copper X 3,000 tons X $25/ton..	127,500	-	-
Diesel fuel.............11,260 gal/yr X $0.16/gal..	1,800	-	-
Miscellaneous operating supplies	3,500	-	-
Subtotal	-	$135,900	$0.023
Direct labor:			
26 man-hr/day...........$3.25/man-hr X 260 day/yr..	22,000	-	-
Supervision.............1 full-time metallurgist..	14,000	-	-
Subtotal	-	36,000	.006
Maintenance (by plant crew and charged pro rata):			
5 man-hr/day...........$3.60/man-hr X 365 day/yr..	6,600	-	-
Supervision...................20 percent of labor..	1,300	-	-
Equipment maintenance supplies and parts	17,600	-	-
Subtotal	-	25,500	.004
Payroll overhead.............25 percent of payroll..	-	11,000	.002
Total direct cost	-	208,400	.035
Indirect cost:			
Administrative, technical, and clerical labor	14,300	-	.002
Payroll overhead 25 percent of administrative payroll..	3,600	-	.001
Buildings and facilities maintenance and supplies 5 percent of plant facilities..	2,900	-	.002
General overhead includes head office charges, and research............5 percent of direct costs..	10,400	-	.002
Total indirect cost	-	31,200	.005
Fixed cost:			
Taxes and insurance...2 percent of total plant cost..	12,600	-	.002
Depreciation.............................15 years..	28,800	-	.005
Depreciation.............................10 years..	20,000	-	.003
Amortized future equipment requirements	6,700	-	.001
Total fixed cost	-	68,100	.011
Gross operating cost	-	307,700	.051

Figure D-3 is a flow diagram of one of the four solvent extraction circuits used in the operation. Table D-7 contains a listing of equipment and associated costs required for the four-circuit plant.

In the extraction circuit, copper-leach solution is agitated in four stages with LIX64N solution to transfer the copper to the latter. The mixture of the two solutions is then separated by gravity into a lighter organic portion containing the copper and a barren acid solution which is returned to the leach dumps. Strong sulfuric acid in the form of spent electrolyte from the electrowinning section is added to the organic solution and the mixture of the two is agitated in a three-stage stripper circuit. The copper combines with SO_4 in the acid during agitation. The mixture of the solutions is then separated by gravity and the organic solution is returned to the extraction circuit while the acid-copper solution (enriched electrolyte) is transferred to the electrowinning section.

Figure D-4 is a flow diagram of an electrowinning section containing a starter-sheet circuit and a commercial section. Table D-8 contains a listing of equipment and associated costs for the installation of the electrowinning section.

The enriched electrolyte is used as feed to a circuit preparing starter sheets as well as the commercial circuit which uses the starter sheets to recover copper by electrolysis from the enriched electrolyte. Heat exchangers are provided to maintain the solution at 110° to 120° F. A continuous flow of electrolyte is maintained through the cells with overflow recirculating through the system. The spent electrolyte is recycled to the third stage of stripper circuit in the solvent extraction section.

The total estimated capital requirement for the solvent extraction and electrowinning sections, including facilities, utilities, and working capital, is \$6.4 million (table D-9).

The estimated annual operating cost (table D-10), including direct, indirect, and fixed costs, is \$1.35 million or \$0.096 per pound of recoverable copper.

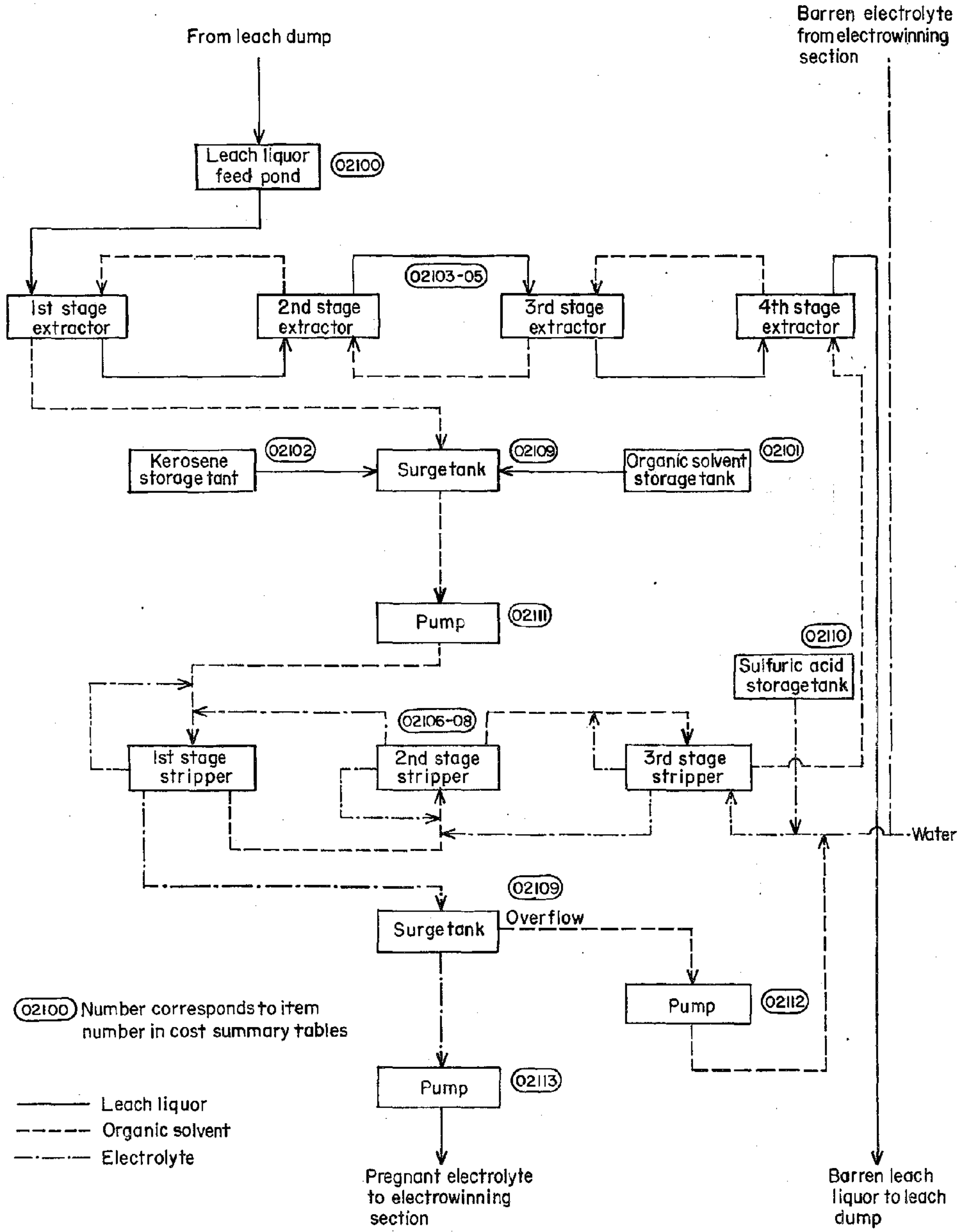

FIGURE D-3. - Flow diagram of solvent extraction section, 3,000-gpm solvent extraction and 7,000-tpy electrowinning copper-leach operation.

TABLE D-7. - Cost summary, solvent extraction section, 3,000-gpm solvent extraction and 7,000-tpy electrowinning copper-leach operation

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost: Material	Cost: Labor	Total cost
02100	Leach liquor feed pond......	1	100 ft by 300 ft by 20 ft deep, concrete and clay lined earth.	-	-	$37,200	$22,300	$59,500
02101	Organic solvent storage tank	1	1,000 gal, stainless steel........	-	-	2,000	300	2,300
02102	Kerosene storage tank.......	1	10,000 gal, stainless steel.......	-	-	10,100	1,600	11,700
02103	Extractor mixer tank........	16	8-ft diam by 9 ft, stainless steel	-	-	82,000	13,200	95,200
02104	Pumping type agitator.......	16	Stainless steel..................	15	240	66,900	4,700	71,600
02105	Extractor settler tank......	16	3 ft 9 in by 14 ft by 64 ft, stainless steel.	-	-	327,000	53,000	380,000
02106	Stripper mixer tank.........	12	7-ft diam by 9 ft, stainless steel	-	-	50,000	8,100	58,100
02107	Stripper settler tank.......	12	3 ft 9 in by 14 ft by 64 ft, stainless steel.	-	-	270,200	43,700	313,900
02108	Pumping type agitator.......	12	Stainless steel..................	15	180	50,200	3,500	53,700
02109	Pregnant organic electrolyte surge tank.	2	60,000 gal, stainless steel.......	-	-	67,600	10,800	78,400
02110	Sulfuric acid storage tank..	1	10,000 gal, stainless steel.......	-	-	10,100	1,600	11,700
02111	Pregnant organic supply pump	4	1-in stainless steel..............	.5	2	4,300	300	4,600
02112	Overflow return pump........	4	................do................	.5	2	4,300	300	4,600
02113	Pregnant electrolyte feed pump.	4	2-in stainless steel..............	15	60	16,800	1,200	18,000
	Subtotal...............	-	-	-	484	998,700	164,600	1,163,300
	Excavation..................	-	-	-	-	14,500	82,500	97,000
	Concrete....................	-	-	-	-	105,200	113,900	219,100
	Buildings...................	-	-	-	-	54,100	15,300	69,400
	Piping......................	-	-	-	-	245,900	100,500	346,400
	Electrical..................	-	-	-	-	86,400	67,900	154,300
	Painting....................	-	-	-	-	4,500	3,600	8,100
	Instrumentation.............	-	-	-	-	119,100	39,600	158,700
	Insulation..................	-	-	-	-	9,000	1,200	10,200
	Subtotal...............	-	-	-	-	638,700	424,500	1,063,200
	Total direct cost......	-	-	-	-	1,637,400	589,100	2,226,500
	Field indirect..............	-	-	-	-	-	-	294,600
	Total construction.....	-	-	-	-	-	-	2,521,100
	Engineering.................	-	-	-	-	-	-	126,100
	Administration and overhead.	-	-	-	-	-	-	126,100
	Subtotal...............	-	-	-	-	-	-	2,773,300
	Contingency.................	-	-	-	-	-	-	277,300
	Subtotal...............	-	-	-	-	-	-	3,050,600
	Fee.........................	-	-	-	-	-	-	152,500
	Total..................	-	-	-	-	-	-	3,203,100

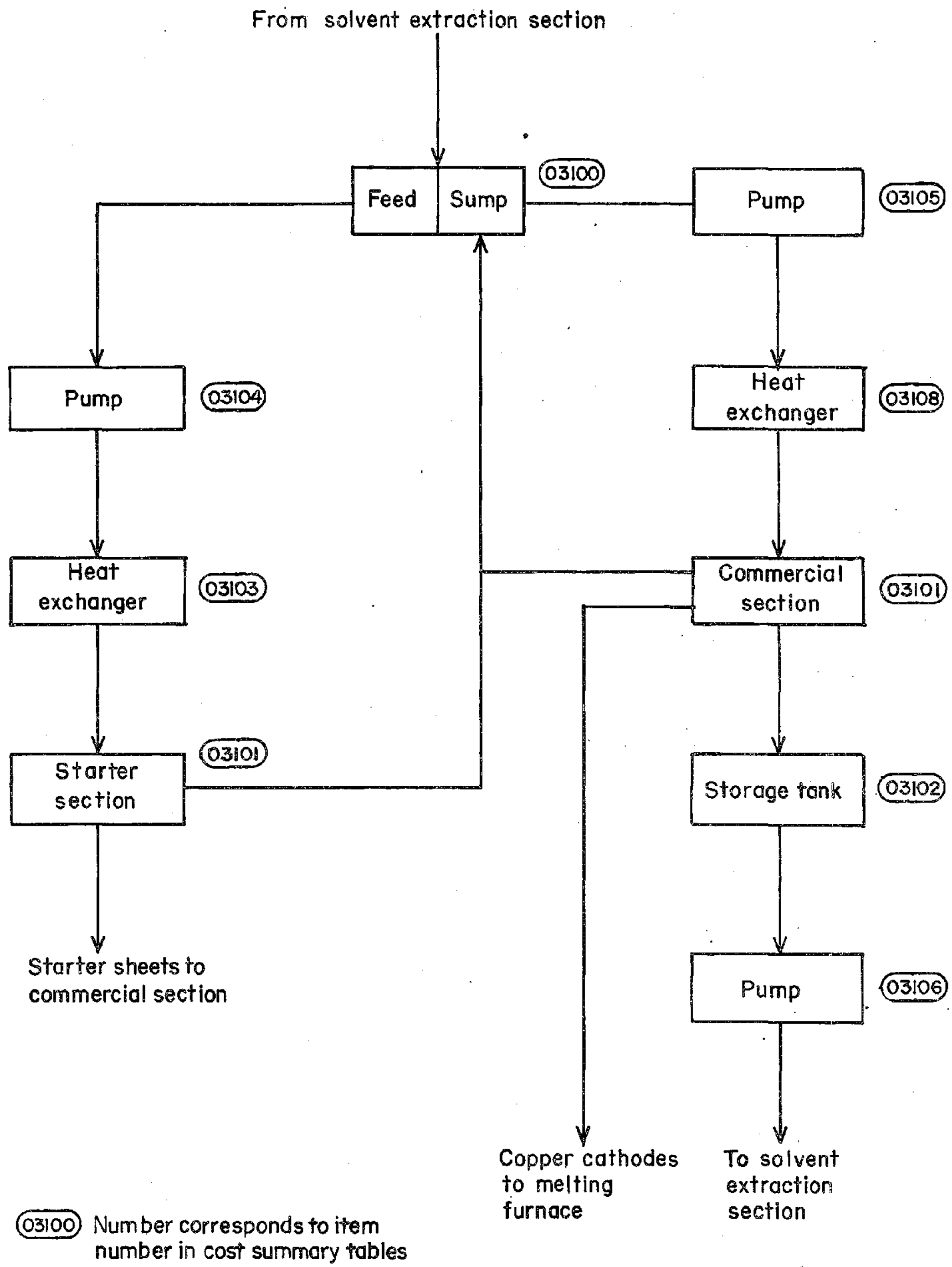

FIGURE D-4. - Flow diagram of electrowinning section, 3,000-gpm solvent extraction, 7,000-tpy electrowinning copper-leach operation.

TABLE D-8. - Cost summary, electrowinning section, 3,000-gpm solvent extraction and 7,000-tpy electrowinning copper-leach operation

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost Material	Cost Labor	Total cost
03100	Electrolyte feed sump..........	1	22 ft by 32 ft by 8 ft deep concrete, PVC lined.	-	-	$4,900	$5,300	$10,200
03101	Electrowinning tanks...........	48	4 ft by 17 ft by 5 ft deep concrete, PVC lined.	-	-	63,600	69,000	132,600
03102	Electrolyte tails tank.........	1	17 ft by 17 ft by 10 ft deep.	-	-	5,300	5,800	11,100
03103	Electrolyte feed heat exchanger	1	Stainless steel..............	-	-	13,200	900	14,100
03104	Electrolyte pump (starter) sheet section recirculator.	1	750 gpm, stainless steel.....	25	25	10,600	800	11,400
03105	Electrolyte pump (commercial section recirculator).	1	2,880 gpm, stainless steel...	100	100	14,900	1,100	16,000
03106	Electrolyte pump tails.........	1	133 gpm, stainless steel.....	15	15	7,000	500	7,500
03107	Bridge crane...................	1	5-ton, 40-ft span............	-	-	13,000	2,000	15,000
03108	Aqueous recycle heat exchanger.	1	8 in by 22 ft stainless steel	-	-	5,700	400	6,100
03109	Boiler plant...................	1	Complete.....................	-	-	75,300	2,800	78,100
	Subtotal.................	-	-	-	140	213,500	88,600	302,100
	Excavation.....................	-	-	-	-	2,700	15,400	18,100
	Concrete.......................	-	-	-	-	75,400	81,600	157,000
	Buildings......................	-	-	-	-	178,800	50,400	229,200
	Piping.........................	-	-	-	-	135,200	55,200	190,400
	Electrical.....................	-	-	-	-	370,200	290,800	661,000
	Painting.......................	-	-	-	-	3,100	2,400	5,500
	Instrumentation................	-	-	-	-	13,500	4,500	18,000
	Insulation.....................	-	-	-	-	5,000	700	5,700
	Subtotal.................	-	-	-	-	783,900	501,000	1,284,900
	Total direct costs........	-	-	-	-	997,400	589,600	1,587,000
	Field indirect.................	-	-	-	-	-	-	294,800
	Total construction........	-	-	-	-	-	-	1,881,800
	Engineering....................	-	-	-	-	-	-	94,100
	Administration and overhead....	-	-	-	-	-	-	94,100
	Subtotal.................	-	-	-	-	-	-	2,070,000
	Contingency....................	-	-	-	-	-	-	207,000
	Subtotal.................	-	-	-	-	-	-	2,277,000
	Fee............................	-	-	-	-	-	-	113,900
	Total....................	-	-	-	-	-	-	2,390,900

TABLE D-9. - Estimated capital requirements, 3,000-gpm solvent extraction and 7,000-tpy electrowinning sections of copper-leach operation

Unit	Cost
Solvent extraction section	$3,203,100
Electrowinning section	2,390,900
Subtotal	5,594,000
General facilities and utilities	559,400
Subtotal for depreciation, taxes, and insurance	6,153,400
Working capital[1]	259,800
Total capital required	6,413,200

[1]Estimated as the total of a supply and spare part inventory equal to 2 months' consumption and of a cash reserve equal to 3 months' direct, indirect, and insurance cost.

TABLE D-10. - Estimated annual operating cost, 3,000-gpm solvent extraction and 7,000-tpy electrowinning sections of copper-leach operation

	Annual cost	Total	Cost per pound copper
Direct cost:			
Materials and utilities:			
Power..1,850 kW-hr/hr x 8,760 hr/yr x $0.007/kW-hr	$113,400	-	-
Natural gas..14 Mscf/hr x 8,760 hr/yr x $0.43/Mscf	52,700	-	-
Organic solvent..62,680 lb x $2.50/lb	156,700	-	-
Kerosene	15,100	-	-
Stripping acid	14,000	-	-
Miscellaneous operating supplies	10,800	-	-
Subtotal	-	$362,700	$0.026
Direct labor:			
112 man-hr/day..$3.46/man-hr x 365 day/yr	141,400	-	-
Supervision..15 percent of labor	21,200	-	-
Subtotal	-	162,600	.012
Maintenance (partially by plant crew and charged pro rata):			
32 man-hr/day..$3.65/man-hr x 365 day/yr	42,600	-	-
Supervision..20 percent of labor	8,500	-	-
Maintenance supplies and parts	52,700	-	-
Subtotal	-	103,800	.007
Payroll overhead..25 percent of payroll	-	53,400	.004
Total direct cost	-	682,500	.049
Indirect cost:			
Administrative, technical, and clerical labor	41,100	-	.003
Payroll overhead 25 percent of administrative payroll	10,300	-	.001
Buildings and facilities maintenance and supplies 5 percent of cost	44,400	-	.003
General overhead includes head office charges, and research..5 percent of direct costs	34,100	-	.002
Total indirect cost	-	129,900	.009
Fixed cost:			
Taxes and insurance..2 percent of plant cost	123,100	-	.009
Depreciation..15 years	410,200	-	.029
Total fixed cost	-	533,300	.038
Gross operating cost	-	1,345,700	.096

APPENDIX E.--COST ANALYSIS OF A COPPER SMELTER

Capital and operating costs were estimated for a smelter operation using the direct-converter smelting method in which a portion of the copper concentrate is fed directly to the converter where it is combined with matte prepared in the reverberatory furnace. Designed input capacity of the plant is a nominal 391,000 tpy of dry concentrate, plus moderate quantities of copper precipitates and scrap. Output is 152,000 tpy of copper anodes and 1,075 tpd of byproduct 93-percent sulfuric acid.

For the purpose of estimating capital and operating costs, a feed of copper-containing materials and flux having the compositions shown in table E-1 was used. This table shows the composition and daily consumption of all feed material and composition and quantity of material in intermediate smelter processing streams and final products.

Process Description

The process, with the exception of the direct-converter smelting, is similar to that used at a typical smelter (11).[1] The smelting plant consists of materials handling and smelting sections.

Materials Handling

The concentrates are delivered to the smelter by railroad car and are fed directly to the reverberatory furnace or converters without further treatment. Other feed materials delivered are copper precipitates, scrap metal, and flux (silica rock).

[1] Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

TABLE E-1. - Streams of material flow through a 391,000-tpy copper smelter

	Material and stream number[1]																	
	Concentrate		Precipi-tate		Flux		Dust	Gas and dust		Slag		Matte	Matte shells	Reject anodes	Scrap	Blis-ter	Gas[2]	
Item....	1	10	2	11	3	12	4	5	9	6	7	8	13	14	15	16	17	18
Water...	73.4	45.7	8.2	5.1	-	-	-	365.7	50.8	-	-	-	-	-	-	-	416.5	416.5
Copper..	184.0	114.7	63.7	39.6	-	-	4.6	2.3	2.3	3.7	23.9	270.2	10.1	56.3	13.7	412.0	-	-
Iron....	163.6	101.9	3.5	2.2	15.3	13.3	18.2	9.1	9.1	299.8	308.1	199.8	10.0	-	-	-	-	-
Sulfur..	209.3	130.6	.9	.6	5.9	5.3	-	-	-	8.6	12.7	174.5	7.8	-	-	-	-	-
Silica..	59.4	37.0	2.3	1.4	156.0	135.1	18.2	9.1	9.1	391.2	175.4	11.0	1.4	-	-	-	-	-
Aluminum oxide..	15.4	9.6	2.6	1.6	5.0	4.5	-	-	-	38.7	20.9	5.2	.4	-	-	-	-	-
Calcium oxide..	4.4	2.7	.3	.2	4.1	3.5	-	-	-	15.2	12.9	6.5	.4	-	-	-	-	-
Nitrogen	-	-	-	-	-	-	-	2,160.0	1,134.7	-	-	-	-	-	-	-	3,294.9	3,294.7
Sulfur dioxide	-	-	-	-	-	-	-	92.4	596.6	-	-	-	-	-	-	-	689.0	34.5
Oxygen..	-	-	-	-	-	-	-	50.8	12.3	[3]152.3	[3]97.7	-	-	-	-	-	63.1	63.1
Carbon dioxide	-	-	-	-	-	-	-	346.9	-	-	-	-	-	-	-	-	346.9	346.9
Other...	23.5	14.6	-	-	49.8	43.0	10.0	5.0	5.0	129.3	54.2	3.2	-	-	3.7	5.3	-	-
Total	733.5	456.8	81.5	50.7	236.1	204.7	51.0	3,041.3	1,819.9	1,038.8	705.8	670.4	30.1	56.3	17.4	417.3	4,810.2	4,155.7

[1]For location of the material stream in the process refer to figure E-2; stream quantity is in tons per day.
[2]Does not include water and gases added in gas cleaning and acid plant.
[3]O_2 as FeO and Fe_3O_4.

Figure E-1 is a flow diagram of the materials-handling section. Table E-2 contains a listing of the quantity, size, horsepower, and estimated installation cost of the equipment.

Upon delivery, the concentrates are dumped into a 1,100-ton surge bin and then transferred via a feeder and shuttle conveyor to a 5,000-ton storage bin or a stockpile. Material from the storage bin is conveyed to the converter or reverberatory furnace supply bins; material in the stockpile is loaded with a front-end loader into a hopper and conveyed to the converter or reverberatory supply bins as needed.

Scrap metal, precipitates, anode rejects, matte shells, and skulls are stored and conveyed to the converter supply bin.

Anode rejects, skulls, and matte shells are feed internally generated in the smelting plant, whereas the precipitates, concentrates, and scrap metal are from external sources.

Flux, delivered to the materials-handling section by railroad car, is sized by a grizzly screen resulting in products of plus and minus 6-inch. Plus 6-inch material is fed directly to a jaw crusher for reduction to minus 4-inch. Minus 6-inch material is temporarily stored in a 450-ton surge bin and then fed to a vibrating grizzly screen resulting in a plus and a minus 4-inch product. Plus 4-inch is reduced in the jaw crusher to minus 4-inch product. The minus 4-inch material, conveyed to a vibrating screen, is sized, resulting in a plus 1/2-inch and a minus 1/2-inch product. Minus 1/2-inch bypasses the cone crusher while the plus 1/2-inch is reduced by the crusher to minus 1/2-inch. The combined product is transferred via the shuttle conveyor to a storage bin, stockpile, or fed directly to the converter supply bin. Flux, reclaimed from the storage bin by a crane equipped with a clam shell or from the stockpile by a front-end loader, is conveyed to the converter supply bin as needed.

Smelting

This section includes the reverberatory furnace, converters, holding and refining furnaces, and all associated equipment required to produce a refined anode. Figure E-2 is a flow diagram of the smelting section; numbers on the diagram show the disposition of the feed materials and the sequence of the processing streams listed in table E-1. Table E-3 lists the smelting section equipment.

The reverberatory furnace, 118 feet by 28 feet 8 inches (inside dimensions), has a capacity of 815 tons per furnace day of concentrates and precipitates. Natural gas (essentially methane) is used as fuel; costs are based upon heat requirements of 5.62 million Btu's per ton of solid charge.

The five converters (including one spare) are 13 feet by 30 feet and equipped with mechanical punchers.

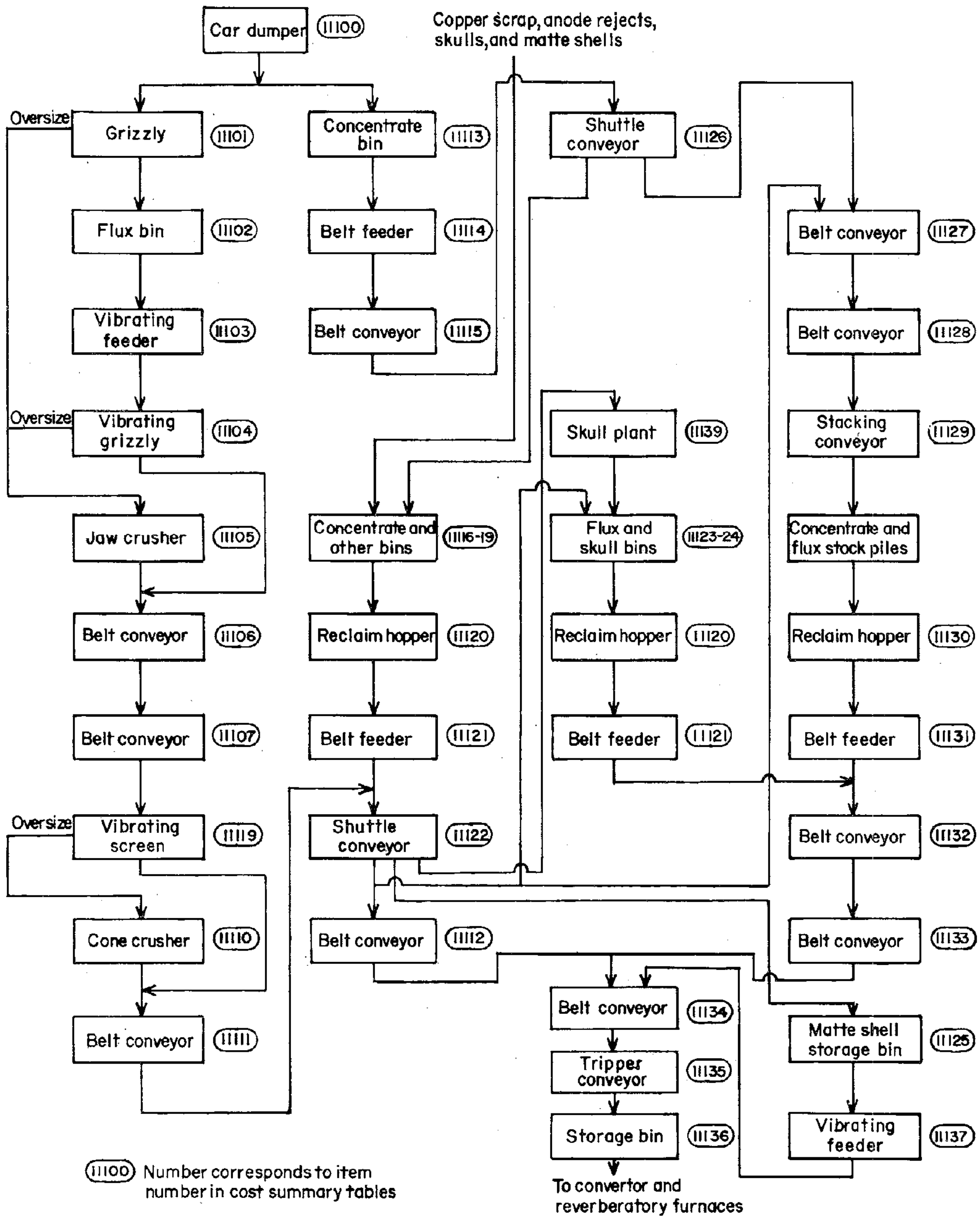

FIGURE E-1. - Flow diagram of materials-handling section, 391,000-tpy copper smelter.

TABLE E-2. - Cost summary, materials-handling section, 391,000-tpy copper smelter

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost: Material	Cost: Labor	Total cost
11100	Rotary car dumper..........	1	70-ton capacity..........	40	40	$97,500	$24,400	$121,900
11101	Stationary grizzly.........	1	20 ft by 20 ft, 6-in openings.	-	-	3,000	300	3,300
11102	Flux bin...................	1	450-ton..................	-	-	13,800	1,400	15,200
11103	Vibrating feeder...........	1	36 in by 60 in...........	2	2	2,100	200	2,300
11104	Vibrating grizzly..........	1	4 in, 250 tph capacity...	10	10	3,100	300	3,400
11105	Jaw crusher................	1	24 in by 36 in...........	125	125	24,000	6,000	30,000
11106	Belt conveyor..............	1	24 in by 55 ft...........	3	3	9,500	1,000	10,500
11107	............do.............	1	24 in by 190 ft..........	20	20	18,900	1,900	20,800
11108	Belt conveyor scale........	1	24 in....................	-	-	3,800	400	4,200
11109	Vibrating screen...........	1	8 ft by 16 ft, double-deck	10	10	8,400	800	9,200
11110	Cone crusher...............	1	5.5 ft standard..........	200	200	82,000	20,500	102,500
11111	Belt conveyor..............	1	24 in by 332 ft..........	35	35	29,100	2,900	32,000
11112	............do.............	1	24 in by 123 ft..........	5	5	13,000	1,300	14,300
11113	Concentrate bin............	1	1,100-ton................	-	-	33,100	3,300	36,400
11114	Belt feeder................	1	30 in by 46 ft...........	3	3	8,400	800	9,200
11115	Belt conveyor..............	1	30 in by 64 ft...........	7.5	7.5	10,400	1,000	11,400
11116	Concentrate storage bin....	1	5,000-ton................	-	-	45,500	4,600	50,100
11117	Anode reject storage bin...	1	500-ton..................	-	-	7,300	700	8,000
11118	Scrap metal storage bin....	1	200-ton..................	-	-	4,200	400	4,600
11119	Precipitate storage bin....	1	1,500-ton................	-	-	16,500	1,700	18,200
11120	Traveling hopper...........	2	200-ton..................	25	50	25,200	2,500	27,700
11121	Belt feeder................	2	24 in by 12.5 ft.........	2	4	7,600	800	8,400
11122	Reversible shuttle conveyor	1	24 in by 114 ft..........	5	5	11,900	1,200	13,100
11123	Silica storage bin.........	1	1,500-ton................	-	-	16,500	1,700	18,200
11124	Skull storage bin..........	1	500-ton..................	-	-	7,300	700	8,000
11125	Matte shell bin............	1	100-ton..................	-	-	5,400	500	5,900
11126	Reversible shuttle conveyor	1	30 in by 114 ft..........	3	3	14,400	1,400	15,800
11127	Belt conveyor..............	1	30 in by 100 ft..........	5	5	12,800	1,300	14,100
11128	............do.............	1	30 in by 76 ft...........	3	3	10,400	1,000	11,400
11129	Stacking conveyor..........	1	30 in by 471 ft..........	7.5	7.5	45,600	4,600	50,200
11130	Fixed hopper...............	1	400-ton..................	-	-	10,100	1,000	11,100
11131	Belt feeder................	1	24 in by 12.5 ft.........	2	2	3,800	400	4,200
11132	Belt conveyor..............	1	36 in by 252 ft..........	45	45	30,800	3,100	33,900
11133	............do.............	1	36 in by 55 ft...........	5	5	10,600	1,100	11,700
11134	............do.............	1	24 in by 414 ft..........	7.5	7.5	31,400	3,100	34,500
11135	Fixed tripper conveyor.....	1	24 in by 380 ft..........	7.5	7.5	36,400	3,600	40,000
11136	Converter feed storage bin.	5	100-ton..................	-	-	18,000	1,800	19,800
11137	Vibrating feeder...........	1	36 in by 60 in...........	2	2	2,100	200	2,300
11138	Crane, clam shell..........	1	15-ton, 6 cu yd..........	53	53	33,000	3,300	36,300
11139	Skull plant................	1	1 tph....................	3	3	46,900	11,700	58,600
	Subtotal..............	-	-	-	663	813,800	118,900	932,700
	Excavation.................	-	-	-	-	81,400	86,700	168,100
	Buildings..................	-	-	-	-	101,700	71,200	172,900
	Piping.....................	-	-	-	-	16,300	8,200	24,500
	Electrical.................	-	-	-	-	81,400	61,100	142,500
	Painting...................	-	-	-	-	2,400	7,200	9,600
	Instrumentation............	-	-	-	-	16,300	6,500	22,800
	Insulation.................	-	-	-	-	1,600	1,600	3,200
	Subtotal..............	-	-	-	-	301,100	242,500	543,600
	Total direct cost.....	-	-	-	-	1,114,900	361,400	1,476,300
	Field indirect.............	-	-	-	-	-	-	180,700
	Total construction.....	-	-	-	-	-	-	1,657,000
	Engineering................	-	-	-	-	-	-	82,900
	Administration and overhead	-	-	-	-	-	-	82,900
	Subtotal..............	-	-	-	-	-	-	1,822,800
	Contingency................	-	-	-	-	-	-	182,300
	Subtotal..............	-	-	-	-	-	-	2,005,100
	Fee........................	-	-	-	-	-	-	100,300
	Subtotal..............	-	-	-	-	-	-	2,105,400
11140	Front-end loader...........	2	Diesel-powered, rubber-tired, 3-cu-yd bucket.	225	450	50,000	-	50,000
11141	Forklift...................	1	Gasoline-powered, 28,000-lb capacity, counterbalanced.	80	80	20,000	-	20,000
11142	Bulldozer..................	2	Diesel-powered, crawler tractor, 50,000-lb draw bar pull.	270	540	140,000	-	140,000
	Subtotal..............	-	-	-	1,070	210,000	0	210,000
	Total.................	-	-	-	-	-	-	2,315,400

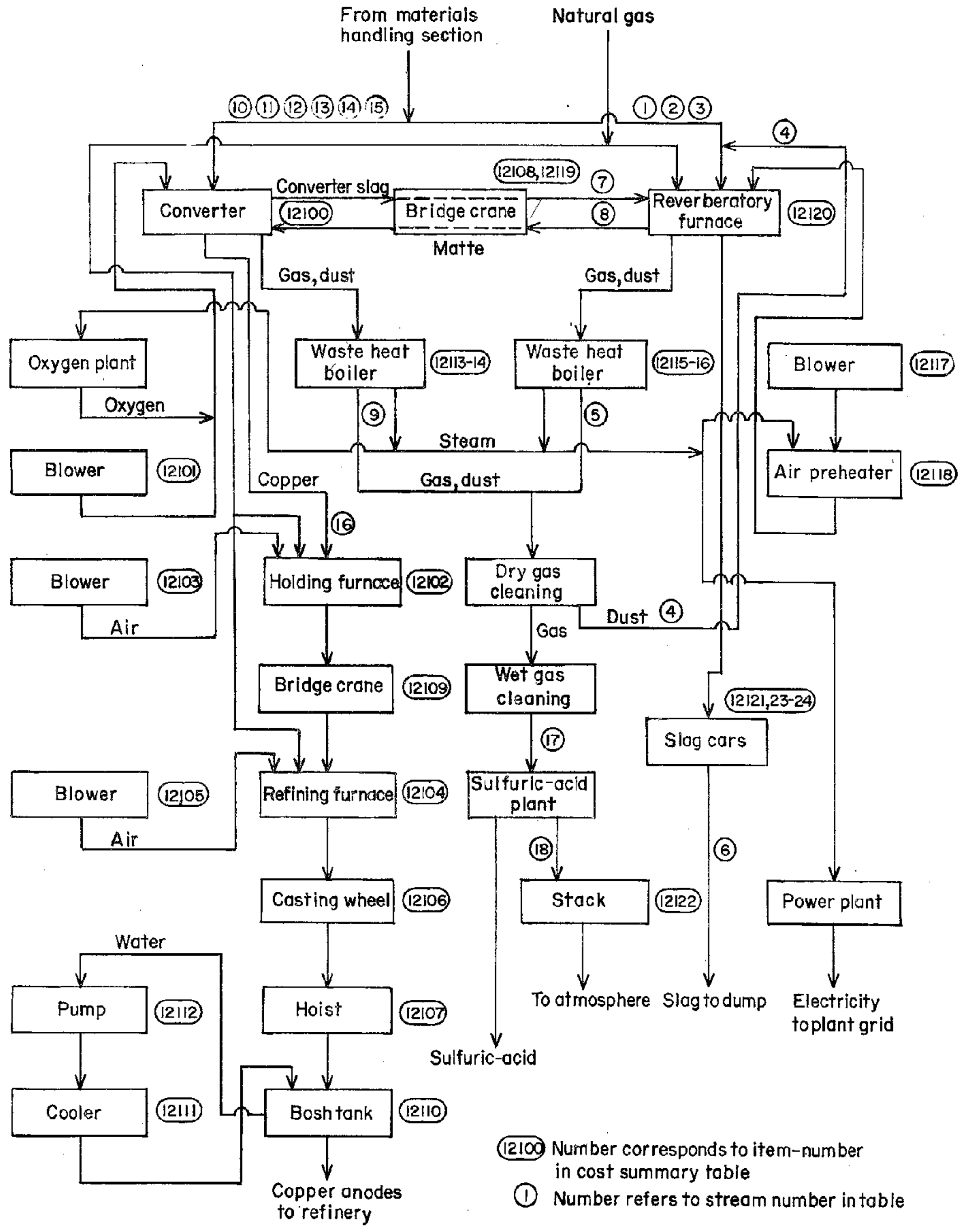

FIGURE E-2. - Flow diagram of smelting section, 391,000-tpy copper smelter.

TABLE E-3. - Cost summary, smelting section, 391,000-tpy copper smelter

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost: Material	Cost: Labor	Total cost
12100	Converter..............	5	13 ft by 30 ft, includes gun and tuyeres, gate, control and instrumentation for tuyeres, and motor.	-	-	$1,985,000	$198,500	$2,183,500
12101	Blower, converter.......	2	14,000 scfm, 14 psi............	1,425	2,850	200,000	50,000	250,000
12102	Holding furnace.........	1	Similar to converter except no tuyeres.	-	-	270,000	27,000	297,000
12103	Blower, holding furnace.	1	400 scfm, 10 psi..............	125	125	6,900	1,700	8,600
12104	Refining furnace........	2	Similar to converter...........	-	-	540,000	54,000	594,000
12105	Blower, refining furnace	1	1,600 scfm.....................	125	125	16,500	4,100	20,600
12106	Casting wheel...........	1	40-ft diam, 26 molds...........	100	100	81,000	8,100	89,100
12107	Hoist, jib tong.........	1	5-ton, 20-ft span..............	15	15	3,000	300	3,300
12108	Bridge crane............	2	60-ton main, 20-ton auxiliary, 60-ft span.	210	420	160,000	16,000	176,000
12109	...........do...........	1	50-ton main, 15-ton auxiliary, 60-ft span.	175	175	71,800	7,200	79,000
12110	Bosh tank...............	3	20 ft by 5 ft by 5 ft..........	5	15	12,000	1,200	13,200
12111	Air cooler..............	1	35,000-sq-ft area, 200° F gas side, 135° F air side, 2 50-hp fans.	100	100	25,200	6,300	31,500
12112	Pump....................	1	180 gpm, 435 psi...............	10	10	2,300	600	2,900
12113	Waste heat boiler, converter.[1]	1	15,000 sq ft, 47,600 lb of steam/hr, 350 psig, 2,200° F gas side, 700° F steam side. U:4.6 superheat; 4.8 vaporize; 4.9 preheat.	-	-	203,400	20,300	223,700
12114	Pump, boiler feed water.	1	100 gpm, 350 psi...............	30	30	3,100	800	3,900
12115	Waste heat boiler, reverberatory.[1]	1	30,190 sq ft, 95,800 lb of steam/hr, 350 psig, 2,200° F gas side, 700° F steam side. U:4.6 superheat; 4.8 vaporize; 4.9 preheat.	-	-	409,400	40,900	450,300
12116	Pump, boiler feed water.	1	190 gpm, 350 psig.............	60	60	4,300	1,300	5,600
12117	Blower..................	2	Air preheater, 14 psi.........	1,125	2,250	320,000	80,000	400,000
12118	Air preheater[1]..........	1	30,660 sq ft, 51,600 cu ft/min, 350 psig, 600° F gas side, 700° F steam side. U:5.	-	-	166,200	16,600	182,800
	Subtotal...........	-	-	-	6,275	4,480,100	534,900	5,015,000
	Excavation.............	-	-	-	-	896,000	954,200	1,850,200
	Buildings..............	-	-	-	-	627,200	403,200	1,030,400
	Piping.................	-	-	-	-	179,200	89,600	268,800
	Electrical.............	-	-	-	-	179,200	134,400	313,600
	Painting...............	-	-	-	-	26,900	67,300	94,200
	Instrumentation........	-	-	-	-	313,600	125,400	439,000
	Insulation.............	-	-	-	-	134,400	268,800	403,200
	Subtotal...........	-	-	-	-	2,356,500	2,042,900	4,399,400
12119	Ladle..................	4	30-ton.........................	-	-	-	-	60,000
12120	Reverberatory furnace...	1	118 ft by 28 ft 8 in, includes storage bin, shuttle conveyor, and charge feeders.	20	-	-	-	2,940,000
12121	Slag haulage system.....	15,840 ft	100-lb rail....................	-	-	-	-	273,600
12122	Stack..................	500 ft	24-ft ID.......................	-	-	-	-	758,000
	Subtotal...........	-	-	-	-	-	-	4,031,600
	Total direct cost..	-	-	-	-	-	-	13,446,000
	Field indirect..........	-	-	-	-	-	-	1,288,900
	Total construction.	-	-	-	-	-	-	14,734,900
	Engineering............	-	-	-	-	-	-	736,700
	Administration and overhead.	-	-	-	-	-	-	736,700
	Subtotal...........	-	-	-	-	-	-	16,208,300
	Contingency............	-	-	-	-	-	-	1,620,800
	Subtotal...........	-	-	-	-	-	-	17,829,100
	Fee....................	-	-	-	-	-	-	891,500
	Subtotal...........	-	-	-	-	-	-	18,720,600
12123	Slag car...............	8	Dual ladle, 150 cu ft, standard gage.	-	-	280,800	-	280,800
12124	Locomotive.............	3	Diesel-electric, 60-ton, heavy-duty.	700	2,100	405,000	-	405,000
12125	Bulldozer..............	1	Diesel-powered, crawler tractor	270	270	70,000	-	70,000
12126	Forklift...............	3	Gasoline-powered, 28,000-lb capacity, counterbalanced.	80	240	60,000	-	60,000
12127	Front-end loader........	1	Diesel-powered, rubber-tired, 3 cu yd.	225	225	25,000	-	25,000
12128	Motor grader...........	1	Diesel-powered, 47,000-lb draw-bar pull.	225	225	60,000	-	60,000
	Subtotal...........	-	-	-	3,060	900,800	-	900,800
	Total..............	-	-	-	-	-	-	19,621,400

[1]U indicates overall heat transfer coefficient; units are Btu/hr/° F.

Concentrates, precipitates, flux, and recycled dust from the converters and reverberatory gas streams, and slag from the converters are fed into the reverberatory furnace to produce a 40.3-percent copper content matte, reverberatory slag, and gases. The matte is fed to the converters, the slag discarded, and the gas and dust stream passed through waste heat boilers to produce 95,800 pounds per hour (pph) of 350-psig, 700° F steam. A portion of this steam, 33,000 pph, is used to preheat air to 600° F for use in the reverberatory furnace, 47,500 pph is used in the powerplant, and the remaining 15,300 pph is used in the oxygen plant.

Matte from the reverberatory furnace, concentrates and precipitates, flux, anode rejects, skulls, matte shells, and scrap metal are fed as solid feed to the converters. Blister copper (98.8 percent), converter slag, gases, and dust are products of the converters. The blister copper is transferred to a holding furnace and thence to the refining furnace. After refining, 700-pound anodes are cast and shipped to a refinery. The converter slag is recycled to the reverberatory furnace. The gas and dust stream is passed through a waste heat boiler to produce 47,600 pounds per hour of 350-psig, 700° F steam; 33,300 pph of this steam is used in the powerplant while the remainder is used for contingency purposes. The combined gas and dust streams from the converters and reverberatory furnaces are cleaned by wet and dry gas cleaning mechanisms. The dust is recycled to the reverberatory furnace while the gases are channeled to a sulfuric acid plant for the production of 1,075 tpd of 93 percent sulfuric acid prior to release to atmosphere. Composition of the gas by volume from the converter is as follows:

Component	Percent
CO_2............	4.9
N_2.............	72.9
SO_2............	6.7
O_2.............	1.2
H_2O............	14.3

Oxygen, generated in an associated plant, is used in the converters at a rate of 63.6 tpd.

The quantities of air delivered to the various areas by blowers are as follows: converter, 27,000 scfm; holding furnace, 400 scfm; refining furnace, 1,500 scfm; and air preheater, 51,600 scfm.

Natural gas requirements are 4,150 scfm to the reverberatory furnace, 400 scfm to the holding furnace, and 100 scfm to the refining furnace.

Capital Investment

Estimated capital requirements (table E-4) include the materials-handling and smelting sections of the smelter plus associated facilities such as the oxygen plant, sulfuric acid plant, gas cleaning facilities, powerplant, plant facilities and utilities, and working capital.

TABLE E-4. - Estimated capital requirements, 391,000-tpy copper smelter

Unit	Cost
Materials-handling section	$2,315,000
Smelting section	19,621,400
Oxygen plant	1,350,000
Sulfuric acid plant and gas cleaning	9,243,000
Powerplant	1,029,000
Subtotal	33,558,400
General facilities and utilities	6,124,500
Subtotal	39,682,900
Working capital[1]	2,424,600
Total capital required	42,107,500

[1]Estimated 3 months' direct, indirect, and insurance cost.

Cost of the oxygen plant was derived from a published paper (8). The cost of the wet and dry gas cleaning and sulfuric acid plant was obtained on a turnkey basis.

Plant facilities include administrative buildings, shops, warehouses, roads, fences, rolling stock, and a railroad spur; utilities include steam and power distribution, water storage and distribution, plant instrument air, fire protection, and sanitary water.

Total capital requirements are $42.1 million which includes $2.4 million working capital (table E-4).

Operating Cost

Estimated operating cost (table E-5), including direct, indirect, and fixed costs, is based on a three-shift-per-day, 365-day-per-year operation. Some portions of the materials-handling section may operate on a one-shift-per-day basis. This condition has been allowed for in the computations of the man-hours per day. The wage rate is estimated on the basis of the required job descriptions and weighted to reflect the differences in position wage rates.

Electrical power requirements in excess of on-site generating capabilities and natural gas are purchased from commercial sources; plant utility requirements are listed in table E-6.

Converter refractory downtime for repair and relining is allowed for by the existence of a spare converter. Reverberatory furnace repair will be by the hot-patching method.

The annual operating cost, assuming a credit for the sulfuric acid at $3.00 per ton, is $11.8 million or $0.040 per pound of copper. Allowing for a 12-percent return on the investment using the discounted-cash-flow method and allowing for Federal tax at 50 percent of gross profit the smelting cost is $0.064 per pound of copper.

TABLE E-5. - Estimated annual operating cost, 391,000-tpy copper smelter

	Annual cost	Total	Cost per pound copper
Direct cost:			
Materials and utilities:			
Power....4,150 kW-hr/hr X 8,760 hr/yr X $0.01/kW-hr..	$363,500	-	-
Natural gas..258.0 Mscf/hr X 8,760 hr/yr X $0.60/Mscf..	1,356,000	-	-
Flux, silica rock.....441 tpd X 365 day/yr X $5/ton..	804,800	-	-
Water.......27.0 Mgal/hr X 8,760 hr/yr X $0.10/Mgal..	23,700	-	-
Refractory..	468,000	-	-
Subtotal..	-	$3,016,000	$0.010
Direct labor:			
1,576 man-hr/day............$4/man-hr X 365 day/yr..	2,301,000	-	-
Supervision....................15 percent of labor..	345,200	-	-
Subtotal..	-	2,646,200	.009
Maintenance:			
Labor....444 man-hr/day X $4.25/man-hr X 365 day/yr..	688,800	-	-
Supervision....................20 percent of labor..	137,800	-	-
Maintenance supplies and parts......................	344,400	-	-
Subtotal..	-	1,171,000	.004
Payroll overhead................25 percent of payroll..	-	868,200	.003
Operating supplies....20 percent of plant maintenance..	-	234,200	.001
Total direct cost..................................	-	7,935,600	.027
Indirect cost: Administration and general overhead 40 percent of labor, maintenance, and supplies..	1,620,600	-	.005
Total indirect cost................................	-	1,620,600	.005
Fixed cost:			
Taxes and insurance...........2 percent of plant cost..	793,700	-	.003
Depreciation...............................15 years..	2,645,500	-	.009
Total fixed cost...................................	-	3,439,200	.012
Gross operating cost...............................	-	12,995,400	.043
Credit: Sulfuric acid..1,075 tpd X 365 day/yr X $3/ton..	1,177,100	-	-
Total credit.......................................	-	1,177,100	.004
Gross operating cost after credit..................	-	11,818,300	.039

TABLE E-6. - Plant utility requirements, 391,000-tpy copper smelter

Unit	Power, kW-hr/hr	New water, gpm	Cooling water, gpm	Natural gas, Mscf/hr	Steam production and consumption lb/hr at 350 psig and 700° F	
					Produced	Consumed
Materials handling..	290	-	-	-	-	-
Smelter............	6,660	30	-	4,300	143,400	33,000
Sulfuric acid plant.	3,460	50	670	-	-	-
Oxygen plant........	-	-	1,480	-	-	15,300
Subtotal.......	10,410	80	2,150	4,300	143,400	48,300
Powerplant..........	-	-	5,300	-	-	80,800
Cooling water.......	300	280	-	-	-	-
Lighting............	80	-	-	-	-	-
Sanitary water......	50	10	-	-	-	-
General facilities..	40	30	-	-	-	-
Miscellaneous and contingency........	620	50	550	-	-	14,300
Subtotal.......	1,090	370	5,850	0	0	95,100
Total..........	11,500	450	8,000	4,300	143,400	143,400

APPENDIX F.--COST ANALYSIS OF AN ELECTROLYTIC COPPER REFINERY

The smelter product, copper anodes, is further refined in an electrolytic refinery. Products of the process are copper oxide, wire bar, and billets; byproducts consist of sulfuric acid, nickel sulfate, and precious metals. In the process the copper of the anodes is electrically redeposited forming a cathode which is then melted and cast into wire bars and billets. The impurities such as precious metals are contained in slimes which are treated separately.

Process Description

The process flow diagram is that of a typical copper refinery consisting of two major sections. In the tankhouse section the anodes are converted into cathodes while in the melting and casting section the cathodes are cast into wire bar and billets.

Tankhouse Section

Figure F-1 is a flow diagram of the tankhouse section; table F-1 contains a listing of the equipment required in this section.

The tankhouse is arranged into three sections--the commercial section consisting of 1,566 commercial cells (tanks), a starting section containing 88 cells, and a section of 62 cells containing the liberator cells and standby cells for a total of 1,716 cells. The commercial section is subdivided into four electrolyte circulating circuits, each containing eight sections of 44 tanks and one circulating circuit containing 158 tanks.

The individual electrolytic cells are precast concrete lined with 8-pound 6-percent antimonial lead; the cells are connected using the Whitehead system.

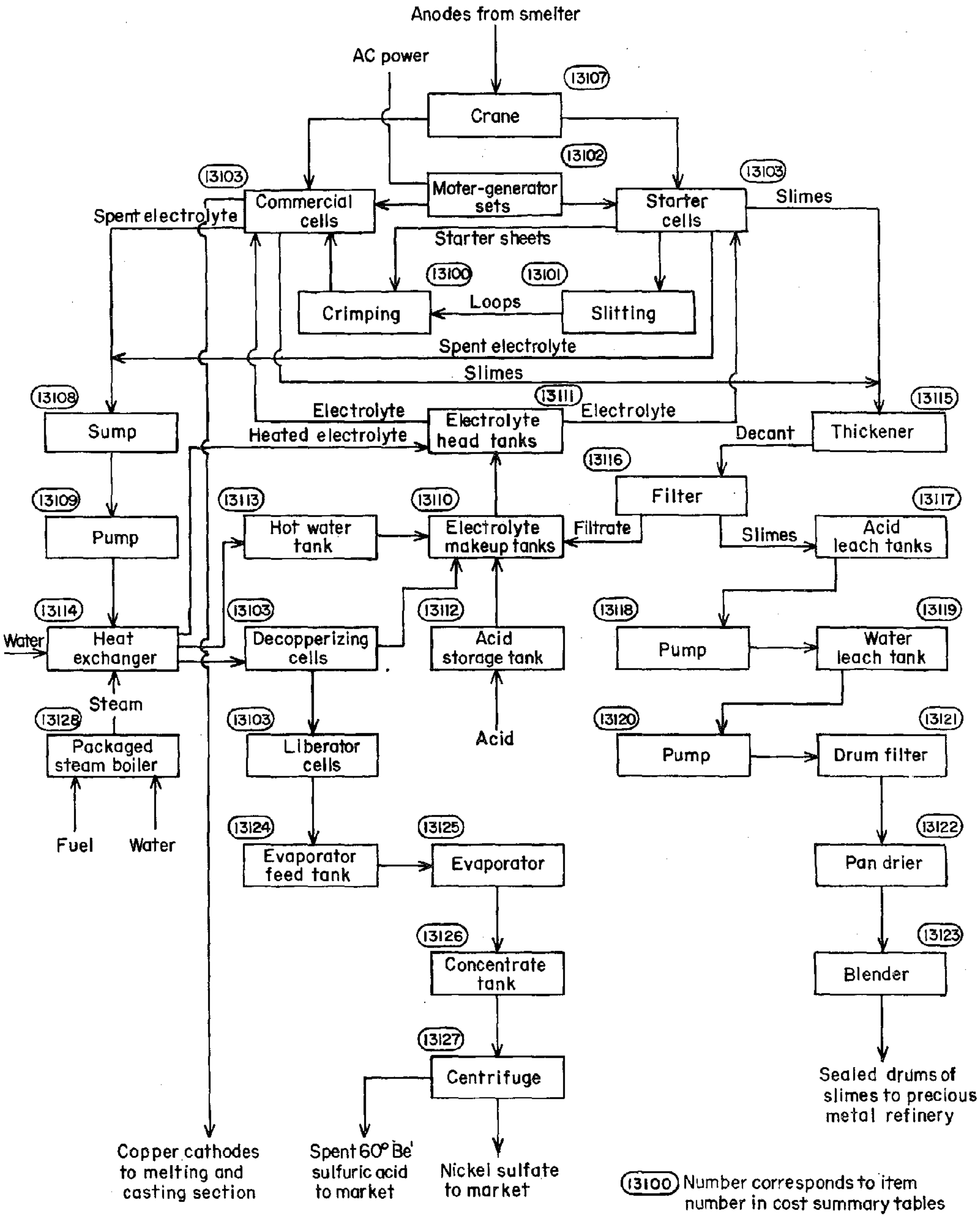

FIGURE F-1. - Flow diagram of tankhouse section, 300,000-tpy electrolytic copper refinery.

TABLE F-1. - Cost summary, tankhouse section, 300,000-tpy electrolytic copper refinery

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost Material	Cost Labor	Total cost
13100	Crimping machine......	1	-	5	5	$4,400	$400	$4,800
13101	Slitting machine......	1	-	5	5	5,000	500	5,500
13102	Motor-generator set...	8	1,000 kW, 125 volts	1,350	10,800	960,000	240,000	1,200,000
13103	Tanks, deposition.....	1,716	18 ft 9 in by 3 ft 7.5 in by 4 ft 1.5 in.	-	-	10,646,100	1,064,600	11,710,700
13104	Piping, lead-lined....	15,250 ft	-	-	-	135,600	13,600	149,200
13105	Launders, lead-lined..	16,000 ft	12 in..............	-	-	313,400	31,300	344,700
13106	Bus bars and connectors.	275,000 lb	-	-	-	137,500	13,800	151,300
13107	Crane, 15-ton overhead	9	80-ft span.........	50	450	1,012,500	607,500	1,620,000
13108	Sump..................	5	16,000 gal.........	-	-	63,000	6,300	69,300
13109	Pump (5 spares).......	15	800 gpm............	20	300	135,000	33,800	168,800
13110	Tank, electrolytic makeup.	5	16,000 gal.........	-	-	73,000	7,300	80,300
13111	Tank, head............	5	16,000 gal.........	-	-	73,000	7,300	80,300
13112	Tank, acid storage....	5	16,000 gal.........	-	-	73,000	7,300	80,300
13113	Tank, hot water.......	5	16,000 gal.........	-	-	73,000	7,300	80,300
13114	Heat exchanger........	5	600 sq ft..........	-	-	41,000	10,300	51,300
13115	Thickener.............	1	40-ft diam.........	10	10	45,400	4,500	49,900
13116	Filter, plate and frame.	1	20 sq ft...........	-	-	13,000	1,300	14,300
13117	Tank, acid leach......	2	1,000 gal..........	-	-	16,200	1,600	17,800
13118	Pump, acid leach tank.	2	100 gpm, 5 psi.....	½	1	7,500	1,900	9,400
13119	Tank, water leach.....	2	1,000 gal..........	-	-	16,200	1,600	17,800
13120	Pump, water leach tank	2	100 gpm, 5 psi.....	½	1	2,600	700	3,300
13121	Filter, rotary drum...	1	6 sq ft............	1	1	18,900	4,700	23,600
13122	Pan drier.............	1	3-ft diam..........	3	3	12,200	1,200	13,400
13123	Blender...............	1	30 cu ft...........	20	20	7,500	1,900	9,400
13124	Tank, evaporator feed.	1	2,260 cu ft........	-	-	15,200	1,500	16,700
13125	Evaporator............	1	90 sq ft...........	-	-	13,000	1,300	14,300
13126	Tank, nickel sulfate concentrator.	1	510 cu ft..........	-	-	4,900	500	5,400
13127	Centrifuge............	1	4-ft basket........	20	20	19,000	4,800	23,800
	Subtotal...........	-	-	-	11,616	13,937,100	2,078,800	16,015,900
	Excavation............	-	-	-	-	975,600	1,076,000	2,051,600
	Buildings.............	-	-	-	-	975,600	766,600	1,742,200
	Instrumentation.......	-	-	-	-	278,700	111,500	390,200
	Insulation............	-	-	-	-	278,700	418,100	696,800
	Electrical............	-	-	-	-	696,900	522,700	1,219,600
	Piping................	-	-	-	-	696,900	348,500	1,045,400
	Painting..............	-	-	-	-	41,800	125,400	167,200
	Subtotal...........	-	-	-	-	3,944,200	3,368,800	7,313,000
	Total direct........	-	-	-	-	17,881,300	5,447,600	23,328,900
	Field indirect........	-	-	-	-	-	-	2,723,800
	Total construction.	-	-	-	-	-	-	26,052,700
	Engineering...........	-	-	-	-	-	-	1,302,600
	Administration and overhead.	-	-	-	-	-	-	1,302,600
	Subtotal...........	-	-	-	-	-	-	28,657,900
	Contingency...........	-	-	-	-	-	-	2,865,800
	Subtotal...........	-	-	-	-	-	-	31,523,700
	Fee...................	-	-	-	-	-	-	1,576,200
	Subtotal...........	-	-	-	-	-	-	33,099,900
13128	Forklift..............	10	Gasoline-powered, 28,000-lb capacity, counterbalanced.	80	800	199,000	-	199,000
13129	Straddle carriers.....	4	Gasoline-powered, 45,000-lb capacity.	120	480	84,800	-	84,800
13130	Package steamplant....	1	Natural gas fired, 80,000 lb steam/hr at 50 psig and 298° F.	200	200	169,000	-	169,000
	Subtotal...........	-	-	-	1,480	452,800	0	452,800
	Total..............	-	-	-	-	-	-	33,552,700

Pertinent data about tankhouse operation and equipment, upon which the estimated costs are based, are contained in table F-2.

TABLE F-2. - Tankhouse data, 300,000-tpy electrolytic copper refinery

Anodes:		Electrolyte:	
Length....inches..	36	Specific gravity....	1.25
Width....do....	36	Cu....grams per liter..	42
Thickness....do....	1.75	Free acid....do....	200
Weight....pounds..	700	As....do....	7
Type suspension....cast lugs..	-	Ni....do....	10
Spacing center-to-center inches..	4.5	Fe....do....	0.5
Dissolution time....days..	28	Circulation rate....gpm..	4.5
Scrap....percent..	14.3	Pump type....centrifugal..	-
Cu....do....	99.40	Temperature (cell inlet)...° F..	150
Au....ounces per ton..	1.523	Temperature (cell outlet)..° F..	136
Ag....do....	17.138	Heating equipment (karbate tubular heat exchangers)....	-
Se....percent..	0.047	Purification method:	
Te....do....	0.022	Cu, As, Sb electrolytic liberation..	-
As....do....	0.062	Ni, Fe, etc....concentration..	-
Sp....do....	0.023	Addition agents:	
Bi....do....	0.004	Glue....pounds per ton cathode..	0.05
Pb....do....	0.035	Goulac....do....	0.25
Ni....do....	0.075	Power:	
Fe....do....	0.014	Amperes per cell....	16,000
S....do....	0.006	Cathode current density, amperes per square foot....	17.8
Insoluble....do....	0.046	Cell voltage....	0.210
O....do....	0.22	Conversion equipment, motor generator sets....	-
Anode slimes:		Generator size....kilowatts..	1,000
Quantity..pounds per anode-ton..	15	Generator....voltage..	125
Removal frequency....days..	28	Generator....amperage..	8,000
Cu....percent..	26.4	Current efficiency....percent..	95
Au....ounces per ton..	404	Power consumption (per ton cathode)....kilowatt-hours..	175
Ag....do....	4,428	Electrolytic cells:	
Se....percent..	11.59	Material (concrete)....	-
Te....do....	4.84	Lining (8-pound 6-percent antimonial lead)....	-
As....do....	1.40	Length inside....feet..	18.75
Sb....do....	0.49	Width inside....inches..	43.5
Bi....do....	0.14	Depth inside....do....	49.5
Pb....do....	8.64	Anodes per cell....	48
Starting sheets:		Cathodes per cell....	49
Length....inches..	37	System and arrangement (Whitehead)....	-
Width....do....	37.5	Bus bar, amperes per square inch	375
Thickness....do....	0.023	Electrolytic cell inlet (bottom)	-
Weight....pounds..	13		
Type suspension....1 wide loop..	-		
Cathodes:			
Deposition time....days..	14		
Weight....pounds..	300		
Washing method...machine spray..	-		
Wet flapping....	-		
Inspection interval....hours..	24		

The electrolyte is circulated at approximately 4-1/2 gallons per minute (gpm) per tank in the solution circuits. The electrolyte, containing 42 grams per liter (gpl) of copper and 200 gpl of free acid, flows by gravity from section-head tanks through a system of 8-pound 6-percent antimonial lead-lined pipes into the individual tanks. The solution overflow from the tanks flows into a system of lead-lined launders to section electrolyte sumps. The electrolyte is transferred to karbate heaters by centrifugal pumps, heated to the desired temperature, and returned to the section-head tanks. The electrolyte, which is basically a solution of copper sulfate and sulfuric acid, increases in copper and nickel content in time. Periodically, a portion of the electrolyte is withdrawn from the system and the nickel and copper content is reduced. The copper content of the solution is lowered to a desired level in the electrolytic liberator cells; the nickel, as nickel sulfate, and the acid, as spent 60° Bé sulfuric acid, is recovered from the solution by evaporation and concentration.

In the tankhouse section, 700-pound anodes containing 99.4 percent copper as received from smelters are electrolytically refined into 300-pound cathodes containing 99.96 percent copper. The general refining procedure is as follows. Anodes are placed in the tanks where they are electrolytically decomposed and redeposited on starter sheets as cathodes. Impurities such as gold, silver, and other metals contained in the anode copper form slimes at the bottom of the tanks. Periodically the slimes are removed, washed, filtered, dried, packaged in sealed drums, and shipped to a precious metals refinery.

Power is supplied to the deposition cells by six 1,000-kilowatt, 125-volt, 8,000-ampere motor-generator sets. There are three power circuits, each with two sets in parallel. Two additional motor-generator sets provide standby power. Cathode current density is 17.8 amperes per square foot with a cell voltage of 0.210 volt. Cathode production is 275 pounds per kilowatt day.

Starting sheets are prepared in the stripping section where thin copper blanks are inserted in the tanks and copper allowed to deposit for a 24-hour period. The blanks are then removed from the tanks, water-washed, and a starter sheet peeled from each side of the blank. Some of the starter sheets are cut into thin sheets by a slitting machine; these thin sheets, referred to as slits or loops, are crimped to the remaining starter sheets. With a hanger inserted through the loops, the sheets are transferred to the commercial-cell section where they serve as nuclei for the formation of cathodes in the electrolytic deposition of copper. The period allowed for redeposition of copper from the anode to form a cathode is 14 days.

Cathodes are removed from the tanks (cells) by overhead cranes and transferred to washing machines in the melting and casting section by forklift trucks and straddle carriers.

Melting and Casting Section

Major equipment items in the melting and casting section are the washing machines, charging machine, cathode preheater, arc furnace, induction furnaces, wire-bar casting wheel, continuous billet casting machines, and materials-handling equipment.

Figure F-2 is a flow diagram of the section; table F-3 contains a listing of the equipment, including quantity, size description, and installed costs.

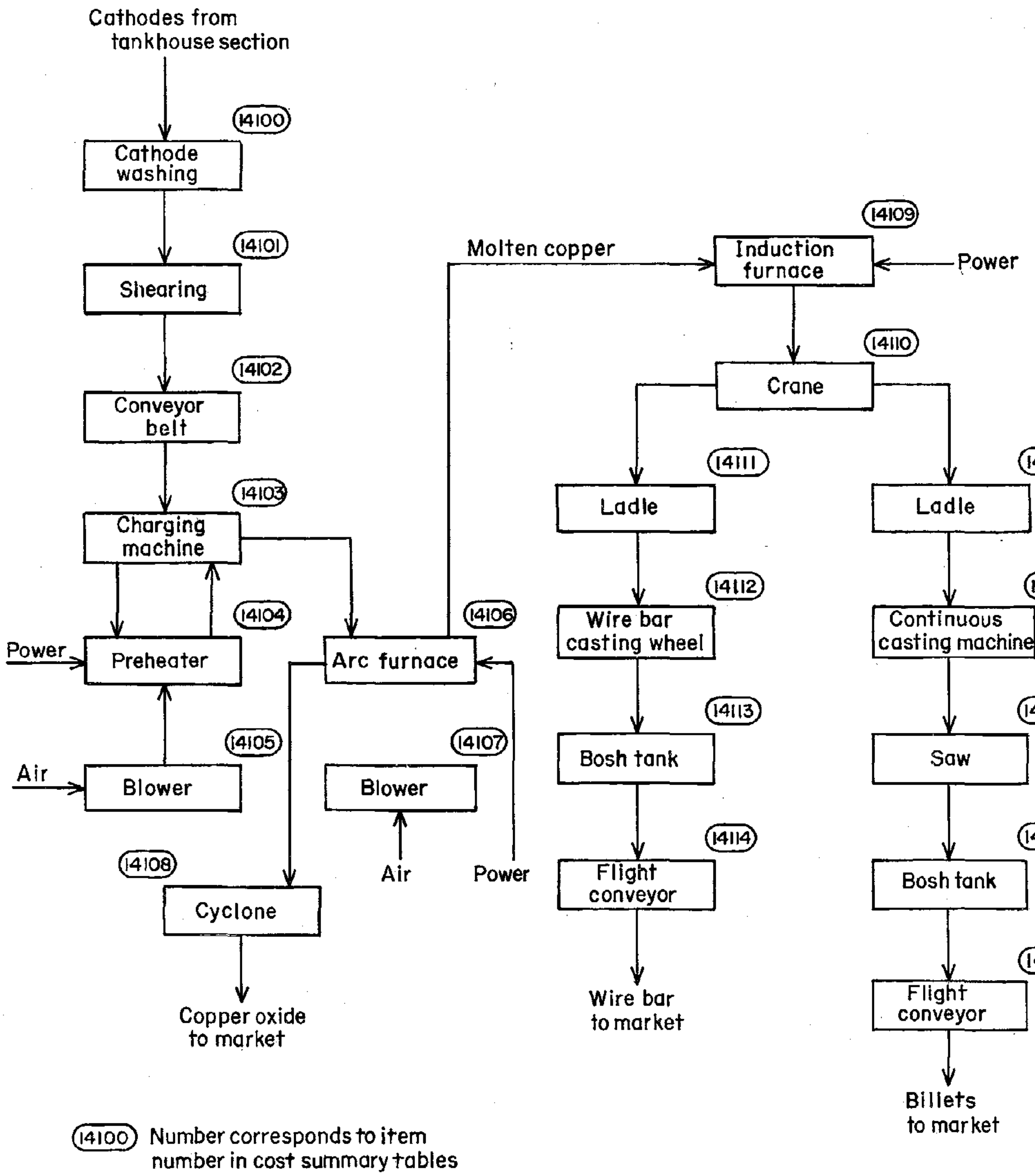

FIGURE F-2. - Flow diagram of melting and casting section, 300,000-tpy electrolytic copper refinery.

TABLE F-3. - Cost summary, melting and casting section, 300,000-tpy electrolytic copper refinery

Item No.	Item	Quantity	Size	Unit hp	Total hp	Cost: Material	Cost: Labor	Total cost
14100	Washing machine	3	40 in by 50 ft	-	-	$21,600	$2,200	$23,800
14101	Shearing machine	3	1/2 in	5	15	13,200	1,300	14,500
14102	Belt conveyor	1	42 in by 100 ft	5	5	13,400	1,300	14,700
14103	Charging machine	1	7,000 lb/hr	10	10	100,000	10,000	110,000
14104	Preheater	1	58-ft diam	300	300	230,000	23,000	253,000
14105	Blower	1	5,620 scfm	575	575	60,000	15,000	75,000
14106	Arc furnace	2	35,000 kV-A	-	-	1,280,000	576,000	1,856,000
14107	Blower	2	5,500 scfm	40	40	17,000	4,300	21,300
14108	Cyclone	2	29,200 scfm	-	-	14,600	1,500	16,100
14109	Induction furnace	5	300 kW	-	-	1,440,900	144,100	1,585,000
14110	Crane, 10-ton	4	30-ft span	25	100	152,000	91,200	243,200
14111	Ladle	4	5-ton	-	-	20,000	2,000	22,000
14112	Casting wheel, wire bar	1	28-ft diam	100	100	100,000	10,000	110,000
14113	Bosh tank	5	20 ft by 10 ft by 5 ft	-	-	42,500	4,300	46,800
14114	Flight conveyor	5	36-in pan, 60 ft	7.5	37.5	83,000	8,300	91,300
14115	Continuous casting machine	4	3-in-diam billet	50	200	400,000	40,000	440,000
14116	Saw	4	14 in	2	8	8,000	800	8,800
	Subtotal	-	-	-	1,391	3,996,200	935,300	4,931,500
	Excavation	-	-	-	-	412,200	394,300	806,500
	Buildings	-	-	-	-	229,100	229,100	458,200
	Instrumentation	-	-	-	-	91,600	36,600	128,200
	Insulation	-	-	-	-	-	-	-
	Electrical	-	-	-	-	274,900	205,600	480,500
	Piping	-	-	-	-	229,100	114,200	343,300
	Painting	-	-	-	-	13,800	41,200	55,000
	Subtotal	-	-	-	-	1,250,700	1,021,000	2,271,700
	Total direct	-	-	-	-	5,246,900	1,956,300	7,203,200
	Field indirect	-	-	-	-	-	-	978,200
	Total construction	-	-	-	-	-	-	8,181,400
	Engineering	-	-	-	-	-	-	409,100
	Administration and overhead	-	-	-	-	-	-	409,100
	Subtotal	-	-	-	-	-	-	8,999,600
	Contingency	-	-	-	-	-	-	900,000
	Subtotal	-	-	-	-	-	-	9,899,600
	Fee	-	-	-	-	-	-	495,000
	Subtotal	-	-	-	-	-	-	10,394,600
14117	Straddle carriers	2	Gasoline-powered, 45,000-lb capacity.	120	240	42,400	-	42,400
14118	Forklifts	4	Gasoline-powered, 28,000-lb capacity, counterbalanced.	80	320	79,600	-	79,600
	Subtotal	-	-	-	560	122,000	0	122,000
	Total	-	-	-	-	-	-	10,516,600

The cathodes received from the tankhouse are first washed with hot water to remove adhering electrolyte. Washing machines are gravity conveyors passing through a tunnel containing hot-water sprays. The hot water is condensate from steam used in the heat exchangers and the evaporator in the tankhouse section. After the cathodes have been washed and the hangers and loops removed by the cutting machine they are stacked in 1-ton lots to be fed into the gas-fired rotary hearth gas preheater. A peel-arm-type charging machine is used for servicing both the preheater and the arc furnaces.

The charging machine removes cathodes from the stacking area and places them in the preheater. Cathodes enter the preheater at approximately 90° F and emerge at 1,400° F. After depositing the cathodes in the preheater the charging machine removes heated cathodes, rotates to the receiving door of the arc furnace where a ram on the charging machine inserts the cathodes into the furnace. The two 90-ton, three-phase 35,000 kV-A water-cooled furnaces consume 280 kilowatt-hours per ton of melted copper and 4 pounds of electrode per ton of copper. Wet cyclone scrubbers attached to the arc furnaces collect the dust; principally copper oxide which is packaged and marketed.

The molten metal is transferred from the arc furnaces through launders to 5-ton, 300-kilowatt induction-type holding furnaces. These furnaces consume approximately 49 kilowatt-hours per hour. Molten metal is fed from the induction furnaces to the wire bar casting wheel and the continuous billet casting machine. The casting wheel, which is 28 feet in diameter, contains 18 molds with four bars per mold. It is a traditional Walker-type, water-cooled wheel. The bars produced by the continuous casting machine are cut into segments by flying saws.

The products from the casting wheel and continuous casting machine are cooled in bosh tanks and conveyed to inspection and chipping stations where defective products are removed and rough edges are smoothed. The bars and billets are conveyed to stations and bundled for market.

The arc furnaces, casting machines, and cooling boshes require approximately 2,000 gpm of cooling water.

Capital Investment

Total estimated capital requirements (table F-4) include the tankhouse section, melting and casting section, plant facilities and utilities, initial catalyst requirements, and working capital.

The total capital investment is $57.0 million of which $4.3 million is working capital and $0.6 million is initial catalyst.

TABLE F-4. - Estimated capital requirements, 300,000-tpy electrolytic copper refinery

Unit	Cost
Tankhouse section	$33,552,700
Melting and casting section	10,516,600
Subtotal	44,069,300
General facilities and utilities	8,042,700
Subtotal	52,112,000
Initial catalyst requirement	573,100
Subtotal for depreciation, taxes, and insurance	52,685,100
Working capital[1]	4,339,200
Total capital required	57,024,300

[1]Estimated 3 months' direct, indirect, and insurance cost, plus spare part inventory.

Operating Cost

Total estimated operating cost (table F-5) includes direct, indirect, and fixed costs as well as a credit for byproduct nickel sulfate crystals, copper oxide, and spent 60° Bé sulfuric acid. Credit for precious metal slimes consisting of gold and silver is not included since it is assumed to be a revenue to the shipper of the concentrates.

Operating costs are based on a three-shift-per-day 365-day-per-year schedule.

The wage rate is a weighted average based on manpower requirements for the specific job descriptions.

Utility requirements are listed in table F-6.

The value of byproducts recovered is based on prices of $26.21 per ton for 60° Bé sulfuric acid, $0.46 per pound for nickel sulfate, and $0.67 per pound for copper oxide. The quantities of byproduct materials recovered are listed in table F-5. The annual operating cost after byproduct credit is $18.4 million or $0.031 per pound of copper.

Allowing for a 12-percent return on the investment using the discounted-cash-flow method and allowing for Federal income tax at 50 percent of gross profit the unit refining cost is increased to $0.048 per pound of copper.

TABLE F-5. - Estimated annual operating cost, 300,000-tpy electrolytic copper refinery

	Annual cost	Total	Cost per pound copper
Direct cost:			
Materials and utilities:			
Power........18,000 kW-hr/hr X 8,760 hr/yr X $0.01/kW-hr..	$1,576,800	-	-
Natural gas.....136.2 Mscf/hr X 8,760 hr/yr X $0.60/Mscf..	715,900	-	-
Sulfuric acid...........20 tpd X 365 day/yr X $31.45/ton..	229,600	-	-
Graphite electrode.....4 lb/ton X 300,000 tpy X $0.09/lb..	108,000	-	-
Water............54.0 Mgal/hr X 8,760 hr/yr X $0.10/Mgal..	47,300	-	-
Glue................0.05 lb/ton X 300,000 tpy X $0.20/lb..	3,000	-	-
Goulac............0.25 lb/ton X 300,000 tpy X $0.0475/lb..	3,600	-	-
Subtotal..	-	$2,684,200	$0.004
Direct labor:			
3,915 man-hr/day...............$3.75/man-hr X 365 day/yr..	5,358,700	-	-
Supervision.........................15 percent of labor..	803,800	-	-
Subtotal..	-	6,152,500	.010
Maintenance:			
Labor.........683 man-hr/day X $3.87/man-hr X 365 day/yr..	964,800	-	-
Supervision.........................20 percent of labor..	193,000	-	-
Maintenance supplies and parts.........................	482,400	-	-
Subtotal..	-	1,640,200	.003
Payroll overhead....................25 percent of payroll..	-	1,830,100	.003
Operating supplies.........20 percent of plant maintenance..	-	328,000	.001
Total direct cost..................................	-	12,645,000	.021
Indirect cost: Administration and general overhead 40 percent of labor, maintenance, and supplies..	3,252,300	-	.006
Total indirect cost................................	-	3,252,300	.006
Fixed cost:			
Taxes and insurance................2 percent of plant cost..	1,053,700	-	.002
Depreciation...................................20 years..	2,634,300	-	.004
Total fixed cost...................................	-	3,688,000	.006
Gross operating cost...............................	-	19,585,300	.033
Credit:			
Nickel sulfate crystals 3,716 lb/day X 365 day/yr X $0.46/lb..	623,900	-	-
Copper oxide dry......1,750 lb/day X 365 day/yr X $0.67/lb..	428,000	-	-
Spent 60° Bé sulfuric acid 17.6 tpd X 365 day/yr X $26.21/ton..	168,400	-	-
Total credit.......................................	-	1,220,300	-
Gross operating cost after credits..................	-	18,365,000	.031

TABLE F-6. - Plant utility requirements, 300,000-tpy electrolytic copper refinery

Unit	Power, kW-hr/hr	New water, gpm	Cooling water, gpm	Natural gas, Mscf/hr	Steam production and consumption lb/hr at 50 psig and 298° F	
					Produced	Consumed
Tankhouse section.........	6,560	370	-	2,270	80,000	73,600
Melting and casting section..................	10,960	200	2,000	-	-	-
Subtotal............	17,520	570	2,000	2,270	80,000	73,600
Cooling water............	80	200	-	-	-	-
Lighting..................	80	-	-	-	-	-
Sanitary water............	70	30	-	-	-	-
General facilities........	50	40	-	-	-	-
Miscellaneous and contingency.............	200	60	100	230	-	6,400
Subtotal............	480	330	100	230	0	6,400
Total...............	18,000	900	2,100	2,500	80,000	80,000

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