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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

COPPER PRODUCTION IN DEVELOPING COUNTRIES

UNITED NATIONS

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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
VIENNA

COPPER PRODUCTION IN DEVELOPING COUNTRIES

Report of the Seminar on the Copper Industry held in Moscow, 1—6 October 1970

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EXPLANATORY NOTES

Reference to pounds (£) is to pounds sterling.
Reference to dollars ($) is to United States dollars.
Reference to tons is to metric tons, unless otherwise specified.

The following acronyms are used in this volume:

ENAMI	Empresa Nacional de Mineria (state-owned mines of Chile)
GATT	General Agreement on Tariffs and Trade
LME	London Metal Exchange
LPF	Leaching-precipitation-flotation (process of extracting copper from copper compounds)
UNCTAD	United Nations Conference on Trade and Development
IBRD	International Bank for Reconstruction and Development
IMF	International Monetary Fund

Letter of transmittal to
the Executive Director of UNIDO
Mr. I. H. Abdel-Rahman

Dear Mr. Abdel-Rahman,

We have the honour to present herewith the report of the Seminar on Copper Production in Developing Countries, held in Moscow from 1–6 October 1970, under the auspices of the United Nations Industrial Development Organization and in close co-operation with the appropriate USSR authorities.

The participants discussed the substance of the papers presented at the Seminar and reviewed various practical considerations of the development of the copper industry under the conditions prevailing in developing countries. The discussions covered current and new technological processes used in the production and transformation of copper, including their economic aspects.

The conclusions and recommendations reflect the spirit of the discussions held and opinions expressed. We sincerely hope that these recommendations will provide you with a sound basis for your future work programme.

We wish to express our deep appreciation to UNIDO for the opportunity to attend this Seminar and to the USSR authorities for their assistance and hospitality.

Yours sincerely,

Chairman
K. I. Ushakov
Director, State Institute of Non-Ferrous Metallurgy
USSR

Discussion Leader
B. Leuschner
Regional Adviser on Technological Research for Industry
Economic Commission for Latin America
Chile

Rapporteur
G. S. Somerset
Assistant Director and Secretary
British Non-Ferrous Metals Federation
United Kingdom

Introduction

1. The purpose of the Seminar, whose conclusions and recommendations are given in chapters 1 and 2, was to study and evaluate the technical and economic aspects of the application of modern metallurgical processes to the production and transformation of copper, and to assess their importance to developing countries for increasing the revenues from their copper industries. The list of papers discussed during the Seminar is presented in annex 2.

2. The participants included 54 representatives from developed countries and 14 from developing countries. The full list of participants is given in annex 1.

3. The meeting opened with an assessment of the world market for copper and the possibilities for the developing countries to compete in this market. This appraisal is given in chapter 3. Chapter 4 examines the requirements of the developing countries. Chapter 5 indicates trends in the development of the copper industry. Chapters 6 and 7 cover the technical developments in smelting and refining described by the experts, and chapter 8 summarizes developments in copper transformation. Chapter 9 outlines the history of the copper industry in two developing countries—Chile and Bulgaria.

4. The Seminar was followed by a tour of plants in the USSR, which included mines, smelters, refineries and plants fabricating copper and copper-alloy products.

5. The Group elected Mr. K. Ushakov as Chairman, Mr. B. Leuschner as Discussion Leader, and Mr. G. S. Somerset as Rapporteur. Mr. Christo Popov of the UNIDO secretariat served as Technical Secretary. In addition to Mr. Ushakov, representatives of the host Government were Mr. J. P. Voronenkov, Deputy Minister, Ministry of Non-Ferrous Metallurgy, USSR; Mr. L. K. Davidov, who served as Technical Secretary of the Seminar; Mr. V. I. Vlassov, who was the officer responsible for organizing the visits to plants; and Mr. V. V. Mikhailov, who was the officer responsible for organization of interpretation.

6. The experts attended the meeting in a personal capacity and the views expressed are not necessarily those of their organizations or of their Governments.

7. This report is the second to be prepared by UNIDO on the copper industry. The first report, "Modernization and Expansion of Plants in the Copper Industry" (ID/WG.12/7), was prepared by an Expert Consulting Group following a meeting held in Vienna in November 1967. The recommendations of that meeting remain valid and should be taken into account.

1. CONCLUSIONS

8. The following main trends in the world copper industry have become apparent in recent years and they are likely to continue in the foreseeable future:

(1) A sustained increase in production and consumption;
(2) A growing tendency towards developing relatively poor ores;
(3) Greater processing of secondary raw materials;
(4) An increasing emphasis on the comprehensive utilization of copper-containing raw materials, involving the extraction not only of copper but also of sulphur, precious metals, lead, zinc, iron, molybdenum and other associated metals, materials and chemicals. Sulphuric acid and fertilizers and other products may be of particular interest to developing countries;
(5) Wider application of underground, heap and dump leaching of copper from oxidized and sulphide-oxide ores; solutions are either cemented and subjected to electrowinning or purified and concentrated for electrowinning. As a result, additional amounts of copper are obtained from complex raw materials and dumps with a modest capital investment and with low production costs;
(6) The application of improved hydrometallurgical and pyrometallurgical processes for the extraction of copper from mixed and oxidized ores as well as from oxidized carbonate ores;
(7) Copper sulphide concentrates are processed in the main by pyrometallurgical techniques. Lately, pyrometallurgical research has been aimed at intensifying existing processes and developing continuous and combined processes. Such processes may be less capital intensive, allow for improved utilization of raw materials and reduce fuel consumption;
(8) Increasing attention is being given to utilizing the heat of exhaust gases. The use of oxygen in copper processing is expanding;
(9) Electrorefining techniques have made considerable progress with the mechanization of production processes, current reversal, higher current densities, new reagents, corrosion-resistant materials, semiconductor rectifiers, and the use of the latest instruments for process control and short-circuit detection;

(10) Recently, the main copper-producing and exporting countries have made substantial changes in the legal status of ownership of their copper industries, with their Governments assuming a decisive role. These changes are starting to produce a favourable effect on their economies, to augment the receipts of foreign currency, to consolidate their balance of payments, and to create additional employment;

(11) Copper resources now known, or likely to be discovered, in developing countries are expected to be of the same types as those found throughout the world. Existing proven technology is adequate for the immediate exploitation of most of these resources, although the new technology should be useful;

(12) The shortage of skilled personnel hampers the growth of the copper industry and makes the training of personnel a primary consideration for the developing countries;

(13) It is worth noting the example of Chile, where a state-owned company, Empresa Nacional de Mineria (ENAMI), purchases copper raw materials from small-scale producers and processes them at its metallurgical plants. It also gives financial and technical assistance to these producers. The total production from these mines is about 10 per cent of the total output of the country;

(14) Some copper-consuming countries follow a policy of buying copper products of lower aggregate value from the developing countries supplying raw materials such as concentrates and unrefined copper;

(15) The increasing amounts of copper scrap in developed countries provide them with an alternative source of copper supplies that is in competition with the primary copper produced by the developing countries. This situation is unlikely to change in the near future in view of the low *per capita* copper consumption in developing countries and their small share of the total world consumption;

(16) The production and export of semimanufactures and fabricated products from developing countries is almost negligible.

2. RECOMMENDATIONS

9. The recommendations that resulted from the discussion are directed to UNIDO, the developing countries and the developed countries.

A. *It was recommended that the United Nations Industrial Development Organization:*

(1) Increase the technical assistance devoted to the development of copper industry in developing countries. This assistance includes:

(a) Expert missions;

(b) Consulting services;

(c) Preparation of preliminary feasibility studies;

(d) Fellowship programmes;

(e) Arrangements for carrying out laboratory tests and other studies in industrialized countries as they are needed;

(f) Assistance aimed at increasing the degree of domestic processing of available copper raw materials, along with the production of copper and its further fabrication;

(g) Assistance aimed at improving the economic and technological performance of existing copper extraction and transformation plants;

(h) Assistance in the preparation of requests for technical assistance from developing countries on problems related to their copper industry.

(2) Evaluate new metallurgical processes with a view to their possible application in developing countries;

(3) Stimulate and assist in the establishment of research and development centres for non-ferrous metallurgy in those developing countries where conditions are appropriate;

(4) Collect and circulate to developing countries information on legislation pertaining to the copper industry. This information should cover legislation related to fiscal matters and also to the granting of exploration and mining licences;

(5) Inform the United Nations Conference on Trade and Development (UNCTAD) and the General Agreement on Tariffs and Trade (GATT) that the problem of tariffs on copper products exported from devel-

oping countries has been discussed, and that these organizations should make efforts to reduce these tariffs with a view to facilitating the further development of the copper industry, which is the basis of the economy of a number of developing countries;

(6) Inform the international financial organizations, such as the International Bank for Reconstruction and Development (IBRD), that an endeavour should be made to augment the funds needed for the development of the copper industry in order to decrease the dependency on industrialized countries;

(7) Organize future meetings of experts from various countries on the financial, taxation, economic and marketing problems as well as on problems connected with the establishment of new copper industries in developing countries.

B. It was recommended that developing countries:

(1) Look into the possibilities of expanding their primary copper production and developing an integrated industry to produce a range of products such as blister, refined copper and semimanufactures where this is economically feasible. Since a major part of world primary copper is produced in developing countries, prospecting, exploration and processing should be encouraged in these countries. In this connexion it is important to note that the capital costs of facilities for the production of final copper products are substantially less than those for copper mining; but the benefits are also less;

(2) Consider the application of newly proven commercial technology for the extraction of copper from sulphide, oxide and mixed sulphide-oxide ores, for the utilization of waste dumps, and for the design and operation of concentrators, smelters and refineries that may be appropriate to the existing or planned operations in each country;

(3) Study and evaluate the most efficient scale of production facilities for refinery operations, on the basis of local conditions;

(4) Encourage the use of the services of outside experts in the design, construction and commissioning of metallurgical enterprises and for the training of local personnel;

(5) Work out forecasts for world copper production, consumption and exports, with the assistance of UNIDO, with a view to improving their knowledge of the market situation and the likely trends in the future;

(6) Establish pilot plants, whenever applicable and economically feasible, for the treatment of indigenous copper-containing minerals using the most efficient processes, with the assistance and support, if desired, of UNIDO and the industrialized countries;

(7) Create conditions that would encourage the investment of capital from international financial institutions and other sources;

(8) Take into account the experience of the copper industry in those countries that have developed their copper industry within the last 15–20 years.

C. *It was recommended that the developed countries:*

(1) Continue the development of copper-production technology in order to improve the efficiency, recovery, productivity and the quality of copper products and reduce the cost of copper and its by-products and co-product metals and materials. Such advanced procedures should include the elimination of pollution from production wastes;

(2) Assist the developing countries in their search for capital investment to build production facilities;

(3) Keep the developing countries informed on the latest developments in the technology, engineering and economics of copper production.

3. ECONOMIC ASPECTS AND MARKETING POSSIBILITIES OF COPPER PRODUCTION FOR DEVELOPING COUNTRIES

Production

10. Copper is present in the earth's surface in many countries, but it is mined primarily in Canada, Chile, Peru, the Union of Soviet Socialist Republics, the United States, the Republic of Zaire and Zambia. Table 1 gives the figures for the world production of copper mines. The output of the mines increased over the ten years of the development decade (1960–1969) by 1.7 million tons or 40 per cent.

11. The data in table 2 indicate that about 60 per cent of the world production of copper over this period was mined in the developed countries. The balance was accounted for mainly by the developing countries in Africa, Asia and Latin America. Table 2 also gives figures for the mine production of the developing countries over the same period, during which these countries produced 40 per cent of the world output.

12. The smelting of copper is carried out in many cases close to or at the mines, but it is also done by custom smelters in the countries consuming copper. Tables 3 and 4 give figures for the world production of smelters. This includes the production from concentrates and the production of secondary blister and rough copper from scrap residues.

13. Some years ago it appeared that primary copper would be smelted and refined increasingly at or close to the mines rather than in the copper-consuming countries. Even if this had occurred, however, the large secondary metal industry, which is based on the use of scrap and residues as a raw material, would continue to be located in the industrialized countries where scrap is produced.

14. The output of blister copper in the developing countries is about one third of the world total or less than the proportion for mine output. This is explained by the fact that concentrates are shipped to the industrialized countries for smelting.

15. It appears now, however, that this trend is reversing. Some countries —notably Japan and, to a lesser extent, the countries of Western Europe— are contracting for the supply of concentrates and blister to feed their smelters

TABLE 1. WORLD PRODUCTION OF MINES, 1960—1969
(Thousand tons)

		1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
North America	Total[1]	1,378.4	1,455.3	1,529.3	1,511.2	1,572.8	1,687.0	1,755.6	1,421.9	1,667.3	1,913.6
US		979.9	1,057.0	1,114.4	1,100.6	1,131.1	1,226.3	1,296.5	865.5	1,092.8	1,413.4
Canada		398.5	398.3	414.9	410.6	441.7	460.7	459.1	556.4	574.5	500.2
Africa	Total	981.4	984.4	968.7	987.9	1,043.9	1,122.6	1,141.4	1,182.0	1,205.5	1,276.4
Zambia		576.4	574.7	562.3	588.1	632.3	695.7	623.4	663.0	684.9	719.5
Zaire, Rep. of		302.3	295.2	297.0	271.3	276.6	288.6	316.9	321.5	325.5	364.8
South and South West Africa		69.7	79.3	72.1	89.5	95.7	99.9	162.5	161.3	155.8	152.5
Rest		33.0	35.2	37.3	39.0	39.3	38.4	38.6	36.2	38.3	39.5
Centrally planned economies	Total	625.2	679.7	744.6	749.3	850.8	917.5	980.5	1,015.0	1,055.0	1,083.0
USSR		500.0	550.0	600.0	600.0	700.0	750.0	800.0	825.0	850.0	875.0
Rest		125.2	129.7	144.6	149.3	150.8	167.5	180.5	190.0	205.0	208.0
Latin America	Total	795.8	813.6	820.6	862.6	878.0	845.8	905.4	930.5	961.9	980.1
Chile		532.1	547.4	585.9	601.1	621.7	585.3	636.7	660.2	658.2	686.8
Peru		181.7	198.1	166.8	180.0	176.4	177.4	184.0	186.4	213.5	199.0
Rest		82.0	68.1	67.9	81.5	79.9	83.1	84.7	83.9	90.2	94.3
Asia	Total	215.2	229.6	236.0	246.3	240.3	249.9	263.4	281.8	305.8	325.2
Japan		89.2	96.4	103.6	107.2	106.0	107.1	111.7	117.8	119.7	120.3
Philippines		44.2	51.9	54.7	63.9	60.5	62.7	73.8	86.2	110.3	131.4
Rest		81.8	81.3	77.7	75.2	73.8	80.1	77.9	77.8	75.8	73.5
Europe	Total	127.4	135.4	151.8	157.8	156.3	150.4	144.3	150.5	169.9	202.5
Australia	Total	111.2	97.2	108.7	114.8	106.3	91.8	111.3	91.8	108.6	128.1
WORLD TOTAL		4,234.6	4,395.2	4,559.7	4,629.9	4,848.4	5,065.0	5,301.9	5,073.5	5,474.0	5,908.9

TABLE 2. PRODUCTION OF MINES, BY DEVELOPED AND DEVELOPING COUNTRIES, 1960–1969

(Thousand tons)

	World total	*Developed countries*	*Developing countries*
1960	4,234.6	2,401.1	1,833.5
1961	4,395.2	2,543.3	1,851.9
1962	4,559.7	2,710.1	1,849.6
1963	4,629.9	2,729.8	1,900.1
1964	4,848.4	2,887.9	1,960.5
1965	5,065.0	3,053.7	2,011.3
1966	5,301.9	3,265.9	2,036.0
1967	5,073.5	2,958.3	2,115.2
1968	5,474.0	3,276.3	2,196.7
1969	5,908.9	3,600.1	2,308.8
ANNUAL AVERAGE RATE OF GROWTH	+3.8%	+4.6%	+2.6%

and refineries. The companies concerned have offered to finance the development of new mining ventures. In exchange they have entered into long-term contracts with the mines for the supply of minerals.

16. The production of refined copper is dispersed much more widely throughout the world and much of the refining takes place in the industrialized countries. Refined copper can be produced both from primary and secondary blister and also from scrap. The output of refined copper, which now amounts to over 7 million tons per annum, is substantially higher than smelter production. The production figures are given in tables 5 and 6. The total output of refined copper has risen by some 2.2 million tons in the last decade and 1.3 million tons in the last five years. The output of secondary refined copper from scrap and residues has almost doubled in the last decade and now amounts to about 1.2 million tons. The production of secondary copper takes place almost entirely in the industrialized countries of the world, principally in the Federal Republic of Germany, Japan, the Union of Soviet Socialist Republics, the United Kingdom and the United States.

17. During these ten years the output of refined copper in Japan rose to 630,000 tons. Most of this copper is produced from imported raw materials. Other countries where there has been an important increase in refined copper production are Chile, the Union of Soviet Socialist Republics, the United States and Zambia.

18. The growth rate in the output for the principal producing areas is shown in table 7 (for mines) and table 8 (for refineries). Mine production did not increase in the developing countries as rapidly during this period. Large new projects are being developed in Chile, but they are not yet in full operation. Mine production in the countries with centrally planned economies almost doubled over this decade.

TABLE 3. WORLD PRODUCTION OF SMELTERS, 1960—1969

(Thousand tons)

		1960	*1961*	*1962*	*1963*	*1964*	*1965*	*1966*	*1967*	*1968*	*1969*
North America	Total	1,558.6	1,530.6	1,559.3	1,569.3	1,622.8	1,710.1	1,750.3	1,271.3	1,677.1	1,880.8
US		1,186.7	1,166.4	1,217.0	1,230.1	1,256.9	1,325.2	1,364.7	846.5	1,225.9	1,508.5
Canada		371.9	364.2	342.3	339.2	365.9	384.9	385.6	424.8	451.2	372.3
Africa	Total	941.9	941.6	927.3	957.5	1,032.2	1,104.6	1,093.5	1,142.2	1,191.2	1,260.5
Zambia		575.6	568.5	554.0	578.1	638.8	695.9	595.5	633.1	663.7	703.7
Zaire, Rep. of		301.9	294.1	295.4	271.1	276.6	288.6	316.9	321.5	325.5	364.8
South and South West Africa		48.4	53.1	49.2	77.1	83.0	85.6	148.0	156.0	166.9	155.3
Rest		16.1	25.9	28.7	31.2	33.8	34.5	33.1	31.6	35.1	36.7
Centrally planned economies[a]	Total	634.0	688.6	751.0	762.5	861.8	924.6	986.0	1,025.1	1,064.0	1,097.0
USSR		500.0	550.0	600.0	600.0	700.0	750.0	800.0	825.0	850.0	875.0
Rest		134.0	138.6	151.0	162.5	161.8	174.6	186.0	200.1	214.0	222.0
Latin America	Total	733.0	754.0	757.9	767.2	794.7	770.8	813.9	847.2	866.9	877.8
Chile		504.8	524.5	557.9	557.0	586.7	557.5	605.9	630.5	623.1	646.6
Peru		166.8	179.8	145.1	157.2	155.7	158.4	153.7	163.9	187.8	170.3
Rest		61.4	49.7	54.9	53.0	52.3	54.9	54.3	52.8	56.0	60.9
Europe	Total	316.5	308.0	351.7	356.5	369.0	408.3	436.8	447.0	502.2	526.5
Germany, Fed. Rep. of		94.1	94.2	98.8	96.9	113.9	127.6	143.5	149.1	191.8	200.0
Rest		222.4	213.8	252.9	259.6	255.1	280.7	293.3	297.9	310.4	326.5
Asia	Total	283.6	321.5	322.0	339.6	378.6	377.6	405.1	426.7	477.4	516.1
Japan		247.1	289.7	281.8	302.0	338.9	337.4	363.8	386.8	437.8	480.0
Rest		36.5	31.8	40.2	37.6	39.7	40.2	41.3	39.9	39.6	36.1
Australia	Total	75.2	65.1	90.2	92.0	83.3	79.5	96.6	79.2	101.9	123.3
WORLD TOTAL		4,542.8	4,609.4	4,759.4	4,844.6	5,142.4	5,375.5	5,582.2	5,238.7	5,880.7	6,282.0

[a] Primary metal only.

TABLE 4. PRODUCTION OF SMELTERS, BY DEVELOPED AND DEVELOPING COUNTRIES, 1960–1969

(Thousand tons)

	World total	*Developed countries*	*Developing countries*
1960	4,542.9	2,879.8	1,663.1
1961	4,609.4	2,935.1	1,674.3
1962	4.759.4	3,083.2	1,676.2
1963	4,844.6	3,159.4	1,685.2
1964	5,142.4	3,358.8	1,783.6
1965	5,375.5	3,545.5	1,830.0
1966	5,582.2	3,781.5	1,800.7
1967	5,238.7	3,365.4	1,873.3
1968	5,880.7	3,949.9	1,930.8
1969	6,282.0	4,262.9	2,019.1
ANNUAL AVERAGE RATE OF GROWTH	+3.7%	+4.4%	+2.2%

19. Some developing countries—Peru, the Republic of Zaire and Zambia—have extensive development programmes. In addition, new mine production may be expected fairly soon in Botswana, Bougainville (Solomon Islands), Indonesia, Malaysia and Mauritania. Much of the output of these mines will go to Japan.

CONSUMPTION

20. Copper is consumed in one form or another in all countries of the world. The greatest consumption, however, is in the industrialized countries. Tables 9 and 10 give the world consumption of refined copper. This rose in the period 1960–1969 by some 2.3 million tons. The main increases in consumption have been in Canada, the Federal Republic of Germany, France, Italy, Japan, the US and the USSR.

21. Over these ten years consumption grew at a rate of 4.4 per cent per annum compared with a rate of only 4.1 per cent for production. The growth of consumption has therefore outstripped the available supplies, which have had to be replenished by releases from the US Government stockpile of 798,000 tons. This rapid rise in consumption is explained by the growth of industrial output, improved standards of living, and the growth of population.

22. The developing countries consume only 3.5 per cent of the total consumption of copper in all forms. Thus, the consumption of copper varies enormously among the countries of the world. Table 11 indicates that the consumption *per capita* in certain developed countries ranged from 4 to 12 kg in 1968; in the same year, consumption in certain developing countries ranged from 0.1 to 0.6 kg (table 12). Although consumption in the developing areas is small, future prospects are extremely favourable.

TABLE 5. WORLD PRODUCTION OF REFINED COPPER, 1960 – 1969

(Thousand tons)

		1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
North America	Total	2,020.8	2,030.4	2,073.1	2,065.9	2,191.2	2,350.5	2,390.2	1,850.2	2,157.7	2,435.3
US		1,642.6	1,661.8	1,725.8	1,722.2	1,821.1	1,956.7	1,997.4	1,396.7	1,681.9	2,026.5
Canada		378.2	368.6	347.3	343.7	370.1	393.8	392.8	453.5	475.8	408.8
Centrally planned economies	Total	799.9	850.9	908.9	941.0	1,051.4	1,110.6	1,173.6	1,213.9	1,247.7	1,262.0
USSR		610.0	660.0	700.0	720.0	820.0	875.0	930.0	960.0	990.0	1,002.0
Rest		189.9	190.9	208.9	221.0	231.4	235.6	243.6	253.9	257.7	260.0
Western Europe	Total	970.9	977.7	994.2	1,014.1	1,079.8	1,137.0	1,129.0	1,139.9	1,262.1	1,229.3
Belgium		201.8	202.8	202.0	250.0	260.0	280.0	293.0	305.0	330.3	286.7
Germany, Fed. Rep. of		320.1	314.9	318.8	302.8	324.2	342.4	352.3	355.7	407.4	402.1
UK		213.1	226.0	221.1	200.5	224.9	227.6	179.8	169.3	197.7	198.2
Rest		235.9	234.0	252.3	260.8	270.7	287.0	303.9	309.9	326.7	342.3
Africa	Total	560.3	598.3	595.4	603.2	667.7	708.1	682.4	728.5	800.8	863.3
Zambia		402.6	418.9	433.5	439.2	497.1	522.3	493.7	535.1	550.7	598.1
Zaire, Rep. of		144.7	150.9	136.2	132.0	141.3	152.6	157.6	161.0	167.0	183.3
South Africa		11.8	17.2	12.6	16.9	13.9	16.0	13.9	15.2	62.6	61.2
Rest		1.2	11.3	13.1	15.1	15.4	17.2	17.2	17.2	20.5	20.7
Asia	Total	271.5	301.6	296.5	323.2	365.4	386.1	425.6	493.2	573.1	658.9
Japan		248.1	277.0	270.4	295.2	341.7	365.7	404.8	470.0	548.4	629.2
Rest		23.4	24.6	26.1	28.0	23.7	20.4	20.8	23.2	24.7	29.7
Latin America	Total	286.2	289.7	331.9	329.6	353.6	378.6	443.9	471.8	490.4	561.4
Chile		225.6	226.3	263.7	259.0	277.9	288.8	357.2	386.4	393.6	453.0
Rest		60.6	63.4	68.2	70.6	75.7	89.8	86.7	85.4	96.8	108.4
Australia	Total	84.2	78.6	92.7	104.0	101.7	95.2	115.4	96.9	118.9	137.3
WORLD TOTAL		4,993.8	5,127.2	5,292.7	5,381.0	5,810.8	6,166.1	6,360.1	5,994.4	6,650.7	7,147.5

TABLE 6. PRODUCTION OF REFINED COPPER, BY DEVELOPED AND DEVELOPING COUNTRIES, 1960 – 1969
(Thousand tons)

	World total	*Developed countries*	*Developing countries*
1960	4,993.8	4,135.7	858.1
1961	5,127.2	4,231.8	895.4
1962	5,292.7	4,351.9	940.8
1963	5,381.0	4,437.1	943.9
1964	5,810.8	4,779.7	1,031.1
1965	6,166.1	5,075.0	1,091.1
1966	6,360.1	5,226.9	1,133.2
1967	5,994.4	4,786.1	1,208.3
1968	6,650.7	5,397.4	1,253.3
1969	7,147.5	5,754.3	1,393.2
ANNUAL AVERAGE RATE OF GROWTH	+4.1%	+3.7%	+5.5%

TABLE 7. GROWTH RATE IN MINE PRODUCTION, BY MAIN PRODUCING AREAS, 1960 – 1969
(Thousand tons)

	1960	*1969*	*Average annual rate of growth*
DEVELOPED AREAS			
US	979.9	1,413.4	+4.2%
Canada	398.5	500.2	+4.7%
Centrally planned economies	625.2	1,083.0	+6.3%
Western Europe	127.4	202.5	+5.3%
South and South West Africa	69.7	152.6	+9.1%
Australia	111.2	128.1	+1.6%
Japan	89.2	120.3	+3.4%
Total	2,401.1	3,600.1	+4.6%
DEVELOPING AREAS			
Africa			
Zaire, Rep. of	576.4	719.5	+2.5%
Zambia	302.3	364.8	+2.1%
Rest	33.0	39.5	+2.0%
Latin America			
Chile	532.1	686.8	+2.9%
Peru	181.7	199.0	+1.0%
Rest	82.0	94.3	+1.6%
Asia	126.0	204.9	+5.6%
Total	1,833.5	2,308.8	+2.6%
WORLD TOTAL	4,234.6	5,908.9	+3.8%

TABLE 8. GROWTH RATE IN PRODUCTION OF REFINED COPPER, BY MAIN PRODUCING AREAS, 1960–1969

(Thousand tons)

	1960	*1969*	*Average annual rate of growth*
DEVELOPED AREAS			
US	1,642.6	2,026.5	+ 2.4%
Canada	378.2	408.8	+ 2.9%
Centrally planned economies	799.9	1,262.0	+ 5.2%
Western Europe	970.9	1,229.3	+ 2.7%
Japan	248.1	629.2	+10.9%
Australia	84.2	137.3	+ 5.5%
South Africa	11.8	61.2	+20.1%
Total	4,135.7	5,754.3	+ 3.7%
DEVELOPING AREAS			
Africa			
Zambia	402.6	598.1	+ 4.5%
Zaire, Rep. of	144.7	183.3	+ 2.7%
Rest	1.2	20.7	+37.2%
Latin America			
Chile	225.6	453.0	+ 8.0%
Rest	60.6	108.4	+ 6.7%
Asia	23.4	29.7	+ 2.7%
Total	858.1	1,393.2	+ 5.5%
WORLD TOTAL	4,993.8	7,147.5	+ 4.1%

SEMIMANUFACTURES AND CASTINGS

23. Copper is used for the production of a variety of semimanufactures. These include sheet, strip and plate, wire, rods, bars and sections and tubes. About 10 per cent of the copper is used for castings, and a small amount is used for chemical compounds—mainly copper sulphate. World production of semimanufactures is given in table 13.

24. Many developing countries start by mining copper and then erect smelters for the production of blister copper. They later build refineries for the production of fire-refined and electrolytic copper.

25. The problems of smelting and refining partly involve technical know-how and partly the availability of sufficient investment funds for building the plants. The minimum economic scale for a refinery is now about 100,000 tons per annum, if profit loss criteria are taken into consideration. Other considerations reflecting local conditions, however, may make feasible copper refineries of less capacity.

TABLE 9. WORLD CONSUMPTION OF REFINED COPPER, 1960–1969

(Thousand tons)

		1960	*1961*	*1962*	*1963*	*1964*	*1965*	*1966*	*1967*	*1968*	*1969*
Western Europe	**Total**	1,912.7	1,978.4	1,898.9	1,942.7	2,154.7	2,144.6	2,021.0	1,984.9	2,169.1	2,338.7
Germany, Fed. Rep. of		516.2	561.9	500.6	493.5	561.1	536.3	458.7	501.2	608.8	655.7
UK		560.3	528.9	526.1	558.0	632.9	650.1	592.5	514.3	539.2	546.8
France		236.7	243.6	243.7	250.3	291.6	287.0	291.6	271.3	292.9	334.8
Italy		185.0	202.0	214.0	228.0	202.0	192.0	195.0	222.0	226.0	260.3
Rest		414.5	442.0	414.5	412.9	467.1	479.2	483.2	476.1	502.2	541.1
North America	**Total**	1,331.3	1,455.9	1,588.7	1,736.4	1,839.4	2,022.4	2,379.1	1,959.5	1,932.7	2,142.2
US		1,224.6	1,327.1	1,451.2	1,582.4	1,655.9	1,818.6	2,140.9	1,755.9	1,705.8	1,924.2
Canada		106.7	128.8	137.5	154.0	183.5	203.8	238.2	203.6	226.9	218.0
Centrally planned economies	**Total**	911.6	951.8	1,025.1	1,041.0	1,055.0	1,114.6	1,177.3	1,247.4	1,275.0	1,320.0
USSR		651.6	681.8	735.1	736.0	740.0	782.6	817.3	867.4	875.0	900.0
Rest		260.0	270.0	290.0	305.0	315.0	332.0	360.0	380.0	400.0	420.0
Asia	**Total**	376.7	453.7	397.3	445.9	542.4	508.0	531.2	679.1	752.1	870.0
Japan		304.0	372.9	301.1	352.0	457.5	427.5	482.5	616.0	695.2	806.9
Rest		72.7	80.8	96.2	93.9	84.9	80.5	48.7	63.1	56.9	63.1
Latin America	**Total**	90.1	95.6	99.9	104.5	172.6	176.1	145.4	117.5	161.1	178.8
Australasia	**Total**	65.8	60.1	78.0	84.5	99.4	102.5	109.5	90.7	103.2	99.7
Africa	**Total**	35.3	32.4	39.9	42.7	47.8	44.4	41.7	39.5	40.2	45.9
WORLD TOTAL		4,723.5	5,027.9	5,127.8	5,397.7	5,911.3	6,112.6	6,405.2	6,118.6	6,433.4	6,995.3

TABLE 10. CONSUMPTION OF REFINED COPPER, BY DEVELOPED AND DEVELOPING COUNTRIES, 1960–1969

(Thousand tons)

	World total	*Developed countries*	*Developing countries*
1960	4,723.5	4,551.4	172.1
1961	5,027.9	4,846.1	181.8
1962	5,127.8	4,921.8	206.0
1963	5,397.7	5,186.8	210.9
1964	5,911.3	5,639.6	271.7
1965	6,112.6	5,844.0	268.6
1966	6,405.2	6,199.4	205.8
1967	6,118.6	5,926.8	191.8
1968	6,433.4	6,204.2	229.2
1969	6,995.3	6,742.2	253.1
ANNUAL AVERAGE RATE OF GROWTH	+4.4%	+4.5%	+4.4%

TABLE 11. PER CAPITA CONSUMPTION OF COPPER IN ALL FORMS IN CERTAIN DEVELOPED COUNTRIES, 1968

(kg)

	1968
Austria	4.5
Belgium	6.8
France	7.5
Germany, Fed. Rep. of	11.7
Great Britain	11.2
Italy	6.5
Japan	9.6
Netherlands	7.9
Scandinavia	9.0
Switzerland	10.7
US	12.2

26. Although about 40 per cent of the world's copper is produced by the developing countries, their production of copper semimanufactures is small. Out of a total production of 9.6 million tons, only about 3.5 per cent is accounted for by the developing countries. The reasons are partly economic and partly historical. Fabricating must be done on a large scale; hence, these products are difficult to produce economically in some developing areas with small local markets, unless regional co-operation is established.

27. The scale of operation for the production of semimanufactures is rising rapidly and much larger units are now being formed in all industrialized countries. To establish these units in the developing areas, it would be necessary to extend the markets. Many semimanufactures are sophisticated products which must have a high quality and be made in a large range of sizes, shapes

TABLE 12. PER CAPITA CONSUMPTION OF COPPER IN ALL FORMS IN CERTAIN DEVELOPING COUNTRIES, 1968
(*kg*)

	1968
Latin America	
Colombia	0.1
Venezuela	0.6
Africa	
Algeria	0.1
Ghana	0.1
Libya	0.5
Morocco	0.2
Tunisia	0.1
Zambia	0.1
Asia	
Iran	0.2
Israel	2.9
Philippines	0.1
Thailand	0.1

and alloys. They are therefore most easily produced near the market. The development of semimanufactures, however, creates additional employment in the countries concerned, and this phenomenon has obvious benefits. On the whole, though, copper-fabricating is not a labour-intensive industry.

28. Thus, the main problems involved in establishing a copper-fabricating industry are:

(*a*) The size of the home market;

(*b*) The necessity of using scrap and residues;

(*c*) The necessity of importing the alloying elements (zinc, nickel etc.);

(*d*) The acquisition of technical know-how;

(*e*) The distance from export markets;

(*f*) The large amount of investment funds required;

(*g*) The cost of transport: since shipping rates are fixed in relation to both the value and the volume of the cargo, semimanufactures cost more to transport;

(*h*) The fact that many countries have erected tariff barriers against the import of semimanufactures;

(*i*) The multiplicity of products and sizes required.

Table 13. World production of copper and copper-alloy semimanufactures, 1960—1969
(Thousand tons)

		1960	*1961*	*1962*	*1963*	*1964*	*1965*	*1966*	*1967*	*1968*	*1969*
Western Europe	**Total**	2,455	2,573	2,478	2,623	2,939	3,024	2,860	2,738	2,988	3,298
Germany, Fed. Rep. of		603	670	594	611	723	750	670	664	771	896
UK		764	724	688	734	840	853	783	691	725	738
France		315	327	339	356	399	391	393	384	398	473
Italy		234	275	294	323	293	303	326	355	373	390
Rest		539	577	563	599	684	727	688	644	721	801
US		1,542	1,641	1,811	1,895	2,167	2,336	2,640	2,248	2,322	2,584
Centrally planned economies		1,160	1,210	1,310	1,335	1,410	1,550	1,590	1,696	1,750	1,820
Japan		501	596	552	575	761	684	719	901	1,039	1,178
Other developed countries		223	237	277	300	357	362	412	368	393	397
Developing countries		180	230	260	280	350	360	270	250	300	340
World total		6,061	6,487	6,688	7,008	7,984	8,316	8,491	8,201	8,792	9,617

PRODUCTION FORECASTS

29. It is possible to forecast production of newly mined copper with a fair degree of accuracy, since it takes about five years to develop a new mine. Even projected extensions of existing mines are usually known well in advance, because they require not only time to carry out the physical work but also time to raise the large sums needed for investment.

30. It is considered likely that the mine production of copper will increase to 9.5 million tons by 1980. Smelter production is forecast to rise to 10.1 million tons by this date. Of the mine output, it is estimated that the developing countries will provide 3.5 million tons. The output of refined copper is forecast to rise to about 11.3 million tons by 1980.

CONSUMPTION FORECASTS

31. Since 96 per cent of the world's copper is now used in the industrialized countries, forecasts about consumption over the next decade must inevitably be based on conditions in these countries. Even a spectacular growth in copper consumption in the developing countries would not make a substantial difference in the world's use of copper. In the long run, however, the future of copper consumption will depend largely on the use made of it by the very large—and rising—population of the developing countries.

32. The forecasts for consumption are based on the usage of copper, i.e. primary refined copper, secondary refined copper and scrap used directly, encompassing the total market for copper. Consumers do not use primary copper as such; they use copper in its most economic and convenient form. For some uses they require newly mined copper; for others they almost invariably employ scrap. A range of intermediary uses require either one or both.

33. It is clear that the growth in consumption will continue, although the rise is likely to be somewhat slower in the second half of the decade. Total consumption is estimated to grow to about 14.5 million tons by 1980. The world will thus need 3.7 million tons more copper by the end of the decade; however, the industry should be capable of producing more by this date.

34. These figures may seem to indicate that a surplus of copper is likely to arise in the future, and that this will result in a depressed market. Such a conclusion would be quite incorrect. In the past the mines have been able to operate on the average at about 93 per cent of their normal rated capacity. For practical purposes, this is the maximum rate of operation that they are likely to achieve over the years, although in a particular year the operating rate may be higher or lower. The production figures really represent the maximum obtainable tonnage in the long run. Thus, these forecasts indicate that the mines may in the future operate at about 85 per cent rather than over 90 per cent of capacity.

Scrap

35. A meeting on the Utilization of Non-Ferrous Scrap in Developed Countries was held in Vienna in November 1969, under the auspices of UNIDO. The meeting dealt mainly with the technical and economic problems that arise in the utilization of scrap.

36. Scrap is a very important raw material for the copper industry. The movement of scrap and its availability has a major influence on the market and the price of primary copper. Many copper products can be made either from scrap, from secondary refined copper or from primary copper. The fabricators are therefore able to choose which they wish to use.

37. The total scrap now used amounts to about 3.6 million tons. This represents nearly 40 per cent of the world copper consumption. Scrap is used mainly in the highly industrialized countries.

38. Scrap is produced in the developed countries, frequently close to a metal consumer. It therefore invariably finds a market and indeed may on occasion replace primary copper. The supply line for primary copper between developing and developed countries is usually very long, while the supply line for scrap is very short. Moreover, scrap is created as a by-product and its cost of production is nil. The price therefore depends entirely on supply and demand.

Price

39. The key to the growth in the revenues of developing countries is the future demand for and price of copper. The estimates of demand indicate that there will be a ready market for additional supplies of copper over the years. The future price level is much more difficult to assess.

40. The basic function of a pricing system is to equate supply and demand. The price level should be high enough to encourage new investment in mining and yet not so high as to price the metal out of the market. The copper industry has always been subject to great fluctuations in the price. There are a number of different prices in use in various parts of the world, but the most important are:

(*a*) The US producer price;
(*b*) The daily London Metal Exchange (LME) quotation;
(*c*) The price levels determined in the countries with centrally planned economies.

41. The average, high and low prices for the UK and the US for the years 1936–1970 are given in tables 14 and 15. The US producer price applies to the sale of primary copper by the large US copper companies. There are, however, other price levels in the US for scrap and custom-smelter copper, and fabricators must use a blended price based on their average buying price for materials.

TABLE 14. SETTLEMENT PRICE OF ELECTROLYTIC COPPER WIREBARS, UNITED KINGDOM, 1936–1970

(£ per ton)

	Average	*High*	*Low*
1936	42	54	37
1937	59	80	41
1938	45	54	36
1939	48	54	4[illegible]
1940	50[a]	50[a]	50[a]
	61[b]	61[b]	61[b]
1941	61	61	61
1942	61	61	61
1943	61	61	61
1944	61	61	61
1945	61	61	61
1946	76	96	61
1947	129	135	115
1948	132	138	130
1949	131	151	102
1950	176	199	151
1951	217	230	199
1952	255	282	223
1953	265[c]	280[c]	248[c]
	229[d]	244[d]	211[d]
1954	245	305	212
1955	345	399	284
1956	324	430	258
1957	216	269	173
1958	194	257	157
1959	234	264	206
1960	242	276	215
1961	226	245	213
1962	230	233	224
1963	230	232	227
1964	345	523	231
1965	461	561	323
1966	546	776	349
1967	411	598	340
1968	517	810	425
1969	611	734	502
1970 (January – May)	698	749	566

a January – August
b September – December
c January – July
d August – December

TABLE 15. PRICE OF ELECTROLYTIC COPPER PRODUCED IN THE UNITED STATES, 1936 – 1970

(Cents per lb)

	Average	*High*	*Low*
1936	9.5	11.8	9.0
1937	13.2	16.8	9.9
1938	10.0	11.0	8.8
1939	11.0	12.3	9.8
1940	11.3	12.3	10.3
1941	11.8	12.0	11.8
1942	11.8	11.8	11.8
1943	11.8	11.8	11.8
1944	11.8	11.8	11.8
1945	11.8	11.8	11.8
1946	13.8	19.3	11.8
1947	21.0	23.3	19.2
1948	22.0	23.2	21.2
1949	19.2	23.2	15.7
1950	21.3	24.2	18.2
1951	24.2	24.2	24.2
1952	24.2	24.2	24.2
1953	28.8	30.8	24.2
1954	29.7	29.7	29.6
1955	37.5	45.3	29.7
1956	41.8	47.8	35.4
1957	29.6	35.6	25.4
1958	25.8	28.8	23.5
1959	31.2	35.2	28.6
1960	32.1	34.2	29.6
1961	29.9	30.7	28.6
1962	30.6	30.6	30.6
1963	30.6	30.6	30.6
1964	32.0	33.8	30.6
1965	35.0	37.0	33.6
1966	36.2	47.2	35.6
1967	38.2	39.6	36.2
1968	48.8	42.3	41.7
1969	47.5	52.8	41.7
1970 (January – May)	57.4	59.7	52.1

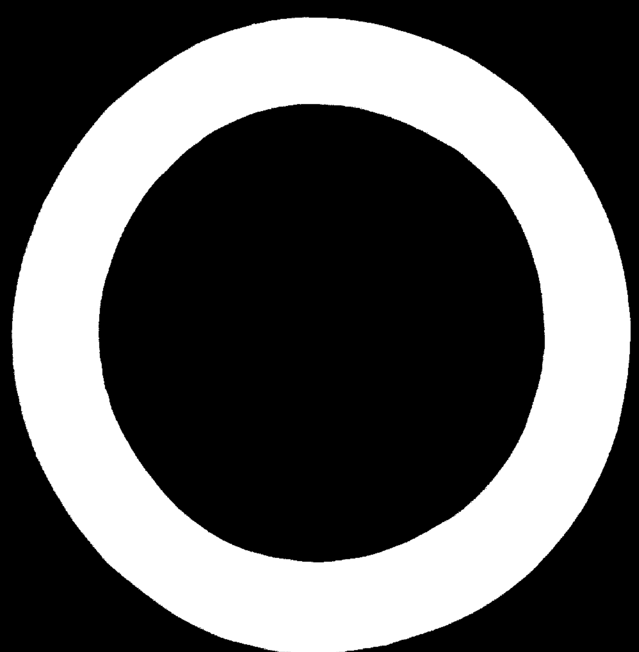
42. The LME is a commodity market that determines the price basis for virtually all transactions other than those in North America and in the countries with centrally planned economies. It is a free market used by almost every country in the world. It therefore reflects the conditions of world supply and demand.

43. The turnover of the LME is over 2.3 million tons per annum, but much of this is in the form of paper transactions, such as hedging and other operations among dealers. The actual physical metal handled by the market is about 230,000 tons per annum. The price quotations are used as a basis for the long-term contracts of the producers and for buying and selling scrap. They influence the pricing of about 6.5 million tons of copper per year.

44. Producers have held in the past that this was an unsatisfactory method of pricing metal. Indeed, the aluminium and nickel producers have established their own prices and they have now been followed by zinc producers. There is now a dual price system for all these metals—one fixed by the producers and one determined in the market. The copper producers have sometimes established their own producer price; for example, when the LME was inoperative during World War II and, more recently, when attempts were made to get away from LME pricing and the daily price fluctuations. These attempts had to be abandoned because of the problems created by dual pricing. In practice it proved to be impossible for two widely different prices for copper to exist for any length of time. This is partly owing to the large supplies of secondary metal and scrap and partly to the desire of some producers to obtain the best possible price.

45. The pricing of commodities by a commodity exchange inevitably leads to an unstable price because there is a daily fixing. The short-term factors prevalent on a particular day influence establishing the price. In addition, the long-term factors of supply and demand operate in the market, but these only affect the long-term movements in price. The wide dispersion of production costs in the industry also contributes to the instability of the price.

46. Fundamentally, however, the price of copper must depend on the long-term supply and demand relationship. If supply grows more rapidly than demand, the price weakens. In recent years there has been a continuing strong market for copper—indeed, demand has risen steadily and more rapidly than production. As a result prices have risen sharply.



4. THE REQUIREMENTS OF THE DEVELOPING COUNTRIES

THE STATUS OF COPPER MINING IN THE DEVELOPING COUNTRIES

47. The developing countries can be divided into three separate groups. Countries in the first group have large copper deposits, extensive mines and use sophisticated technology. These countries are Chile, Peru, the Republic of Zaire and Zambia.

48. Second, some countries and territories have recently started to mine their copper deposits, or are preparing to do so in the near future. These are Botswana, Bougainville (Solomon Islands), Indonesia, Iran and Mauritania.

49. Finally, a number of countries have discovered copper deposits but have no immediate plans for mining the ores. The exploitation of these resources by these countries presents a wide range of problems involving very different needs.

50. Malaysia is now beginning to develop its copper prospects. A deposit containing about 70 million tons of 0.6 per cent copper was discovered recently and exploration licences were granted to a consortium. The development of the deposit is progressing satisfactorily, and production from the open-pit mine is expected in two to three years' time. Malaysia has yet to decide whether to build a smelter in order to mine copper ore or to export concentrates.

51. Production of copper in Indonesia has not yet begun on a substantial scale, but large deposits have been discovered near Ertsberg.

52. Copper production in Burma is at the moment limited to the output of some copper matte from lead smelting. However, large ore deposits have been discovered there, and Burma has plans for mining these properties and for erecting smelters and refineries.

53. Iran also has large copper deposits which will be developed in the near future. The country faces three principal problems. The first is how and where to obtain the necessary capital. The second is what type of copper should be produced that would yield the most benefits for the country; that is, whether it should be in the form of concentrates, blister, refined copper or fabricated products. The third is what the effect would be on the

world market of a sizable export of copper from Iran. Iran has asked for the assistance of the United Nations in working out the answers to some of these problems.

54. Argentina has also discovered copper deposits, but the country has not yet been able to develop them.

Requirements for investment funds

55. Apart from countries with well established copper industries, the requirements of the developing countries for investment funds are very large and the capital available from the developed areas of the world is insufficient to meet this demand.

56. The capital required for developing new mines and for the erection of smelters and refineries is also increasing, owing both to technological developments requiring larger-scale metallurgical units and to the fact that many new mines are based on relatively low-grade ores. Few new high-grade ores or deposits have been discovered in recent years, and it is unlikely that they will be located in the immediate future. The production of copper from a low-grade ore does not necessarily entail higher costs than those for operating existing mines. Indeed, some of the new mines that have come into production in recent years have quite low costs per ton of output despite the fact that the ore is low grade. The increase in the production of copper from opencast pits and the development of methods of large-scale earth moving and extraction have made this possible. But these methods require a very large capital investment in the initial stages.

57. The costs of producing copper have risen sharply in most areas of the world. A few years ago the estimated cost of developing a new mine was about £500 to £600 per ton of annual capacity. Extensions to existing mines were something like a third less. Now a figure as high as £1,200 for developing a new mine is being quoted.

58. The major part of the world copper-mine output is now refined where it is mined. The smelters and refineries in the copper-consuming countries have been using less primary material and have turned more to using scrap. This trend has been evident in Western Europe over the past ten years, but it may well change in the next decade.

59. A number of new mining developments have been financed in part by smelters in developed countries and territories. These include those in Bougainville (Solomon Islands), Indonesia and Mauritania. Much of this financing has been provided by Japan. The smelters and refineries in Japan rely in the main on primary material. The supply of scrap, even including large imports, is insufficient to provide the smelters with raw materials. The Japanese companies have therefore financed many mines throughout the w ld and have then placed contracts with the companies operating these mines for the supply of concentrates and blister copper.

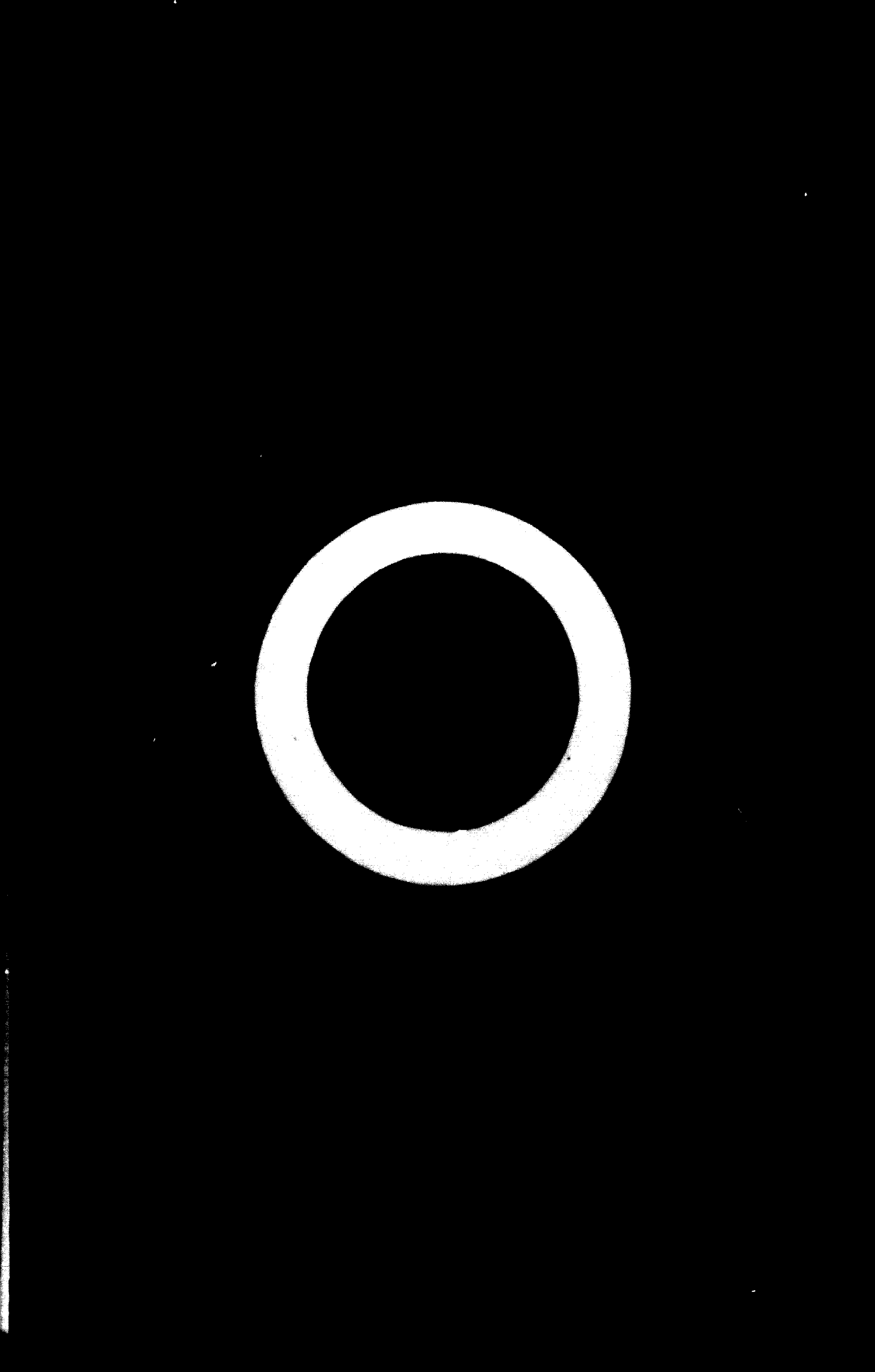
60. Each developing country must decide on the merits of the case whether it will gain more from the investment of a given sum in mining or in fabricating. Indeed, it may well be that capital investment in fields outside the copper industry altogether will result in greater employment and greater productivity. It would therefore be misleading to maintain that it will always benefit the developing countries to fabricate their copper.

61. Apart from financial needs, the developing countries also require technical assistance and advice on the economics of the copper industry. The general level of technology in these countries must be raised. They also require specific technical assistance to evaluate their copper deposits and to determine the most economic methods of processing the ores.

62. The developing countries also need more information about the marketing of copper and they should study future economic prospects of the copper industry. To achieve this goal, UNIDO should try to arrange (when requested) technical/economic missions or individual experts to advise developing countries on questions related to the development of their copper industry.

63. Since the market for copper and its price are affected by the exports of the industrialized countries, particularly of Canada, the countries with centrally planned economies and the US, these countries should indicate their future intentions with respect to the export of copper, together with forecasts of the tonnage involved.

64. Finally, the developing countries face a wide range of financial, economic and marketing problems. UNIDO should organize further meetings of experts to give these countries the advice and guidance that they need.



5. BASIC TRENDS IN THE DEVELOPMENT OF THE COPPER INDUSTRY

65. The expansion of copper production in the developing countries has three main features: it is based on relatively rich raw materials; it is oriented towards the establishment of new plants, incorporating the most modern technological developments; and it is geared largely to exports.

66. The basic changes related to the raw materials for copper production involve:

(a) The decrease in the average copper content in the ores;
(b) The use of low-grade and refractory copper ores;
(c) The development of new sources of copper;
(d) The increase in the utilization of secondary copper.

67. The successful development of and increased effectiveness in the production of copper are dependent on trends in world production. For the developing countries, the most important considerations are changes in the copper content of raw materials, the development of new technological processes, changes in the geographical distribution of plants, and the economics of production and selling.

68. The average copper content of the copper ores that are now being mined is declining. On the whole, the new copper deposits contain a low copper content, less than 1 per cent, although there are a small number of rich new deposits. The decrease in the average copper content in the exploited copper deposits has been compensated for, however, by improvements in copper mining, beneficiation and extraction. There have also been important innovations in treating low-grade and refractory ores. The utilization of secondary copper is also becoming increasingly important. In the developed countries, up to 40 per cent of the copper output is from secondary copper.

69. The main technological changes, which partly reflect changes in the materials, are:

(a) The application of continuous and integrated processes in place of the conventional batch methods;
(b) The complex utilization of raw materials;
(c) The greater recovery of by-products from the ores;

(d) The development of hydrometallurgical processes;
(e) The intensification of the production processes (e.g. the use of oxygen);
(f) The use of new power and fuel sources;
(g) The purification of waste gases and water.

70. New economic developments parallel these technological changes. New plants are frequently erected in areas close to the market, since concentrates are more easily transportable than are some of the products of smelters and refineries.

71. The application of continuous and integrated processes should lead to an improvement in the consumption of power and fuel, a decrease of metal losses, and a reduction of the labour force. Examples of these new integrated processes of roasting and smelting are:

(a) Flash smelting as developed in Canada, Finland and the USSR;
(b) The KIVCET process;
(c) The WORCRA process;
(d) The continuous process developed by the Noranda Company.

72. The effectiveness of such integrated processes can be illustrated by the flash-smelting process (as compared with the classical technology), which allows a decrease of production costs up to 10—15 per cent/ton for blister copper, of labour by 20—30 per cent, of capital funds needed by 10—15 per cent; and permits an increased extraction of sulphur. Some of these integrated processes are operational, whereas others are still at the developmental stage.

73. At present the use of complex materials include the following processes:

(a) Recovery of zinc and pyrite in selective concentrates;
(b) Recovery of molybdenum concentrates from copper-molybdenum ores;
(c) Use of sulphur content in gases for the production of sulphuric acid, liquid sulphur dioxide and elemental sulphur;
(d) Recovery of copper, zinc and other metals from slag;
(e) Use of slag for building material;
(f) Recovery of precious metals, selenium and tellurium from the sludge formed during electrolysis;
(g) Recovery of rare metals from the dust following metallurgical processes.

74. The extraction of sulphur and the treatment and use of slag are very important. They could yield up to 10—20 per cent of additional products, which may be effectively utilized in a developing economy. These may be sulphuric acid, micro-fertilizers, building materials, and, in some instances, pig iron.

75. The need for using refractory ores and the tendency towards the utilization of all components of complex ores have determined the latest developments in the extraction of collective raw materials: copper pyrites, copper-zinc ores, copper-zinc-lead ores etc.

76. Various methods have been developed for treating complex raw materials. Hydrometallurgical (roasting, leaching and extraction of copper and zinc by electrolysis) and pyrometallurgical (the KIVCET process etc). Theoretically, both processes are economic.

77. About 10 per cent of the world copper output is now produced by hydrometallurgical methods of treating refractory ores. The perspectives for such methods are favourable in view of the development of ion-exchanging materials with high selectivity. Economic and technological changes in the hydrometallurgy of copper may lead to the industrial application of ion-exchange processes, whose use can be highly effective for the extraction of copper from diluted solutions.

78. The technology for the treatment of mixed sulphide-oxide ores has been developed in the USSR (Mostovitch method); in the US it is known as the LPF (leaching—precipitation—flotation) process.

79. The following technological processes have been developed recently or are being developed and have good perspectives for the future: wasting of concentrates in fluidized bed; flash smelting; oxygen, or heated-air-blowing smelting; smelting of concentrates in converters using oxygen; increase in the current density in electrolysis; and the use of bacteria in heap-leaching.

80. The output of furnaces roasting concentrates in suspension is 1.5 to 2.0 times higher than that obtained from multi-bottom furnaces, and the production costs are 15—25 per cent less.

81. The use of oxygen during sintering of copper concentrates and in reverberatory smelting of raw concentrates also gives positive results in respect of the intensification of the process.

82. During recent years in the enterprises of the USSR current densities have been substantially increased. This has led to an increase of output. Good economic results are being obtained using current reverse.

83. The general deficit and price increases of fuel have led to the increasing use of natural gas. At present natural gas is used in smelters in the US and the USSR. It has been proved that liquid oil can be economically and feasibly substituted for natural gas.

84. During recent years secondary sources of power have been increasingly utilized. Use of these sources could lead to a decrease in fuel consumption up to 70—80 per cent.

85. In recent years the world has become increasingly conscious of the dangers of pollution of the atmosphere and water. This is particularly so in the more densely urbanized areas. All metallurgical works are, therefore, now erecting extensive plants to reduce these emissions and to recover the metallic and sulphur content. It should be noted that the cost of air- and water-cleaning systems could reach as high as 10–20 per cent of the cost of a given enterprise.

86. The choice of a site for the erection of a copper plant is extremely important, since errors made cannot be corrected during the life of the plant.

87. Some copper smelters and refineries are built close to the source of the raw material, but for others it is more economical to build close to the market. This is particularly so in the case of large chemical/metallurgical complexes, operating not only close to the market for copper but also close to the markets for other metals and by-products.

88. The breakdown of production costs of copper mining and beneficiation and extraction is roughly as follows:

(a) Mining operations, 41 per cent;
(b) Beneficiation, 33 per cent;
(c) Smelting and refining, 26 per cent.

89. The main weight of production costs is during mining operations. These costs may be expected to be reduced as a result of technological developments. However in view of the decreased copper content in the ores used, the costs may remain unchanged or may even be slightly increased.

90. The price of copper in the market economies of the world rose rapidly in the last few years, but it fell sharply during 1970. Costs have also been rising, although much less rapidly.

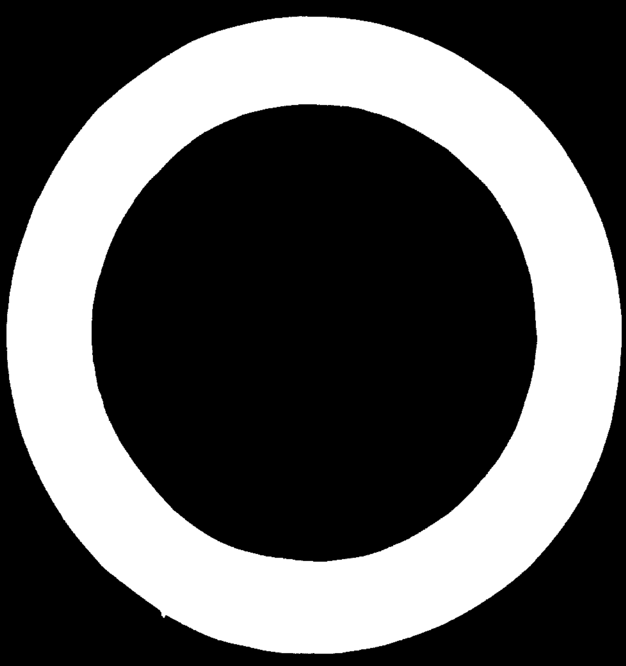
91. The decrease in the metal content of the ores, the depletion of mine resources, the increase of labour costs, the cost of land and water, the increased capital investment in construction and equipment—all tend to raise the costs of production. On the other hand, costs have been reduced by technological progress, the improvement of industrial engineering and technical processes, the reduction of the labour force, the better use of complex raw materials, and the improved treatment of waste products. The total effect of these factors is difficult to predict. It may be expected, however, that serious changes in copper prices in the future may not occur.

92. The rise in prices in the market economies has been due largely to market factors and production problems. Prices in the USSR have also risen but not to the same extent.

93. During recent years the establishment and the reconstruction of the copper industry have been carried out on exceptionally large scales. In the period 1960–1968, 20–30 per cent more funds were invested per ton of copper produced as compared with the period 1950–1960.

94. Technical developments in copper mining should stabilize both the level of capital investment and the level of production costs. With respect to the extraction of copper, capital investment should decrease in view of the intensification of metallurgical processes and the constant introduction of continuous and combined extraction processes. In spite of the influence of some factors that tend to increase costs, capital investment costs generally should either be stabilized or tend to decrease.

95. The main results of the latest advances in the copper industry have been increased output and a decrease in the number of labour employed. A tendency may be observed towards stabilization or even a decrease in the labour employed in the entire copper industry, despite the commissioning of new enterprises.



6. DEVELOPMENT OF HYDROMETALLURGICAL PROCESSES

96. Combined dressing-hydrometallurgical processes are used for oxidized or mixed (sulphide-oxidized) copper ores. These processes involve converting oxidized copper compounds into a solution by leaching, the extraction of copper from the solution, and the flotation of copper compounds that are insoluble in acid (such as sulphides).

97. The details of the processes depend on the mineral composition of the ore and also its physical characteristics.

98. The leaching of oxidized ore is usually carried out with sulphuric acid as this is the cheapest solvent. The cost depends on the method of production and varies from $10 to $20/ton. Part of the acid (less than 30 per cent) is used for copper solution and the rest for the solution of the rock.

99. Complex ores cannot be treated by leaching with sulphuric acid and thus are known as "refractory ores". For these it is necessary to use more concentrated sulphuric-acid solutions and also to heat the mixture. This results in increased acid consumption for dissolving the rock. Acid consumption for these non-carbonate ores is therefore about 4 to 5 kg for 1 kg of copper, and it can reach as high as 12 kg for 1 kg of copper for the ores with a very high content of carbonate.

100. The rate of leaching depends on the size of particles and the leaching methods. Copper can be extracted from a sulphuric-acid solution by electrolysis where the copper content is not lower than 20 g per litre. It is possible to obtain solutions suitable for leaching by means of counter-current percolation or decanting methods.

101. Copper is extracted from lean solutions by cementation with iron scrap. Cement copper concentrate is produced with about 75 per cent copper content. Alternatively, copper may be separated from a solution directly by electrolysis in place of cementation, melting and electrolysis. Direct electrolysis requires less capital and the maintenance costs are lower. This process cannot, however, be used in all cases at the moment, although a method for the extraction of copper concentrates from lean solutions, with the separation of copper through electrolysis, is now being developed.

The LPF (Leaching, Precipitation, Flotation) Process

102. At present the basic combined flotation-hydrometallurgical process of treating oxidized and mixed ores is the **LPF process**, which consists of leaching, precipitation and flotation of copper. Leaching is carried out at pH 1.5 at the beginning and at 2.3–2.5 at the end of the process.

103. Cement copper is produced by using either iron in the form of scrap-iron or iron powder. Iron consumption for cementation is about 1.5 kg for 1 kg of copper. The lowest consumption of the decanter is obtained at pH 3. The cost of scrap-iron varies considerably from country to country but lies within the range of $20 to $60 per ton.

104. The LPF process is most effective in extracting oxidized copper from mixed ores. The process is profitable if it can extract an additional 1 kg of copper per ton of ore.

105. The process can be made more profitable by:

(a) A reduction in the cost of raw materials, namely acid and the precipitator;

(b) Improving equipment and particularly its resistence to corrosion, e.g. by the use of new alloys or plastics;

(c) Reducing the reagent costs;

(d) Automation of control,

(e) The replacement of iron, which is expensive, with cheaper material.

Sorption

106. Copper can be extracted from a pulp solution by an ion-exchanger. Unfortunately, this process has the disadvantage that a bigger apparatus is required at the leaching-sorption stage. The advantage is that it replaces pyrometallurgical processing by electrolysis, and this is a much cheaper process.

107. If hydrogen is available inexpensively, copper can be precipitated in the form of high quality powder in an autoclave. A flotation-sorption combination can increase the production of copper from oxidized ores by over 5 per cent compared with the LPF process.

108. Solvents other than sulphuric acid have not yet been proved in practice. Experiments are now being carried out for the extraction of copper from the sand of flotation tails by percolation, with subsequent copper precipitation in the form of cuprous sulphide and with cyanide regeneration. This process has not yet gone beyond the stage of experimental tests. It requires complicated apparatus and technology and increases the capital costs.

Hydrometallurgical techniques for processing copper ores and concentrates in the US

109. Copper production in the US as in the rest of the world is based on the large-scale smelting of sulphide concentrates.

110. Less copper is produced by leaching, but this process is now used at a number of places. Development work on hydrometallurgical methods for processing sulphide concentrates has also progressed rapidly in recent years, owing in part to the problems of atmospheric pollution by gases from smelters.

111. The methods used in the developed countries for treating concentrates could be applied in the developing countries, including the hydrometallurgical procedures used for oxide ores and mining waste.

112. Out of the total copper production in the US of 1.5 million tons in 1969, 1.3 million tons were produced from sulphide ores by flotation, smelting and refining. In addition, some 2,500 tons of sulphuric acid were produced each day, and half of this was used in leaching copper ores and mine-waste dumps.

113. The need to reduce air pollution caused by the emission of sulphur dioxide indicates that much more acid will be produced from smelter gases in the future. This will then be available for increased leaching of oxide ores and waste. The acid production rate from the gas of copper smelters reached 4,000 tons per day in 1970, and more than half was used in leaching oxide ore and sulphide mine-waste dumps.

114. In 1969 the leaching of waste produced 120,000 tons of cement copper by precipitating the dissolved copper with iron. Most of this cement copper was further processed by the conventional smelters.

115. Leaching of oxide copper followed by cementation and electrolysis or solvent extraction and electrolysis produced 100,000 tons of copper in this year. The solvent extraction and electrolysis process is a marked advance in technology for leach solutions and appears destined for early world-wide use. Leaching of oxide and mixed oxide-sulphide ores is used, followed by cementation with iron in order to recover the copper from the solution.

116. In some places long-term leaching of oxide and mixed sulphide-oxide copper minerals is practiced, including underground leaching of copper from caved mine workings. Ammonia leaching has not been used for some years but is now being investigated for copper-silicate ore containing a large amount of limestone. The ore is first roasted to convert the copper silicate to copper oxide and metallic copper.

117. Processes have also been proposed for the hydrometallurgical treatment of copper sulphides based on ammonia or acid-autoclave leaching. Ammonia pressure-leaching is successfully used in Canada but on nickel-sulphide rather than on copper-sulphide concentrates.

118. The possibility is being investigated of an integrated process for oxide and sulphide ores that are separately mined. The oxide fraction would be leached using acid made in roasting the sulphide concentrates. Sponge iron would be used to precipitate the copper from the oxide-ore-leach solution. However, considerable problems are foreseen, especially in controlling the roasting of the sulphide concentrate.

119. Proposed hydrometallurgical processes for copper-sulphide concentrate have been investigated only on a laboratory scale. No such procedures have been demonstrated in commercial operation, which is an important fact to bear in mind.

7. DEVELOPMENT OF PYROMETALLURGICAL PROCESSES AND OF COPPER REFINING

The utilization of oxygen

120. In one of the copper smelters in the USSR, copper concentrates have been smelted in shaft furnaces with the use of oxygen since 1960. The economic effect of the process is evidenced by a 33 per cent decrease in coke consumption and a 60 per cent increase in output.

121. Enrichment of the blast with oxygen is also one of the most essential innovations in reverberatory smelting. Such industrial-scale operations exist in two smelters: one in the USSR and the other in Copper Cliff, Canada.

122. Over the period 1963–1965 oxygen was introduced in reverberatory furnaces at the Copper Cliff smelter for smelting copper-nickel concentrates. The oxygen content in the blast was calculated at 25 per cent; the use of oxygen resulted in a decrease of fuel consumption by about 13 per cent, and the output of the furnace increased by about 30 per cent.

123. In one of the USSR smelters, blast enrichment with oxygen up to 40 per cent has been tested. During a long period of industrial testing, optimal conditions of the process have proven to be achieved with oxygen blowing at 5,000 m^3/hour (27 per cent); at this rate of oxygen enrichment the furnace output was 5.6 tons/m^2, and the copper content in the slag was about 0.5 per cent and the SO_2 in gases was about 4 per cent.

124. Use of oxygen (as compared with normal blast) resulted in an increase in furnace output by 25 per cent and a decrease in fuel consumption by 25–30 per cent. Enrichment of blast with oxygen above 30 per cent was found to be harmful to the refractories in the first sections of the furnace.

125. During the last 20 years a completely new method of smelting finely ground and pulverized materials has been developed (oxygen flash smelting).

126. The advantages of this process are:

(a) Integration of the two processes—roasting and smelting—in one unit;

(b) Increase of the smelting rate (daily rate of smelting per square unit of hearth furnace);

(c) Decrease of fuel consumption;

(d) Higher grade of matte.

127. The disadvantages are:

(a) The need for thorough drying of the charge;
(b) The need to construct the oxygen plant;
(c) The treatment of slag for copper recovery.

128. The process was developed by the International Nickel Company in 1952 at the Copper Cliff smelter. Oxygen consumption is approximately 140 m^3 per ton of charge. Off-gases contain up to 75 per cent sulphur dioxide and are used for production of liquid sulphur dioxide and sulphuric acid. The process is economically feasible, because imported coal has been replaced by local sources and liquid sulphur dioxide has been obtained as a by-product.

129. A similar smelter was set up in the USSR in 1968 and this included an oxygen plant, furnace and sulphuric-acid plant.

130. According to known published sources, at least seven smelters process copper concentrates in converters using a blend enriched with oxygen. The oxygen content in the blast is 25–35 per cent. Converters can be used for smelting pelletized and dried concentrates as well as wet concentrates.

131. In the majority of cases converter smelting is used for processing very specific concentrates (produced by flotation with 73 per cent of copper, rich sulphide silica and rich sulphide concentrates with a copper content higher than 30 per cent). Converter smelting with oxygen can be applied not only to concentrates, but also to blister and other materials. Oxygen consumption is approximately 90 m^3 per ton of charged concentrate. In the USSR in 1966, semi-industrial tests for roasting copper-zinc sulphides were conducted using oxygen up to 29.8 per cent. The feasibility of this process has been proved. It is envisaged that the process will soon be implemented on an industrial scale.

Smelting process developed in Finland

132. Flash smelting has been developed by the Outokumpu Company, and besides its use by the company's own plants at Harjavalta and Kokkola, Finland, it is now used also in Japan and Romania. In addition, smelters applying this process are under construction or being designed for use in Australia, Botswana, The Federal Republic of Germany, India and Turkey.

133. Flash smelting is a continuous process combining the three stages of conventional copper smelting, namely, roasting, smelting and partly converting, all of which can be carried out in tho same furnace.

134. The flash-smelting furnace uses mainly heat produced during the oxidation of the concentrate for smelting, and the consumption of additional fuel is only a part of that required in the conventional smelting methods. Flash smelting offers good possibilities for the recovery of the heat generated in the process, and if the converter is equipped with waste-heat boilers, the plant is more than self-supporting in terms of power.

135. The grade of matte produced in the furnace varies form 45 to 65 per cent of copper. The matte is then treated further in conventional converters. The slag contains 0.8 – 1.5 per cent of copper and therefore has to be processed further.

136. Flash smelting is flexible with regard to capacity as well as composition of the feed. It is essential for the process that the furnace feed is sufficiently fine and moderately homogenous.

137. Flash smelting also offers good possibilities for the recovery of sulphur. Gases from the flash-smelting furnace with a high sulphur dioxide content, mixed with the converter gases of a lower sulphur dioxide content, are an ideal feed for the sulphuric-acid plant. Nearly all the sulphur can be recovered. The method developed for reducing sulphur dioxide into elemental sulphur offers possibilities for sulphur recovery in areas where sulphuric acid has no demand.

138. The research and development work on the flash-smelting process has recently been devoted to producing a higher grade of matte and producing elemental sulphur from the sulphur-dioxide gases generated in the process.

The KIVCET method

139. The conventional methods of obtaining copper involve, in the main, matte smelting of sulphide ores and subsequent conversion to blister copper. These methods have the following weaknesses:

- *(a)* Low efficiency in the utilization of other elements owing to the loss of zinc, lead, cadmium and other metals contained in the concentrates;
- *(b)* Low efficiency in utilizing sulphide-concentrate heat-producing properties, which means that the smelting processes require additional fuel;
- *(c)* Complicated multi-stage technological pattern;
- *(d)* Difficulties in purifying large quantities of gas and in utilizing the sulphur;
- *(e)* Low and uncontrollable desulphurization, which makes it difficult to regulate the composition of matte.

140. In the USSR semi-industrial tests have been carried out since 1963 with a view to creating a combined metallurgical unit as well as a new method of processing the most complex ores and concentrates based on the use of oxygen and electric energy. This combined unit and method has been developed and has been named the KIVCET process or KIVCET unit.

141. The KIVCET process combines autogenous roasting and smelting of a charge that is dispersed and suspended in a cyclone chamber. The chamber is fed with oxygen and zinc is volatilized in the electrothermic part of the unit. The zinc is then condensed into molten metal, and copper, lead and other

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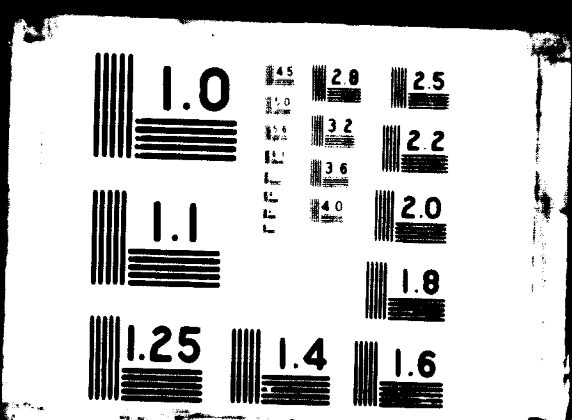

metals are removed from the slag. These operations form a continuous process. One entire cycle gives:

(a) Sulphur extraction to provide rich gases (up to 90 per cent sulphur dioxide);

(b) Copper and precious metals in matte;

(c) Lead, germanium, selenium, rhenium, cadmium and other components are volatilized, and zinc becomes liquid.

142. This process has been functioning since 1965 in a pilot plant. Semi-industrial tests on a unit with a capacity of 50 tons of charge per day are being carried out to obtain optimal construction and performance data.

143. The main technological operations of the KIVCET process are:

(a) Charge preparation for smelting;

(b) Roast smelting of charge in cyclone chamber;

(c) Slag and matte separation;

(d) Electrothermic stripping of smelt;

(e) Condensation of zinc;

(f) Cooling and purification of gases.

144. Work has been carried out on the processing of copper-zinc concentrates containing: 16—20 per cent copper, 7.3—10.5 per cent zinc, 1.5—2.0 per cent lead, 24—26 per cent iron, and 32—34 per cent sulphur.

145. Table 16 gives data on the extraction of various metals and sulphur by the KIVCET and other methods of processing.

TABLE 16. COMPARATIVE YIELD OF METALS AND SULPHUR FROM COPPER-ZINC CONCENTRATES BY VARIOUS EXTRACTION METHODS

(Per cent)

Method	*Copper*	*Lead*	*Zinc*	*Sulphur*	*Gold*	*Silver*
KIVCET	95.0	62.0	70.8	90.0	94.6	94.5
Electrosmelting (with sintered charge)	95.0	68.0	70.8	90.0	93.0	93.0
Reverberatory smelting	93.0	30.0	—	60.0	—	—
Shaft smelting	93.4	9.4	60.8	—	96.5	95.3

146. The KIVCET method, in comparison with other processes, requires less fuel, electric energy and oxygen per ton of charge because of the better utilization of the thermal effect of sulphide-oxidation. This can be seen from the figures in table 17.

TABLE 17. CONSUMPTION OF THERMAL AND ELECTRIC ENERGY PER TON OF EXTRACTED METAL BY VARIOUS METHODS OF SMELTING

(kWh)

KIVCET	*Reverberatory smelting*	*Shaft smelting*	*Electrothermic smelting*
1,978	4,027	3,347	4,542

147. At present, a pilot industrial KIVCET complex with the capacity of 500 tons/24 hours is being commissioned in one of the copper smelters of the USSR. Another furnace, with a capacity of 1,200 tons/24 hours, is being designed.

148. Copper-nickel concentrates have been smelted using different technologies. The chemical composition of the concentrates was as follows: 3.9—4.3 per cent nickel, 1.8—2.1 per cent copper, 0.1—0.15 per cent cobalt, 14.7—15.7 per cent sulphur, 23.2—24.6 per cent iron, 25.7—26.1 per cent silica, and 7.9—10.2 per cent magnesium. The percentage of metals extracted in matte in the KIVCET furnace was as follows: 97.8 per cent nickel, 96.2 per cent copper, and 80.8 per cent cobalt. The comparative consumption of oxygen, fuel, blast and electric energy for the various smelting processes is given in table 18.

TABLE 18. COMPARATIVE CONSUMPTION OF OXYGEN, FUEL, BLAST AND ELECTRIC ENERGY BY VARIOUS METHODS OF EXTRACTION

(Per cent)

Electrosmelting (with sintered charge)	*Smelter "Thompson"*	*KIVCET*
100	84.5	70

149. Rich sulphide copper-nickel ore (8—10 per cent copper, 3—4.9 per cent nickel, 0.08—1.12 per cent cobalt, 40—45 per cent iron, 28 per cent sulphur, 6—8 per cent silica, 2 per cent alumina) has also been tested in the KIVCET furnace. It was found that the process is autogenous and that in the cyclone chamber it is stable under the following conditions: a rate of desulphurization of not less than 60 per cent, and not more than 30 per cent of silica in the slag. The extraction of metals in matte is as follows: 96.3 per cent copper, 96.7 per cent nickel and 77 per cent cobalt.

150. Semi-industrial tests have been carried out in the KIVCET furnace with copper-pyrite concentrates, containing gold (3.8 per cent copper, 3.8 per cent sulphur, 32 per cent iron, 21 per cent silica, 10 g/ton gold, 40 g/ton silver). The extraction of metals in matte is as follows: 93.1 per cent copper, 90 per cent gold, and 95.2 per cent silver.

151. During 1969 copper concentrates were smelted in the KIVCET furnace to blister. Results were promising, and further tests are now under way.

THE WORCRA PROCESS

152. Further development of the WORCRA process has been made in the last three years. Essentially, this process combines the smelting and converting operations in one furnace. The different operations are carried out in the three different zones of the furnace. The process has the great advantage of producing metal rather than matte directly from concentrates. Moreover, the fuel requirements are much lower than those for conventional methods, and sulphur or sulphur dioxide can be recovered as a by-product.

153. The process is still in the development stage. Work on an experimental scale has been carried on at the Sulphide Corporation Ltd in Australia. More recently, Conzinc Rio Tinto of Australia Ltd has built a semi-commercial WORCRA furnace at the works of the Electrolytic Refining & Smelting Co. of Australia Ltd, at Port Kembla.

154. The furnace has undergone three separate campaigns of about a year each, and experience has shown that the process can be worked on a commercial scale. The Port Kembla plant has a capacity of about 6,000 tons of copper per annum. During operations a number of deficiencies in the ancillary plant became evident, but these have now been rectified. The fuel requirement for a bigger furnace would probably be about half that required for a conventional reverberatory furnace.

155. The conclusion to be derived from the operation of the pilot plant and the semi-commercial installation is that the metallurgy of the WORCRA process for the continuous direct smelting-converting of copper concentrates is well established. However, before a plant is built on a full commercial scale, more work on the engineering side is required to achieve the maximum potential for this operation. The next step would be to build a plant with a capacity of 20,000—30,000 tons of copper per annum.

156. The advantages of the WORCRA process as compared with the conventional methods are:

(a) Lower capital costs, which are expected to be some 20—30 per cent lower than reverberatory and convector furnaces of the same capacity. This is particularly important for the developing countries as they are frequently short of capital to invest in their industries.

(b) Lower operating costs, which would bring greater economic returns to the countries that adopt the process. The extent of the cost savings would depend on local conditions, but they would be particularly evident for fuel, power and labour.

(c) The WORCRA furnace would be economically viable at much smaller capacities than conventional smelting. The plant could probably produce, economically, an output in the range of 10,000—20,000 tons of copper per year. It could, therefore, be adopted by the developing countries, which have relatively small copper deposits and are not able to build the very large smelters now in use.

(d) Sulphur can be recovered efficiently from the waste gases. Virtually all the sulphur could be recovered apart from the small quantities contained in the copper produced and in the slag. As a result, atmospheric pollution could be greatly reduced. This problem is becoming increasingly important.

(e) Recovery of copper from the concentrates should be as high as in the existing processes.

ELECTROLYTIC REFINING OF COPPER

157. The electrolytic process for refining copper has made great progress in the last decade, although the process has not undergone a fundamental change; it is still performed in box-type tanks with fixed electrodes.

158. As a result of the latest improvements in the process and the use of new materials, the current load in the tank has been greatly increased. Its production capacity can be raised by increasing the electrode surface in the tank, and by raising the current density.

159. At present a current density as high as 250–300 A/m² is applied in some refineries in Japan and in the USSR. The intensification of the refining process by raising the current density up to 400–600 A/m² is made by using current reversal. It has also been demonstrated that raising the current density up to 400–600 A/m² is possible without current reversal, for various types of copper.

160. Labour-intensive processes, e.g. the removal of copper sheets from dies and the preparation of cathodes, have also been substantially mechanized. Continuous process lines have been mechanized, and mechanized methods are now used for cleaning tanks of sludge. The washing of cathodes has also been simplified.

161. Further research work is progressing in the same direction, namely, on mechanization and the search for new materials.

162. The main improvements in the process have been:

- *(a)* The stabilization of the regime;
- *(b)* The use of new materials for tanks and electric transmissions;
- *(c)* The intensification of the electrorefining process;
- *(d)* The mechanization of production operations.

163. The principal developments giving rise to these improvements have been:

- *(a)* The substitution of current semiconductor rectifiers for motor generator sets;
- *(b)* Heating the electrolyte by tubular heaters;
- *(c)* New instruments for automated control of the process;
- *(d)* Improvement in the quality of cathode sediments;
- *(e)* New apparatus for detecting short circuits.

164. Despite these improvements, the general level of automation in the process is still rather low.

165. The new materials that are being used include corrosion-resistant thermoplastic materials for lining tanks, acid-resistant stainless steel for pumps and titanium for dies.

8. DEVELOPMENTS IN COPPER TRANSFORMATION

166. Transformation, or fabrication, includes the processes of converting copper raw material into a variety of products, which may be used by the engineering, electrical, transport and construction industry. Basically, these processes involve the use of unwrought copper to produce wire, strip, sheet and plate, rod, tubes and castings. These products are made either of copper or of a wide range of copper alloys.

167. About half the copper in the world is used for electrical conductors. In the main, this is in the form of wire that has been produced from wirebars, first by a hot rolling process down to wire rod, and thereafter by drawing. These processes involve large capital expenditure and many different stages. At various stages the metal has to be heated and then cooled, processed and annealed.

168. The developments in fabricating generally are aimed at eliminating some of these many processes and wasteful heat treatments.

169. The recent developments are described below.

Copper wire rod and wire

170. The conventional hot rolling-mill uses wirebars as a raw material. The wirebars have to be cast in the first place from cathodes and then have to be reheated to allow for hot rolling. The production of wirebars is carried out in the copper refineries. They are then transported to the rod rolling-mills for rolling into wire rod.

171. To replace these two separate, conventional processes, development work has been carried out on the integration of the casting and rolling processes, and new methods have been devised for continuous casting and integrated rolling-mills, e.g. the Properzi South Wire system. As an alternative, the General Electric Co. of the US has developed a dip-forming process, which eliminates the wirebar and forms wire rod directly from melted cathodes. Both these processes yield a wire rod that is subsequently drawn down into wire.

172. Further developments have taken place on the hydrostatic extrusion of copper wire directly from the wirebar to finished wire. This is a variation of the conventional extrusion process but the billet is surrounded by pressurized fluid.

173. Work has also been carried out on reducing the drawing processes This can be done by using hydrostatic or hydrodynamic presses to reduce the working loads, or, alternatively, by using roller-die techniques to reduce the number of drawing operations.

174. Finally, ultrasonic energy may be used in wire-drawing.

Strip, sheet and plate

175. Improvements in producing rolled products have followed basic principles similar to those used for producing wire. The aim is to eliminate some of the intermediate processes.

176. At present copper rolling-slabs are produced by the refineries and alloy slabs in the foundries. These slabs are then reheated for hot rolling into rough rolled strip. This is then cold rolled. At various stages reheating and annealing is necessary.

177. The aim of the new methods is to eliminate some of the above operations, and, in particular, the continual reheating. The basic approach has therefore been to cast wide strip directly, instead of producing it by hot rolling. Continuous casting in wide widths has been developed by the Hazlett and the Hunter engineering presses. Continuous casting in narrow widths has also been developed, using static dies.

178. An alternative process, although probably of less importance, is the centrifugal casting of a hollow cylinder of brass, which is then sawn and flattened to give a thin wide strip for subsequent cold rolling.

179. An alternative approach has been to reduce the number of working operations by effecting a very large reduction in the thickness of the material in a single operation, instead of passing the metal through rolls many times.

180. All these various processes can be integrated with the continuous casting method already outlined.

181. Other developments in the production of flat products include the compacting of powders or the use of spray-deposition techniques, to produce a strip for subsequent cold working.

182. Greater accuracy of dimensions has also been obtained by using prestressed mateiials.

9. THE COPPER INDUSTRY IN CHILE AND BULGARIA

THE DEVELOPMENT AND STRUCTURE OF THE COPPER INDUSTRY IN CHILE

183. Chile has been one of the world's largest copper producers for more than 100 years. Its output rose to nearly half a million tons per annum during World War II but fell after the war to a level of about 400,000 tons. For a period of years production remained static. The industry was developed in the main by two large American companies—Anaconda and the Kennecott Copper Corporation.

184. In 1964, the Government of Chile formulated a new policy for the industry, which envisaged the following:

(a) Doubling the copper production from 600,000 to 1.2 million tons of copper content per year;

(b) Participation of the Government in ownership of the mines through the purchase of shares;

(c) Integration of the copper industry into the national economic programme so that the industry would buy the major part of its supplies of necessary materials in the country;

(d) Increase in refining capacity;

(e) Active participation of the Government in the marketing of copper products;

(f) Programme for building the infrastructure for the expansion of plants—housing, roads etc.;

(g) Expansion plan for the medium and small mine sectors;

(h) International action by the Government in the copper market, especially through co-operation with the other three main copper exporting countries—Peru, the Republic of Zaire and Zambia;

(i) Nationalization of the copper industry.

185. The legislation to put this programme into effect took two years to be enacted. After it had been passed, detailed arrangements were worked out whereby the State was to acquire controlling interest in the major US-owned mines and eventually to obtain complete ownership.

186. The increase in the production of copper was intended to allow the more rapid nationalization of the copper industry. The rapid rise in the world copper prices gave an incentive to sales.

187. The government-owned Empresa Nacional de Mineria (ENAMI) provides a wide range of services to the medium-sized and small mining industry. These include not only exploration, smelting and refining, but also such activities as the construction of roads and drainage systems, the supply of electrical power and plant and machinery of various types.

New industrial developments in copper smelting and refining in Bulgaria

188. Bulgaria has been a source of copper since ancient times, but in very small quantities. The copper industry really started to develop only after the Second World War when Bulgaria became a centrally planned economy.

189. At that time there were two small metallurgical plants in the country, one of which produced a few hundred tons of copper matte. Several non-ferrous metal ore deposits were discovered and flotation plants were established.

190. In 1970, the total production of non-ferrous metal ores was more than 13 million tons. The copper content of these ores in various years between 1950 and 1970 is given in table 19.

Table 19. Copper ore production in Bulgaria, 1950–1970

(Recoverable metal content)

Year	*Tons*
1950	2,200
1956	5,600
1960	11,000
1965	29,900
1970	ca. 40,000

191. The general trend of development in the world's copper industry has also been reflected in the Bulgarian industry. Low-grade deposits of porphyritic ores are being developed, and some richer ore deposits are being opened up.

192. The ore of the low-grade mines has a metal content that goes as low as 0.4 per cent. Underground mines are producing ores with a copper content of 1 per cent or a little more.

193. In general, therefore, the ore bodies cannot be considered to be very rich, but modern methods of dressing and metallurgical processing give good technical results.

194. In the Dimitrov mine and metallurgical plant, large quantities of low-grade ores are processed. The first blister copper in Bulgaria was produced here in 1952 and the plant still produces only blister copper.

195. Most of the copper raw materials are processed in the copper-extraction works, which started operating in 1959. This plant was enlarged and began operating with increased capacity in 1966–1967. The plant not only produces copper, but also extracts some by-products such as sulphur, selenium, tellurium, precious metals and others. Various by-products are also obtained from the spent electrolyte.

196. The programme of operations is:

(a) Preparing the charge out of concentrate and quartz flux;
(b) Drying the charge;
(c) Roasting in the fluidized-bed roaster;
(d) Smelting the roast product in the electro-smelting furnace;
(e) Converting the copper matte;
(f) Fire-refining of the blister copper and anode casting;
(g) Electrolytic refining of the copper anodes.

197. On the basis of these new developments in Bulgaria, the following conclusions can be drawn:

(a) It is possible for a copper industry to be developed effectively even in a small country with comparatively low-grade ores, with a copper content of about 0.4 per cent.
(b) Effective processing of concentrates with relatively low copper content is possible by careful selection of the metallurgical methods and the intensification of metallurgical processes.
(c) In order to obtain favourable economic results, trained specialists are needed who are highly qualified in the development of copper metallurgy in a small country. The results achieved in the development of copper metallurgy in Bulgaria demonstrate that in this country highly qualified specialists can be trained in a short time.

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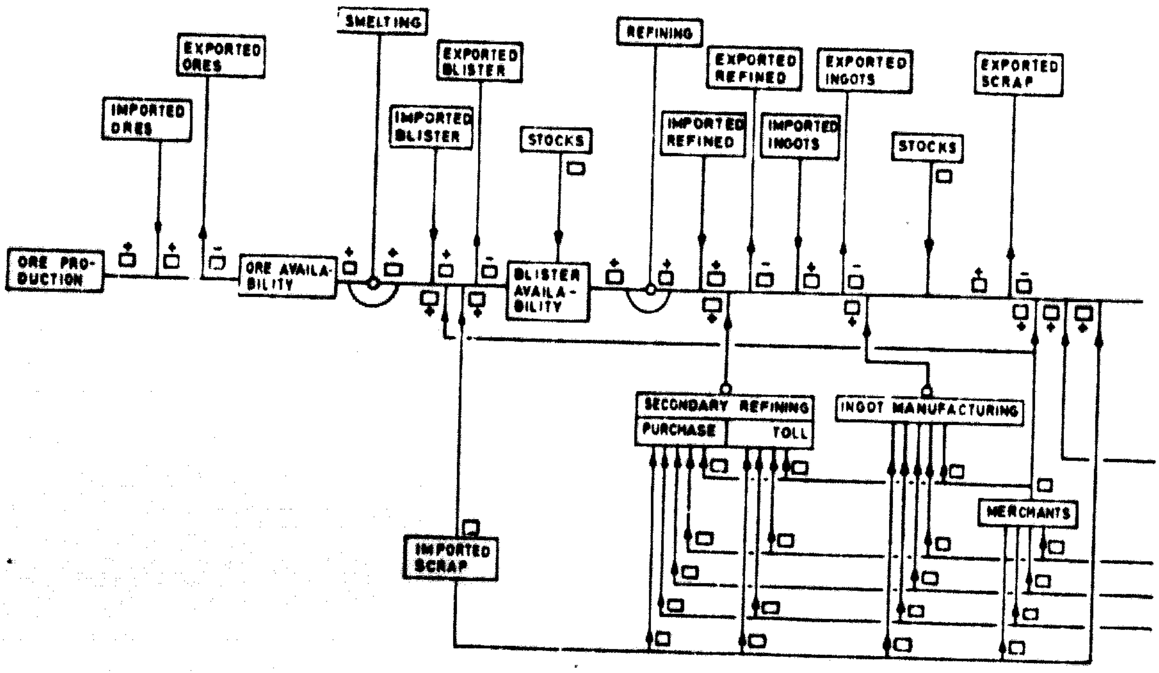
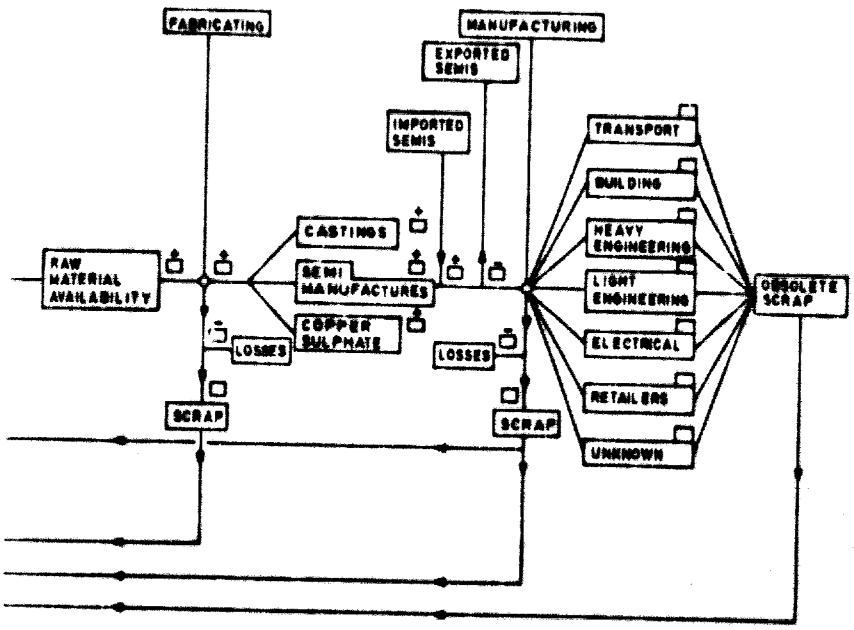
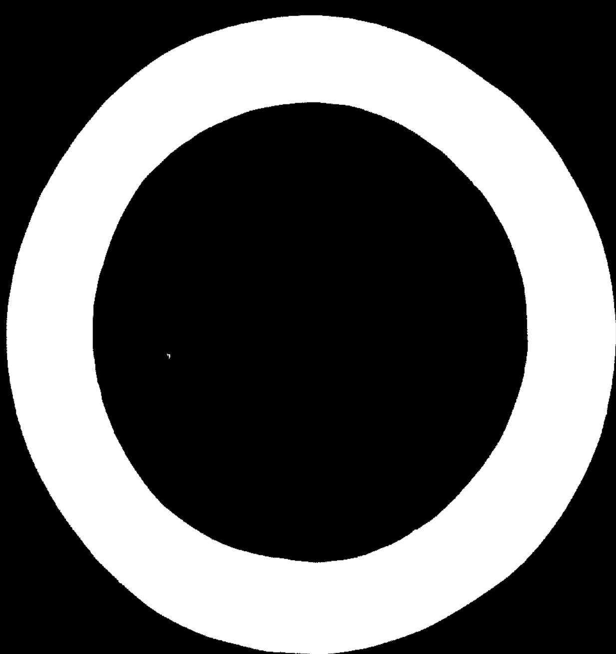


COPPER PRODUCTION





Annex 1

PARTICIPANTS IN THE SEMINAR

In addition to representatives of the host Government, the Union of Soviet Socialist Republics, and the experts who presented papers, ten fellows, who were given grants by UNIDO to attend the Seminar, and twenty-five observers were also participants.

Representatives of the host Government

L. K. Davidov
Chief, Department of Scientific and Technical Co-operation
Ministry of Non-Ferrous Metallurgy

K. I. Ushakov
Director, USSR State Institute of Non-Ferrous Metallurgy

V. I. Vlassov
Chief, Technical Department
Division of Copper Industry
Ministry of Non-Ferrous Metallurgy

J. P. Voronenkov
Deputy Minister
Ministry of Non-Ferrous Metallurgy

Experts

L. Bochkariov
Manager, Department of Research
State Institute of Non-Ferrous Metallurgy
GINTSVETMET
USSR

K. Kaasila
Manager, Engineering Department
Outokumpu Oy
Finland

V. Leksin
Manager, Department of Techno-Economic Research
GINTSVETMET
USSR

B. Leuschner
Regional Adviser on Technological Research for Industry
Economic Commission for Latin America (ELCA)
Chile

S. Mitrofanov
Manager
Department of Beneficiation
GINTSVETMET
USSR

G. Pakhomova
Senior Research Engineer
GINTSVETMET
USSR

J. B. Rosenbaum
Chief, Salt Lake City
Metallurgy Research Center
Bureau of Mines
US Department of the Interior
USA

G. S. Somerset
Assistant Director and Secretary
British Non-Ferrous Metals
Federation
United Kingdom

S. G. Temple
Technical Manager, Copper Division
Imperial Metal Industries
(Kynoch) Ltd.
United Kingdom

I. Tsygoda
Senior Scientific Engineer
GINTSVETMET
USSR

I. D. Vassilev
Chief, Department of Metallurgy
State Committee on Science
and Technology
Bulgaria

M. Vinogradova
Manager, Department of Hydro-
metallurgy
GINTSVETMET
USSR

H. K. Worner
Director, New Process Development
Conzinc Riotinto of Australia Ltd
Australia

FELLOWS

S. H. Aung
Mill Superintendent
Myanma Bawdwin Corporation
Namtu Concentrating Plant
Mineral Dressing Department
Burma

K. M. K. El Mangou
Engineer
Egyptian Copper Works
Arab Republic of Egypt

R. Eyzaguirre
Chief, Department of Engineering
and Mines and Metallurgy
Copper Corporation
Chile

H. H. Garcia
Chief Geologist
YMAD
(Yacim. Min. Agua de Dionisio)
Argentina

M. J. Gonzalez
Technical and Administrative
Director, Copper Refinery
of Ventanas, ENAMI
Chile

F. Jahangiri
Mining Consultant
Industrial Development
and Renovation Organization
of Iran
Iran

M. S. Bin Majid
Chief Inspector of Mines
Department of Mines
Ministry of Lands and Mines
Malaysia

S. Pešić
Research Engineer
Institute for Copper Metallurgy
Yugoslavia

V. Petković
Research Engineer
Institute for Copper Metallurgy
Yugoslavia

D. Tosić
Research Engineer
Institute for Copper Metallurgy
Yugoslavia

Observers

H. Angermeier
Research Officer
Mineral Resources Group
Federal Office of Minerals Research
Federal Republic of Germany

A. A. Babadchan
Deputy Director
Ural Institute for Copper Research
UNIPROMED
USSR

G. Björling
Professor of Non-Ferrous Extractive Technology
Royal Institute of Technology
Sweden

P. N. Bondarenko
GINTSVETMET
USSR

M. I. Chezenko
Chief Technologist
Karabashskij Copper Combine
USSR

K. Clarke
Assistant Vice-President
International Nickel Company of Canada
Canada

S. Hosokawa
Assistant Manager
Naoshima Smelter and Refinery
Mitsubishi Metal Mining Co.
Japan

M. Ibuki
Senior Counsellor
Research and Development Department
Nippon Mining Co. Ltd
Japan

D. I. Maryaninov
Chief Technologist
Karabashskij Copper Combine
USSR

V. S. Matveev
State Committee on Science and Technology
Division on UN Organization
USSR

V. V. Mikhailov
Information Centre
Ministry of Non-Ferrous Metallurgy
USSR

M. A. Mikhilov
Deputy-Chief Engineer
State Planning Institute for Non-Ferrous Metallurgy
GIPROTSVETMET
USSR

T. Neyman
Head, Office of Mines
Swedish Board of Commerce
Sweden

G. V. Pavlovich
Chief Engineer
Pychemskij Electrolytic Copper Works
USSR

S. M. Pavlovich
Deputy Head of the Electrolytical Shop
Almalikskij Mining Metallurgical Combine
USSR

V. I. Philipov
Head of the Metallurgical Shop
Krasno-Ural Copper Works
USSR

G. K. Popovitch
Head, Technical Department
Moscow Copper and Electrolytic Works
USSR

V. S. Sagarskij
Head, Metallurgical Department of the Technical Office
Ministry of Non-Ferrous Metallurgy
MINTSVETMET
USSR

K. S. Sagitajev
Chief of the Electrothermal Shop
Irtishskij Polimetallitsheskij Combine
USSR

N. P. Savchenko
Chief of the Foundry Shop
Kirovograd Copper Smelter
USSR

C. Schnyder
Executive Director
Centro Brasileiro de Informação do Cobre
Brazil

R. J. Shank
Copper-Nickel Development Officer
Minerals and Metals Division
Metal Resources Branch
Department of Energy, Mines and Resources
Canada

V. D. Shustiskij
Head of the Metallurgical Laboratory
Norilskij Combine
USSR

G. Williams
Concentrator Superintendent
Zambia

A. Zaleski
Chief Engineer of Copper Works
Huta Micolei Polska Lepnica
Poland

UNIDO

C. Popov
Industrial Development Officer

Annex 2

PAPERS PRESENTED TO THE SEMINAR*

ID/WG.74/1/Rev.1	Programme of work
ID/WG.74/2	Flash-smelting process, by K. Kaasila
ID/WG.74/3	Developments in WORCRA copper smelting-converting, by H. K. Worner
ID/WG.74/4	Economic aspects of copper production and marketing possibilities for developing countries, by G. S. Somerset
ID/WG.74/5	Some hydrometallurgical techniques for processing copper ore and concentrates, by J. B. Rosenbaum
ID/WG.74/6	New developments in copper transformation (rolling, extrusion, drawing etc.), by S. Temple
ID/WG.74/7	Chile: Development and structure of the copper industry, by B. Leuschner
ID/WG.74/9	Improvement of pyrometallurgical processes for copper recovery by the application of oxygen, by L. M. Bochkariov
ID/WG.74/10	New trends in the development of world copper industry, by V. N. Leksin
ID/WG.74/11	New achievements in the electrorefining of copper, by G. N. Pakhomova
ID/WG.74/12	Processing of copper-zinc, copper-nickel and other sulphide concentrates and ores by the oxygen-suspended electrothermic technique, by I. M. Tsygoda

* A limited number of copies are available upon request.

ID/WG.74/13	Development of combined dressing-hydrometallurgical processes, by S. I. Mitrofanov and M. A. Vinogradova
ID/WG.74/14	List of participants
ID/WG.74/15	New industrial developments in copper smelting and refining in Bulgaria, by I. D. Vasilev

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