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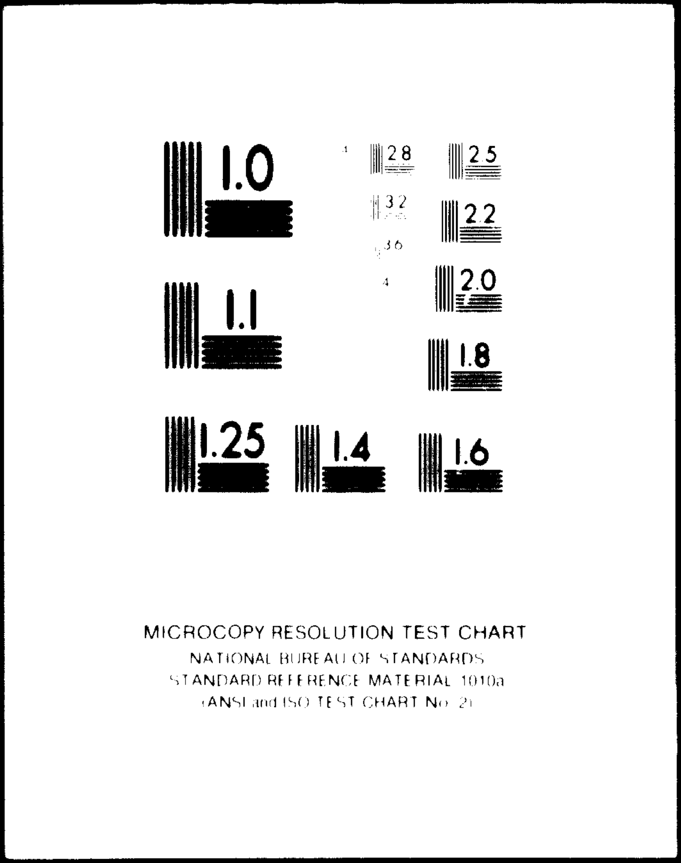

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RECOVERY OF IRON OXIDE AND COPPER FROM SAFI PYRRHOTITE CINDERS--

A FEASIBILITY STUDY

report to

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Arthur D. Little, Inc.

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Morocco.

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December 1971

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Arthur D. Little, Inc.

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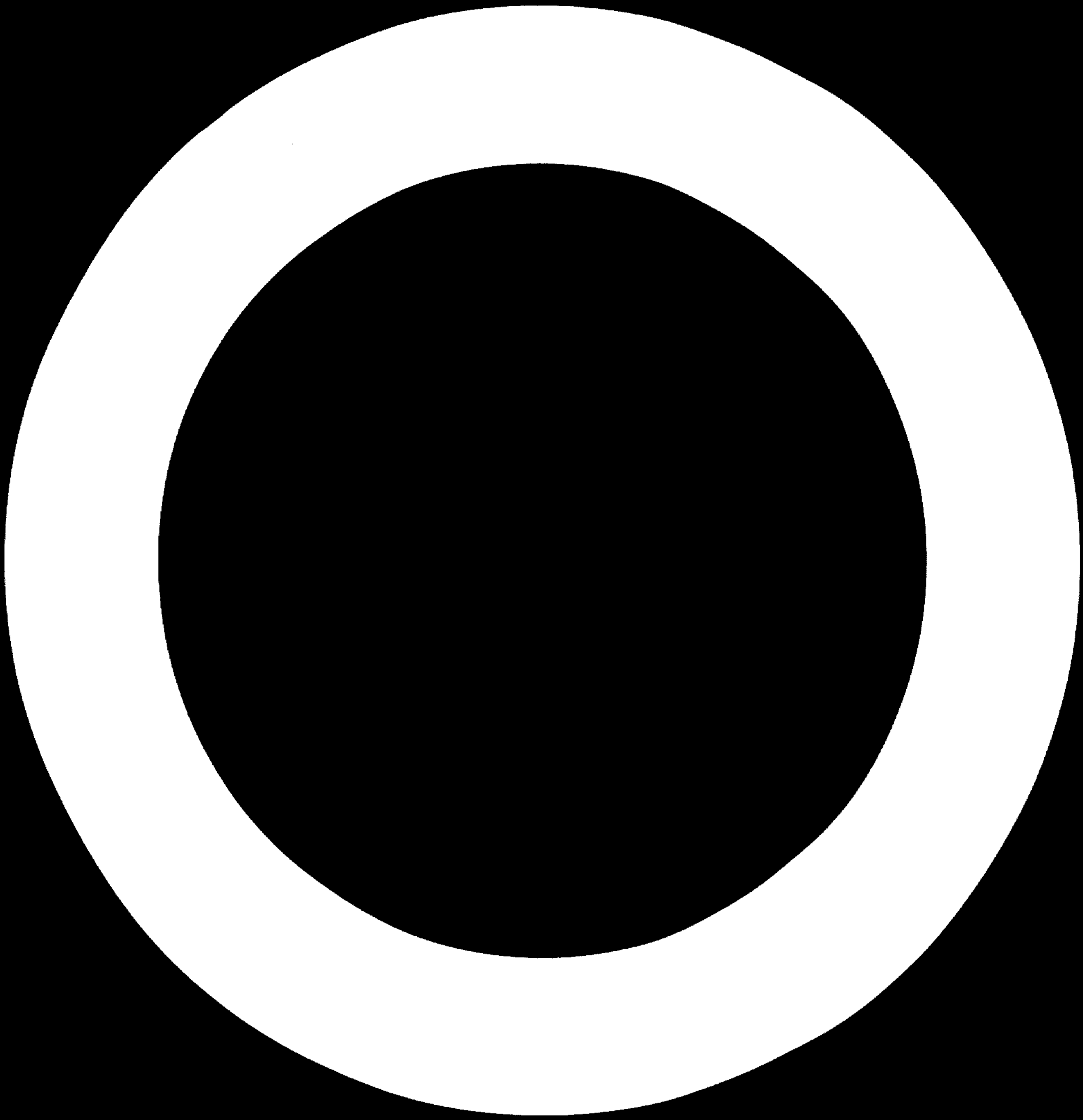

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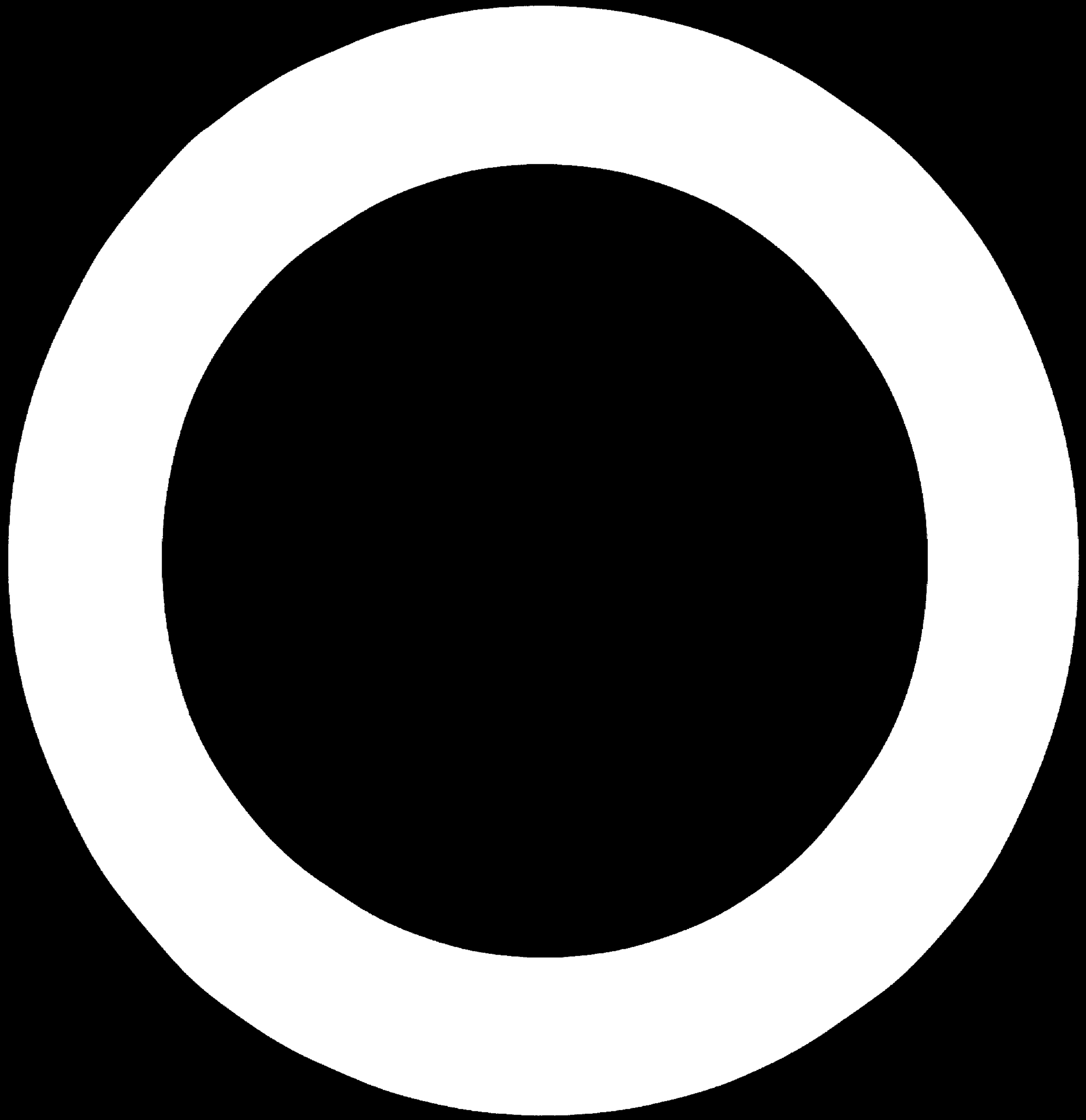

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SUMMARY

A. PURPOSE AND SCOPE

As a result of a sulfuric acid manufacturing operation in Safi, Morocco, a large stockpile of roasted pyrrhotite cinders is being built up. By the end of 1975 this stockpile would consist of:

- 2 million tons of high-silica (12%) cinders
- 1.2 million tons of low-silica (3-4%) cinders
- continuing production of 300,000 tons per year of low-silica (3-4%) cinders

Besides iron oxide and silica, the cinders contain copper (0.8%) and sulfur (1.5-4%) which makes them unacceptable as a feed to blast furnace operations. Bureau de Recherches et de Participations Minieres (BRPM) has been examining the available technology to convert the cinders to a low-sulfur, low-copper, and low-silica feed to blast furnace operations and also obtain at the same time credits for the copper and, if possible, other non-ferrous metal values.

Arthur D. Little, Inc. (ADL), undertook this study to evaluate the technical and economic feasibility of recovering ferrous and copper values from the Safi cinders. We evaluated the experimental work conducted by BRPM and others. After selecting a process for treating the cinders, the capital, operating, and transportation costs were estimated. The overall profitability of the venture was determined based on these costs and an examination of the markets and prices for iron oxide pellets and copper values.

B. FINDINGS

1. Markets

- We find that iron oxide pellets amounting to 400,000-500,000 tons/year could be sold in European markets without difficulty as long as they meet the chemical and physical specifications for these products.
- For the foreseeable future high-iron (64-65% Fe), low-silica (below 6%) iron ore pellets can command a price of about 24 U.S. cents/unit* delivered European ports, while the less desirable low-iron (61% Fe), high-silica (up to 8%) pellets will bring about 23 U.S. cents/unit.

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* (1 unit = 10 kilograms of Fe)

- Copper values could be marketed as wirebar, cathodes, blister, or cement copper. These products are sold at various discounts relative to the price of wirebar. For the foreseeable future wirebar would command an average price of about $1.10 per kilogram. For technical and economic reasons we believe that the most logical way to market the copper values is as cement copper which would be sold at about $0.18 per kilogram below the price of wirebar. There will be little difficulty in marketing copper values as cement copper.

2. Technical

- Of the six processes examined (Kowa Seiko, DKH, LDK, CEEI, Montecatini, and acid leaching), only the leaching, Kowa Seiko, and DKH processes have been used on a commercial scale. Of these three commercial processes, only the Kowa Seiko process has produced agglomerates from Safi pyrrhotite cinder that can meet the low-copper requirements for blast furnace feed.
- No test work has been done on copper recovery after its removal from the cinders. However, all of these processes would involve copper recovery by cementation which is a standard industrial practice and should entail little difficulty although it should be demonstrated before commissioning a commercial facility.
- Pellets produced by the Kowa Seiko process have met the overall physical quality requirements as a blast furnace feed. However, this process requires cinders containing less than about 0.6% sulfur so that the Safi cinders would have to be treated for sulfur removal in order to be acceptable.
- The Kowa Seiko process has successfully produced cement copper as indicated by the commercial operation in Tobata, Japan.
- The pyrrhotite mining operation (SEPYK) is just beginning to supply a low-silica concentrate to Safi. Residual sulfur can be removed from the cinders by flotation or reroasting. Thus, low-silica (<6%), low-sulfur (<0.6%) cinder for the Kowa Seiko process can now be made available.

3. Economic(a)

- While sulfur can be reduced to less than 0.6% by reroasting of cinder, preliminary work done by BRPM indicates it can be more economically removed by flotation.

(a) All costs in this report are in U.S. dollars and cents reflecting conditions in July 1971; all references to tons are metric tons of 1000 Kg.

- A pellet plant wholly based on the stockpiled high-silica cinder is not a profitable venture using present technology.

- A small quantity of stockpiled high-silica cinder can be blended into the low-silica cinder without significantly affecting: (1) the acceptability and quality of the oxide pellets and (2) the recovery of copper.

- A Kowa Seiko plant producing copper and pellets from the blended cinder can produce a return on investment (cash flow basis) ranging from 17.9% (based on 100% equity investment, ten-year depreciation and no tax holiday) to 26.5% (based on 40% equity investment, five-year tax holiday, and an accelerated depreciation of five years).

- In treating the pyrrhotite cinders, approximately 30% of the revenues are generated by the recovered copper and about 70% by the iron oxide pellets. The recovery of only one of these two products is not an interesting venture.

C. CONCLUSIONS

- The results of this preliminary study show that an integrated oxide pellet and copper recovery Kowa Seiko plant based largely on low-silica pyrrhotite cinder is both technically and economically feasible.

- From the point of view of maximizing return on investment, the optimal size of such a plant is about 450,000 annual tons of pellets and about 3,200 annual tons of copper. Such a plant would involve a capital investment of about U.S.$12.6 million.

- Because of projected high operating costs, silica removal should not be considered at this time. Further pilot work might make this concept attractive at some time in the future.

D. RECOMMENDATIONS

If BRPM views this venture favorably, we recommend that a project team be organized to serve as a focal point in moving this project forward. Key areas that would demand attention would include:

- Determining market outlets for the iron oxide pellets and contract prices as a function of silica content so that the plant size and projected returns on investment can be confirmed.

- Confirming with potential pellet purchasers the maximum amount of high-silica cinder that can be blended into the low-silica cinder without suffering penalties for a high-silica product. This in turn will fix the optimal plant size.

- Preparing the necessary quantity of pellets so that they can be evaluated by potential pellet purchasers.
- Determining the market outlets for cement copper and confirming the netbacks shown in this report for copper sales.
- Demonstrating sulfur flotation on a continuous basis and verifying capital and operating costs estimated in this report for sulfur removal.
- Resolving the remaining engineering questions detailed in the body of this report (residual NaCl removal, method of $CaCl_2$ addition, regrinding prior to balling, and separation of non-ferrous values).
- Obtaining bids to fix the capital costs for the construction of the flotation and Kowa Seiko plant for pellet production and copper recovery.
- Negotiating shipping contracts to transport the pellets and cement copper to the markets.
- Determining the method of financing the facility and consider a possible joint venture with Kowa Seiko in terms of the technical information they can bring to the project.
- We do not believe that further work in refining cement copper to fire-refined or electrolytic grades can be justified at this point in time, because of stringent quality control problems and economic considerations. However, this should be re-evaluated if there is a significant increase in domestic consumption of the lower grades of copper.

I. INTRODUCTION

Sulfuric acid manufacturing operations at an integrated fertilizer complex in Safi, Morocco, are based on the oxidizing roasting of pyrrhotite. The pyrrhotite is mined inland at Kettara and transported 40 km by truck and 100 km by rail to the fertilizer plant located at the coast in Safi. The roasters have been in operation since the mid-1960's, and since then pyrrhotite cinders have been stockpiled at the fertilizer plant. These stockpiled cinders are mainly iron oxide (Fe_2O_3) with significant copper values (0.8%). The present inventory of these high-silica (12-15%) cinders amounts to about two million tons. In addition to silica and copper, the cinders contain sulfur (2-4%) which makes them undesirable as a feed to an agglomeration plant supplying blast furnace operations.

Starting this year, the pyrrhotite will be beneficiated to produce a concentrate containing greater than 30% sulfur. This beneficiated pyrrhotite will be roasted to produce cinders containing an estimated 1.5-2.0% sulfur and 3-4% silica. Modifications in roaster operation are being undertaken to reduce the sulfur to even lower levels.

The purchase agreement between the fertilizer complex, Maroc Chimie, and the mine, Societe d'Exportation de Pyrrhotine de Kettara (SEPYK), a partially owned subsidiary of Bureau de Recherches et de Participations Minieres (BRPM), is based on a formula which relates sulfur values contained in the pyrrhotite to prices for elemental sulfur delivered to the plant. Maroc Chimie pays for the sulfur content of the pyrrhotite and the title to the roasted cinders is retained by SEPYK.

The high-copper, high-sulfur, and high-silica cinders are unacceptable to steelmaking operations for the following reasons: Copper has a deleterious effect on the physical properties of steel, except for specific alloy compositions where copper is added intentionally. Because of this it is not generally a desirable constituent in steel products. Since there is no economical way to remove copper from blast furnace pig iron, it is undesirable in any feed for iron- and steelmaking operations.

However, sulfur can be eliminated by slagging in the blast furnace but this requires a high slag volume and therefore more coke for each ton of iron produced. The modern trend in blast furnace operation has been towards lower slag volumes and lower coke rates which requires a uniform charge low in impurities. As a result, acceptable sulfur levels in blast furnace feed have decreased steadily.

BRPM has engaged in extensive research directed toward obtaining additional credits for ferrous and non-ferrous values contained in the cinders. The experimental work involving copper, sulfur, and silica extraction has been conducted at laboratories and plants in Europe and Morocco since about 1963 and is described subsequently. This experimental work has been directed towards finding techniques for extracting copper, sulfur, and silica (if necessary) to convert the cinders to a product acceptable to blast furnace operations while at the same time obtaining credits for copper values. BRPM has been primarily interested in proven technology for building a plant that will convert the cinders to commercially marketable products.

Such a plant will have two types of feed materials available. The first type is the high-sulfur, high-silica material presently stockpiled at Safi and amounting to approximately two million tons. The second type is the low-silica cinder that will be produced from beneficiated pyrrhotite after mid-1971. These low-silica cinders will be produced at the rate of about 300,000 tons per year and by the end of 1975 about 1.2 million tons of these cinders would have accumulated at Safi.

II. PURPOSE AND SCOPE

Arthur D. Little, Inc., undertook this assignment for UNIDO to make an independent evaluation of the work done to date by BRPM and to evaluate the economic viability of the various processes examined by BRPM for the treatment of pyrrhotite cinders. Under the terms of reference, our work covers the following specific aspects:

- Analysis of test results on decopperizing of pyrrhotite cinders, and for copper recovery;
- Evaluation of properties of iron oxide pellets--if produced from high-iron residue;
- Estimation of the market value of the agglomerated product;
- Recommendations regarding the selection of an optimum process for treating the cinders;
- Recommendations regarding additional test work, if this is considered necessary;
- The evaluation of overall technical/economic feasibility of an integrated complex based on the cinders at Safi for recovering ferrous and non-ferrous metal values.

We visited Rabat and Safi, Morocco, in order to obtain information on the past work done by BRPM, the status of the current work, the cost and availability factors for raw materials and utilities, and the operation of the roasters at Safi. The reports and information obtained in the field were analyzed and reviewed by our staff in Cambridge. Based on our past experience, in-house information and discussions with iron ore and metal marketing specialists in the U.S. and Europe, the markets and price for iron oxide pellets and cement copper were determined. Similarly, transportation costs obtained from several sources were evaluated and verified. Based on all the information available, capital and operating costs were estimated for the selected processes and the profitability of a pyrrhotite cinder treatment plant at Safi was evaluated.

III. BACKGROUND

In this chapter, we present a summary and an analysis of the experimental work that has been conducted by and for BRPM in several countries on the Safi pyrrhotite cinders.

An evaluation of this experimental work will be presented in the next chapter.

A. PROCESS DESCRIPTION

BRPM has initiated work to determine the applicability of several processes for decopperizing the cinders. All processes involve copper recovery by cementation with scrap iron, except for the DKH process. The following processes have been considered:

- The DKH process--chloridizing roasting of the cinders with NaCl in multiple hearth roasters followed by an acid leach. The low-copper residue is agglomerated by sintering. A portion of the leached copper is now recovered by the following reaction: $2CuCl + Ca(OH)_2 \rightarrow CaCl_2 + Cu_2O + H_2O$. The rest of the copper is recovered by cementation.

- The LDK process--pelletizing of the cinders followed by drying and hardening in a shaft furnace. Copper removed by treatment with gaseous chlorine in the furnace and recovered by cementation.

- The Montecatini process--the cinders are decopperized by treating with gaseous chlorine in a fluid bed. The copper-free product is subsequently agglomerated.

- The CEEI process--the cinders are decopperized by treating with a ferrous chloride solution spray in a fluid bed. The copper-free product is subsequently agglomerated.

- The Kowa Seiko process--the cinders are mixed with $CaCl_2$ and pelletized. Copper chloride is driven off during the hardening treatment in a rotary kiln with copper recovery accomplished by cementation.

- Acid leaching--the cinders are leached with a mixture of sulfuric acid and seawater. Copper is recovered by cementation.

Some of the sulfur is also removed from the cinders during the decopperizing treatment. Specifically for desulfurization, oxidizing roasting and flotation have been studied.

For silica removal, the following processes have been evaluated:

- The Montecatini process--hematite cinders are reduced to magnetite in a fluid bed. Silica is rejected by grinding and magnetic separation.
- Flotation--hematite is floated with a sulfonate collector at acid pH--silica is floated with a cationic collector at basic pH.

B. RESULTS

The results are summarized in Tables III-1 and III-2. Of the decopperizing processes, DKH and acid leaching were unsuccessful in decreasing copper in the cinders to the desired level. The LDK process successfully decopperized the cinders but the physical quality of the iron oxide pellets was marginal. The LDK, Montecatini, and CEEI processes are untested on a commercial scale. Only the Kowa Seiko process produced high-quality iron oxide pellets acceptably low in copper and sulfur. However, the process requires feed containing below 1% S (preferably below 0.6% S).

Of the two sulfur removal processes, both flotation and reroasting are successful technically. Both are established techniques. Flotation for removal of sulfur from iron oxides is being practiced by Marcona in Peru.

Of the silica removal processes, the Montecatini process and hematite flotation process appear to be technically feasible based on bench-scale tests. Silica flotation could not reduce silica in the cinders to below 9%.

No test work has been done on copper recovery after removal from the cinders. However, all of these processes would involve copper recovery by cementation which is a standard industrial practice and should entail little difficulty although it should be demonstrated before commissioning a commercial facility.

TABLE III-1

SUMMARY OF TEST RESULTS ON DECOPPERIZ

Process	Method	Product	Type of Test	Safi Calcine Treated	Cu Conte of Decopperi Produc
Duisburger Kupferhütte Process (DKH)	NaCl chloridising roast followed by leach	Fines	Continuous	1000 tons	High
Lurgi Duisburger Kupferhütte (LDK)	Chlorine gas treatment in shaft furnace	Pellets	Continuous	2300 tons	Low
Montecatini	Chlorine gas in fluid bed	Fines	Batch	1.5 kg sample	Low
Compagnie Europeanne d'Equipment Industrial (CEEI)	Iron chloride spray in fluid bed	Fines	Continuous	50 kg	Low
Kowa Seiko	$CaCl_2$ chloridising roast	Pellets	Continuous	80 ton	Low
Acid Leaching	Leach cinders with H_2SO_4 and seawater	Fines	Batch	10 kg	High

SECTION 1

TABLE III-1

OF TEST RESULTS ON DECOPPERIZING

Safi Calcine Treated	Cu Content of Decopperized Product	Pellet Strength	Major Drawbacks	Major Advantages
1000 tons	High	No pellets made	High copper residue	Commercially tested process
2300 tons	Low	Poor	Poor pellet strength	Good sized pilot plant tests
1.5 kg sample	Low	No pellets made	Major scale-up problems from tests	Possible to use reducing roast and magnetic beneficiation
50 kg	Low	No pellets made	Major scale-up problems from tests	Same as Montecatini
80 ton	Low	Good	Needs prior sulfur removal to about 0.6%	Commercially tested process
10 kg	High	No pellets made	High copper residue, needs separate sulfur removal	Commercially tested process

SECTION 2

TABLE III-2

SUMMARY OF TEST RESULTS ON SULFUR AND SILICA REMOVAL

	Scale of Testing	Results
A. SULFUR REMOVAL		
1. Reroasting		
a. Kowa Seiko	80 tons	Successful
b. CERI	50 kg	Successful
2. Sulfide Flotation	Bench Scale	Successful
B. SILICA REMOVAL		
1. Montecatini Process	1.5 kg	Successful (<4% SiO_2)
2. Hematite Flotation with Sulfonate	Bench Scale	Successful (<4% SiO_2)
3. Silica Flotation with Amines	Bench Scale	Unsuccessful (>9% SiO_2)

IV. TECHNICAL EVALUATION

A. EVALUATION CRITERIA

The various processes for recovery of iron and copper values from cinders should fulfill the following requirements in order to be utilized in Morocco.

1. Will the process produce products which meet with usual chemical specifications for these products in the market place?

   The DKH process and acid leaching were unable to produce decopperized cinders that would be generally acceptable as blast furnace feed. All other processes were successful in producing cinders suitably low in copper.

   Feed materials for ironmaking also have specifications on silica content. Iron ore pellets containing over 8% SiO_2 are not easily sold. The desired silica content of the pellets is below 5-6%. This means that the cinders made from the beneficiated pyrrhotite can be utilized for pelletizing without prior treatment for silica removal. The stockpile cinders, however, would require a treatment to reduce silica from 12-15% to below 6%.

   Specifications for cement copper are generally low and there should be little difficulty in marketing copper values produced in this fashion.

2. Will the process produce products that meet physical specifications for such commodities?

   Only the Kowa Seiko process when applied to cinders treated to reduce the sulfur to below 1% (and preferably to 0.6% S) successfully produced high-strength iron ore pellets. It was claimed that the LDK process would also be successful on similar low-sulfur cinders. However, during the second series of tests, the sulfur removal procedures prior to decopperization were not adequate and the tests produced iron ore pellets of marginal physical quality. The parameters for production of pellets or sinter of adequate physical quality have not been studied in detail for the other processes. There are no physical quality specifications for marketing cement copper.

3. Is the process established and proven on a commercial scale?

   Only the Kowa Seiko, LDK, and leaching processes meet this criterion. All the other processes have not operated on a commercial scale and a Moroccan plant based on any of these would involve extensive developmental efforts rather than direct technology transfer.

B. PROCESS SELECTION

Only the Kowa Seiko process comes close to fulfilling all the above criteria, but it can be successfully applied only to low-sulfur cinders. The presence of sulfur is undesirable in the Kowa Seiko process because it forms stable calcium sulfate by reaction with the added calcium chloride. During induration (hardening), the pellets apparently reach a relatively high density by the time they reach the temperature for decomposition of calcium sulfate so that sulfur is either not eliminated or its release causes pellet cracking and disintegration.

It should be clearly recognized that there are two types of feed materials available at Safi. The first is the stockpiled cinder which is high in sulfur and silica. This stockpile amounts to about 2 million tons. In order to be an acceptable feedstock for the Kowa Seiko process, sulfur removal is necessary. In order to produce high-grade pellets that are a marketable commodity, silica removal is necessary. Sufficient silica has to be removed from these cinders to produce pellets containing about 6% SiO_2 and not over 8% SiO_2.

The second feedstock is the low-silica cinder that would be produced after mid-1971 from the beneficiated pyrrhotite. This quality of cinder will be produced at the rate of about 300,000 tons per year. This cinder will require only desulfurization in order to be acceptable to the Kowa Seiko process.

While there are several changes occurring at the plant at Safi which make it difficult to predict what the sulfur content of the new cinders (derived from beneficiated pyrrhotite) will be, we have assumed in the remainder of this report that the cinders (stockpiled as well as new) will contain at least 1.5% sulfur and will have to be treated for sulfur removal (down to 0.6%) prior to the Kowa Seiko process. If these changes produce cinders with less than about 0.6% sulfur, the sulfur removal steps will not be necessary and the Kowa Seiko process could be applied directly without modification, at least to the new cinders.

With regard to the high-silica stockpiled cinders, we do not believe (Appendix A) that silica removal can be economically justified at this point in time. However, in order to obtain the economies of a larger plant, we do recommend blending in some high-silica cinder into the low-silica cinder. However, pellets with silica contents greater than about 6% will be penalized and could be more difficult to market.

V. IRON ORE PELLETS

A. PELLET MARKETS AND PRICES

There is considerable interest in Europe in high-grade iron ore pellets and the marketing of up to 500,000 tons/year of high-grade Moroccan pellets would not pose any problems. In Europe, pellet consumption is just beginning and iron units charged into blast furnaces are derived mainly from sized ore and sinter. For instance, in 1968 iron units charged into blast furnaces in pellet form comprised about 15% and 3% of the total iron units used in the U.K. and Europe, respectively. The European producers have used high-grade iron pellets and have paid a premium from 1/2 to 1-1/2 cents per iron unit over equivalent quality sinter. (Note: All pellet prices have been given in U.S. cents/metric ton unit, i.e., 10 kg of contained iron.)

In 1968 European producers were paying 22-1/2¢-23¢/unit for pellets delivered to European ports. This price fluctuated somewhat but remained in the same range until mid-1970 when a temporary shortage of iron units drove the price up to 27-28¢/unit. This shortage has eased and the prices are starting to decline. Based on discussions with iron ore marketing specialists in the U.S. and Europe, we believe that the pellet prices will stabilize at 24-26¢/unit delivered to European ports. We have used the lower figure of 24¢/unit for our calculations. A higher pellet price would increase the profitability of this venture.

B. PELLET QUALITY

1. Chemical Criteria

The chemical quality criteria are concerned with chemical composition and the reducibility of the pellets. The chemical composition of pellets produced from fine concentrates is very uniform. Iron content variations of as low as ±0.30% and silica content variations of ±0.25% can be obtained without elaborate blending of concentrates before pelletizing. When using non-uniform sources of iron oxides for pelletizing, it is important to provide adequate blending facilities in order to attain a chemical quality equivalent to the pellets from beneficiated concentrates.

The permissible levels of non-ferrous impurities in pellets are dictated by ironmaking practice and the impurities found in scrap utilized by steelmakers. The specifications for pellets are set so that the steelmaker can produce acceptable steel based on the appropriate mix of hot metal from blast furnaces and of scrap. In North America and Europe, permissible average impurity levels in pellets vary from one company to another and depend very largely on the end product use. In Europe, there is an increasing tendency to negotiate contracts for ore or pellet sales based on a specified composition for the incoming material which is compatible with the other raw materials purchased by the plant. The contracts have penalty clauses for deviations from this specified composition. For copper, the base level can vary between 0.03-0.05% with a penalty of 10-25¢/ton for each 0.01% in excess copper above the specified level. Similarly, the specifications for sulfur can vary considerably. Some steelmakers will purchase high-sulfur (up to 0.5% S) lump ore, but such levels are not acceptable in pellets. With the increasing tendency towards self-fluxing prepared charges, sulfur levels above about 0.05% cannot be tolerated in pellets. The acceptable upper limits of these and other impurities are tabulated below:

Cu ≤ 0.03-0.05%
Pb + Zn ≤ 0.2 -1.0%
S ≤ 0.01-0.1%
P ≤ 0.01%

Reducibility is measured by the rate of oxygen removal under standard conditions; for instance, the reduction of pellets at 1000°C with 40% CO and 60% N_2 for one hour. In general, the reducibility criteria for pellets is not very important since pellets are generally more reducible than ore or sinter.

2. Physical Criteria

The physical quality criteria involve properties which relate to cold and hot strength of the pellets. The cold strength factor describes the ability of the pellets to resist degradation during handling, shipping, and storage.

Cold strength is commonly evaluated by compression strength and tumble indices of the pellets. The compression strength varies with pellet size and a strength of over 200 kg for an 8 mm x 12 mm pellet is considered adequate.

The hot strength factor indicates the resistance to degradation, disintegration, and deformation during reduction in the blast furnace. If the hot strength factor is inferior, the permeability of the stock column is affected, decreasing gas/solid contact and throughput. However, there are no universally accepted laboratory procedures that will predict the performance of agglomerates in a large blast furnace.

While laboratory evaluation of pellet hot strength (e.g., a test developed by Dr. O. Burghardt in Germany, Linder degradation test, etc.) can help in identifying those pellets which undergo catastrophic swelling or disintegration under load, full-scale tests are necessary in order to adequately characterize the hot strength of the pellets. For this reason large quantities of samples for test purposes may be required before a steelmaker will offer long-term contracts for a new pellet coming on the market.

VI. COPPER

The pyrrhotite cinders in Safi contain a considerable amount of non-ferrous metal values, the principal one being about 0.8% copper. The cinders contain lesser quantities of zinc and lead, nickel, cobalt, gold, and silver. There is no economically commercial way of recovering copper alone from the Safi cinder. In order to be economically feasible, credits must be obtained for both the iron oxide values and the copper values. As indicated subsequently in Table VII-8, the recovery of this copper during the treatment of the cinders by the Kowa Seiko process can generate approximately 30% of the total revenue, the iron oxide pellets being responsible for the remaining 70% of the revenues. Copper is therefore an important co-product of the Kowa Seiko process. At the projected plant capacity of 450,000 tons/year of calcine, approximately 3,600 tons of contained copper are handled by the Kowa Seiko process out of which approximately 90% or about 3,200 tons/year of copper would be recovered in the form of cement copper.

A. COPPER RECOVERY

In all the processes considered and tested by BRPM, copper and other non-ferrous metals are converted to chlorides and obtained subsequently as a dilute solution. Copper is recovered from such dilute solutions almost invariably by cementation, that is, by precipitation with scrap iron. The Kowa Seiko process utilizes the cementation step for copper recovery. The cementation process is very simple and can be operated with minimum equipment and unskilled personnel in a successful manner. The cementation step produces a fine powder containing 70-90% copper, the remainder being fine particles of unreacted iron, unreactive material in the scrap, and a certain amount of oxygen picked up as a result of the conversion of some of the freshly precipitated copper to copper oxide during handling.

The precipitation of copper from dilute streams with iron (cementation) has been known since at least the fourth century and has been used industrially for copper recovery since the sixteenth century. Cementation is carried out in vats, in gravity fed launders, rotating drums or cones to which scrap iron is added. The following factors are important in industrial cementation processes:

- Free acid in solution should be limited to prevent excessive scrap iron consumption. (This is achieved in the Kowa Seiko process by adding $CaCO_3$ to the solution.)

- A large surface area of iron is necessary for rapid cementation.

- Agitation increases the cementation rate.

- The cementation process occurs faster, within limits, at higher temperatures.
- Ferric ions in the incoming solution increase scrap iron consumption and are undesirable.

B. COPPER MARKETS AND PRICES

Cement copper is a marketable commodity as would be blister copper made by fire refining the cement copper and cathode copper made by electrolysis of cement copper or blister. However, cement copper, blister, and cathodes require additional treatment in order to be converted to wirebar, the usual starting material for copper fabrication. Therefore, cement copper or blister would have to be sold to one of several smelters or refineries in Europe (or perhaps to non-ferrous foundries making low-grade alloy products).

A local fire refinery or electrolytic refinery would have to operate on 3,200 tons of copper/year. This scale of operation is much smaller than that usually encountered in the primary copper industry. The structure of the copper industry is such that profits are high in mining and fabrication but not for the intermediate conversion steps. Because of these factors, a small plant for upgrading cement copper to some form of primary copper would be marginal.

The prices for the various grades of copper are usually related to the wirebar price. We believe that over the foreseeable future wirebar would be sold at an average price of about $1.10 per kg. Copper is a volatile commodity and can undergo drastic short-term fluctuations in price. We estimate that cement copper can be marked at a discount of about $0.18 per kg below the wirebar price when delivered to the smelter, and there are several smelters in Europe that would purchase cement copper under these terms.

C. COPPER QUALITY

Cement copper as produced is too high in iron for use in the copper alloy industry (brass and bronze). Around the world, the primary copper smelters will purchase cement copper much in the same fashion as they purchase sulfide concentrates. Cement copper when purchased by a primary smelter has no quality requirements. A primary smelter based on sulfide concentrates can accept a small amount of cement copper as a part of the plant feed (about 5-10%) without any substantial increase in the fuel consumption. As a result, the sale of cement copper to the primary smelters favors the seller. At the smelter, the cement copper is either mixed with the concentrates and fed to the reverberatory furnace or is charged directly to a converter for cooling. In either case the cement copper forms a part of the blister copper product of the smelter.

The conversion of cement copper to high-quality wirebar would probably require both fire refining and electrolytic refining. Wirebars have to meet several types of quality specifications in order to be acceptable in the market place.

The quality of wirebar is based on (1) its chemical purity as indicated by its electrical conductivity and (2) its physical properties as indicated by its ability to be drawn into fine wire (magnet wire). The control of the physical properties is difficult and is achieved only by primary producers with large-scale, automated casting facilities. Cooling temperature and oxygen content in the metal are extremely important in giving the wirebars the correct surface finish and quality. Typical defects in wirebars are: rough edges caused by casting machine vibrations, improper top surface ("set") caused by incorrect oxygen content, heat cracks, bone ash inclusions from mold wash, and incorrect size. For these reasons, we do not recommend producing fire-refined and electrolytic copper at this point in time and believe that the best way to market the copper values is in the form of cement copper.

VII. ECONOMIC EVALUATION

A. INTRODUCTION

In this section of the report, we present an economic evaluation of the pertinent processing options suggested by the Technical Evaluation. Specifically, these are the following:

- A comparison of flotation versus roasting for removal of sulfur from the cinders;
- The economics of treating low-sulfur, low-silica cinders by the Kowa Seiko process; and
- The profitability of the proposed cinder treatment facility at Safi.

B. SULFUR REMOVAL

There are two possible methods for decreasing the sulfur content of the cinders to about 0.6%, the amount desired in a feedstock for the Kowa Seiko process.

1. Sulfur Removal by Flotation: Sulfur, as iron and copper sulfide, can be removed by froth flotation using amyl xanthate as a collector. Preliminary work conducted by BRPM on stockpiled cinder indicates that sulfur can be reduced from about 1.5-3% to 0.2-0.3% by grinding followed by bulk sulfide flotation. Because the sulfide concentrate obtained would be high in copper and sulfur, it would be advisable to recycle it to the roasters. We do not foresee any technical problems in being able to accomplish this.

   The cinders are relatively coarse and wet grinding in ball mills is necessary in order to liberate the unroasted sulfide grains from the cinders. In order to obtain good pelletization on a balling disc or drum, it would be necessary to grind the cinders. Hence, the grinding step will be a part of the processing in either case and is not expected to impose additional economic penalties.

   This method would require some modification, however, from the established practice of the Kowa Seiko process. The modification would involve either mixing of a concentrated $CaCl_2$ solution with a moist filter cake prior to balling or drying of the moist filter cake and addition of $CaCl_2$ solution by spraying on the hot cinders.

This latter possibility appears more realistic and has been used as a basis for the economic evaluation. (Note: A ball mill for blending and kneading of the cinders prior to balling might still be necessary. Prior grinding would substantially decrease the power requirements for the kneading step. Also, the kneading might be accomplished more effectively by a muller. This aspect should be investigated.)

2. Sulfur Removal by Roasting: Sulfur in the cinders can be removed by subjecting the cinders to a second roasting step. The heat for this roasting step can be obtained conveniently by burning fuel oil. During the early stages of operation of Kowa Seiko's Tobata plant, coarse high-sulfur stockpiled cinders were reroasted by feeding them into Dorr-Oliver type fluid bed roasters into which was injected a slurry of finely ground sulfide concentrates. This method used sulfur in the fine concentrate as a fuel for roasting the coarse cinders. Our calculations indicate that this approach would not be suitable for reroasting the cinders due to limited need for sulfuric acid at Safi.

   In Table VII-1 we present a capital and operating cost summary for a battery limits desulfurization section based on fluid bed roasting of the cinders operating at 450,000 tons/year of product. The capital cost includes auxiliary equipment necessary for fluid bed operation such as blowers and dust collection equipment. We have assumed that the low-sulfur off-gases can be vented to the atmosphere. The cost of sulfur removal by this method is about $1.80/ton.

   In Table VII-2 we present a capital and operating cost summary for a desulfurizing section based on flotation and the subsequent drying of a moist filter cake. The capital investment is for a battery limits plant and includes costs for materials handling and all costs generally associated with a flotation mill such as conveyors, bins and feeders, pumps, thickeners, filters, and associated equipment. The cost of grinding and classification is excluded in order to keep the costs in this table on a comparable basis with Table VII-1. The rotary dryer cost includes the cost of dust collection equipment. The operating cost summary includes the incremental cost for handling a larger amount of cinder and for returning the high-sulfur concentrate to the roasters. The cost of sulfur removal is about $1.09/ton which is significantly lower than that for desulfurizing the cinders by roasting. On this basis, we have selected the flotation process for desulfurization of the cinders.

TABLE VII-1

CINDER DESULFURIZATION BY FLUID BED ROASTING

Basis: Capital Investment at U.S. $4.40/Annual Ton
450,000 Tons/Year of Low-Sulfur Cinder

	Units	$/Unit	Units/Ton	$/Ton
Fuel	Ton	20.50	0.027	0.55
Water	Ton	0.04	1.0	0.04
Electric Power	Kwh	0.02	15.00	0.30
Labor with Fringe Benefits	Man-Hr.	0.40	0.13	0.05
Supervision	Man-Hr.	2.00	0.02	0.04
Overhead - 100% Labor & Supervision				0.09
Maintenance Supplies @ 4% Capital Investment				0.18
			Direct Operating Cost	1.25
Depreciation - 10 years				0.44
Local Taxes and Insurance @ 2.5% Capital Investment				0.11
TOTAL COST (EXCLUDING INTEREST ON WORKING CAPITAL)				1.80

TABLE VII-2

CINDER DESULFURIZATION BY FLOTATION AND DRYING

Basis: Capital Investment at $2.30/Annual Ton
450,000 Tons/Year of Low-Sulfur Cinder

	Units	$/Unit	Units/Ton	$/Ton
Fuel	Ton	20.50	0.011	0.22
Water	m^3	0.04	1.50	0.06
Electric Power	Kwh	0.02	5.50	0.11
Amyl Xanthate	kg	0.77	0.12	0.09
Pine Oil	kg	0.33	0.05	0.02
Additional Materials Handling	Ton	0.50	0.10	0.05
Labor	Man-Hr.	0.40	0.125	0.05
Supervision	Man-Hr.	2.00	0.015	0.03
Overhead - 100% Labor & Supervisions				0.08
Maintenance Supplies @ 4% Capital Investment				0.09
			Direct Operating Cost	0.80
Depreciation - 10 years				0.23
Local Taxes and Insurance @ 2.5% Capital Investment				0.06
			TOTAL COST (EXCLUDING INTEREST ON WORKING CAPITAL)	1.09

C. THE PROPOSED PROCESSING PLANT

1. Introduction

If the decision to construct a cinder treatment facility at Safi is reached by mid-1972, about three years would be necessary for detailed design, engineering, and construction, and the plant would operate at its rated capacity after about mid-1975. From mid-1971 to mid-1975, approximately 1.2 million tons of low-silica (4% SiO_2) cinders produced from beneficiated pyrrhotite would have accumulated at Safi. The processing plant would have three sources of cinders available at start-up in 1975:

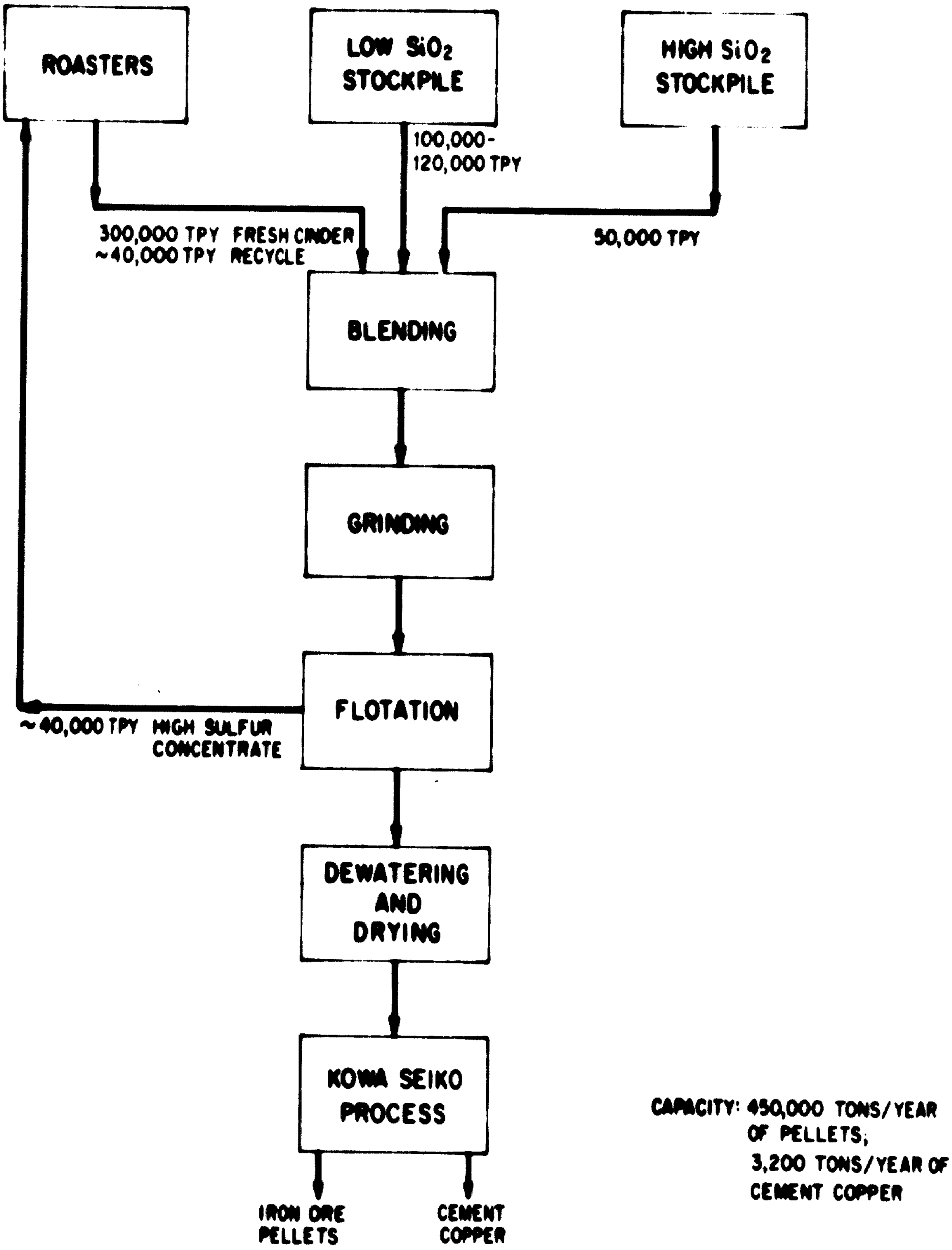
- 300,000 tons/year of low-silica (4%) cinders
- 1,200,000 tons of stockpiled low-silica (4%) cinders
- 2,000,000 tons of stockpiled high-silica (12%) cinders

We have selected a plant capacity of 450,000 tons/year of pellets and 3,200 tons/year cement copper. This plant would utilize 340,000 tons/year of low-silica cinders from the roasters (comprised of 300,000 tons/year of cinders from pyrrhotite feed and about 40,000 tons/year of cinders from the high-sulfur flotation concentrate being recycled), 100,000-120,000 tons/year of cinders from the low-silica cinder stockpile blended with 30,000-50,000 tons/year of cinders from the high-silica stockpile. This blending would decrease the iron content of the mixture from 65% Fe to about 64% to 64.5% Fe. The recovery of cement copper would not be affected.

In 10 to 12 years the low-silica cinder stockpile would be exhausted and about 1.5 million tons of high-silica cinders would still remain unused. Our cost calculations are based on a 10-year depreciation period. We believe that the silica removal step has not been developed to the extent that it could be incorporated in a plant at this point in time. Appendix A presents a detailed discussion of the estimated costs of a silica removal step. We assume that during the intervening period the technology for removal of silica would be developed sufficiently so that it could be incorporated into the pelletizing plant after the low-silica cinder stockpile is exhausted. Alternatively, the fully depreciated plant could be operated at about 75% capacity on only the fresh low-silica cinders.

2. Plant Description

Figure 1 presents a simplified flowsheet of the plant based on desulfurization followed by the Kowa Seiko process. The cinders from the roasters and cinders reclaimed from the low-silica and high-silica stockpiles would be received in bins. Any cinders entering the Kowa Seiko process should not contain sodium chloride. Because of this, the present practice of quenching the roaster discharge with seawater might have to be altered. Possible alternatives are the leaching of sodium chloride from



CAPACITY: 450,000 TONS/YEAR
OF PELLETS;
3,200 TONS/YEAR OF
CEMENT COPPER

FIGURE 1 - SCHEMATIC FLOWSHEET FOR PROPOSED PLANT PRODUCING IRON ORE PELLETS AND CEMENT COPPER

the cinders prior to flotation or supplying Maroc Chimie with fresh water for quenching the cinders. If flotation water is not to be recycled, it might be possible to dissolve and remove NaCl during flotation and by a final wash on the filter.

The cinders from the bins would be wet ground in ball mills and treated by flotation in several stages. We would suggest a coarse grind before the bulk flotation step and regrinding of the middlings in order to avoid settling and filtration problems. The exact flowsheet for the grinding and flotation step would be developed only after further testing at BRPM laboratories.

The dewatered concentrate would be returned to the roasters and the dewatered tailings would be dried in a rotary drier. $CaCl_2$ solution could be sprayed into the dryer or on hot cinders discharging from the dryer. The possible methods for adding the $CaCl_2$ solution to the cinders should be investigated.

The dryer discharge would be conveyed to blending bins of the Kowa Seiko section. We believe that these bins will be necessary since a pelletizing disc requires very uniform feed. The remainder of the plant would be based on the Kowa Seiko process and would involve blending and kneading the cinders, pelletizing on a disc pelletizer, drying on a traveling grate, firing the pellets in a rotary kiln, cooling and storing the pellets for shipment. A detailed flowsheet of this section of the plant based on procedures used at Kowa Seiko's Tobata plant is presented in Figure 2.

The off-gases from the rotary kiln would be scrubbed, demisted, and vented to the atmosphere. The scrubber solution would be treated primarily for copper recovery. The Safi cinders also contain small amounts of lead and zinc, gold and silver, nickel, cobalt, and manganese. These metals will be recovered during solution treatment and purification by the Kowa Seiko process. The specific flowsheet for treatment of this solution will have to be developed based on the non-ferrous impurity levels in the Safi cinders. For our cost calculations we have not claimed any by-product credit for non-ferrous metals except for copper.

3. Capital Investment

Battery limits physical plant costs for the sulfur removal, drying, and Kowa Seiko sections of the plant for iron oxide pellet and copper production are shown in Tables VII-3, VII-4, and VII-5, respectively. We have included an import duty of 16% on equipment that would have to be imported. Total capital investment including additional interconnecting facilities and off-sites, engineering, field indirects, construction fee and contingency are shown in Table VII-6 and amounts to U.S.$11.1 million for the oxide pellet plant alone and U.S.$12.6 million for the oxide pellet plant with copper recovery. This table also includes development costs for the sulfur removal process and anticipated costs for additional work on the Kowa Seiko process.

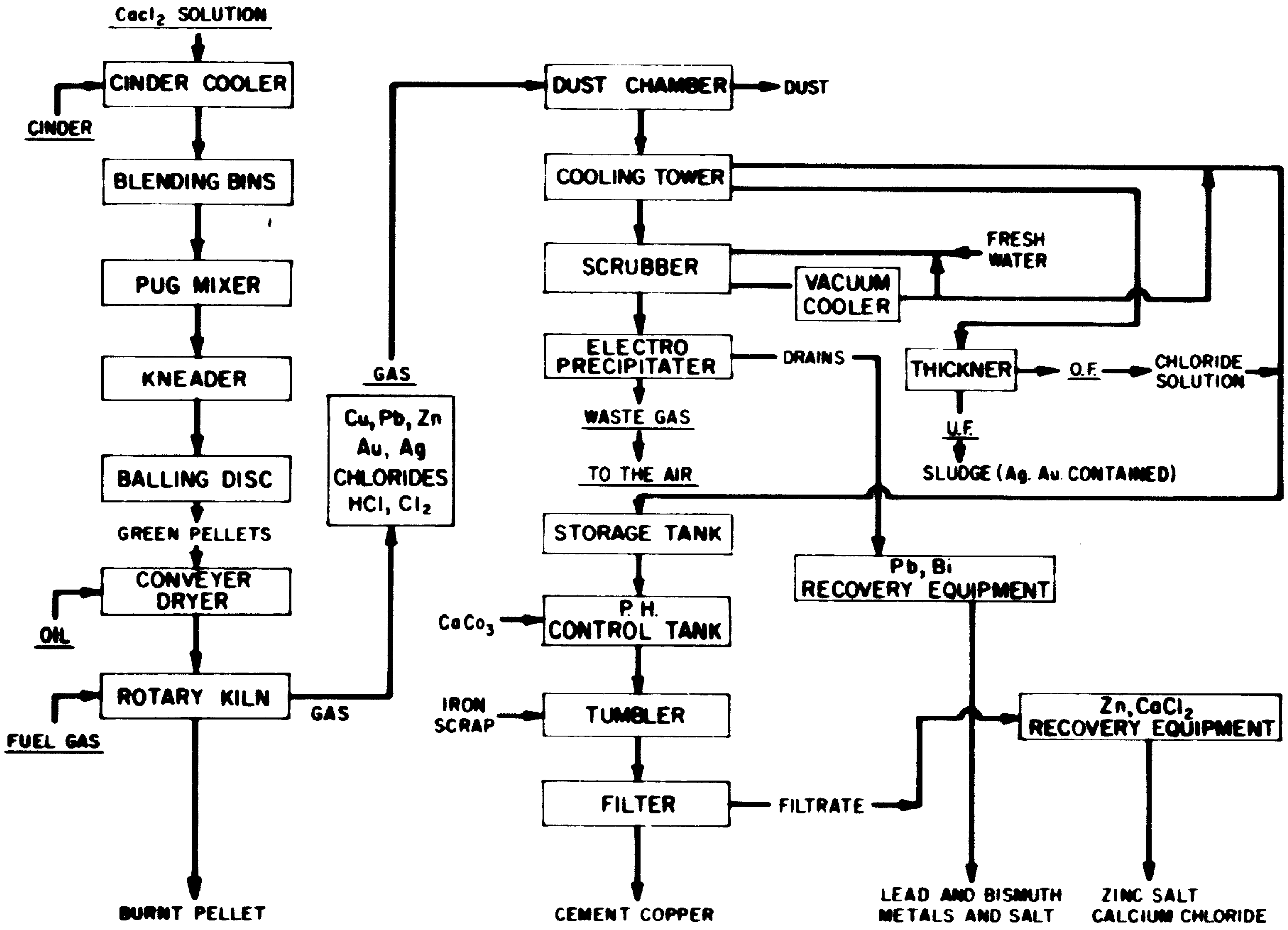


FIGURE 2: FLOW SHEET OF CINDER TREATMENT SECTION OF KOWA SEIKO'S TOBATA PLANT

TABLE VII-3

CAPITAL COSTS FOR FLOTATION SULFUR REMOVAL SECTION

BATTERY LIMITS

(Thousands of U.S. Dollars)

Capacity: 490,000 Tons of Cinders/Year

Bins	125
Conveyors	50
Ball Mills	756
Classifiers	8
Flotation Cells	42
Pumps and Launders	21
Thickeners	31
Filters and Associated Equipment	17
Installed Equipment Cost	1,050
Piping and Launders	238
Electrical	100
Painting	7
Building	230
Stockpile Reclamation Mobile Equipment	100
SULFUR REMOVAL SECTION PHYSICAL PLANT COST	1,725

TABLE VII-4

CAPITAL COSTS FOR ROTARY DRYER SECTION

(Thousands of U.S. Dollars)

Capacity: 517,000 Tons of Filter Cake (15% Moisture)

Installed Equipment Cost	200
Piping and Insulation	16
Electrical	30
Building	40
DRYING SECTION PHYSICAL PLANT COST	286

TABLE VII-5

CAPITAL COSTS FOR KOWA SEIKO SECTION FOR IRON OXIDE PELLET AND COPPER PRODUCTION

(Thousands of U. S. Dollars)

A. PELLET PRODUCTION

Capacity: 450,000 Tons of Pellets/Year

Pretreatment, Kneading, Drying and Firing	2,470
Gas Treatment	600
Installed Equipment Cost	3,070
Piping	460
Insulation	92
Electrical	307
Painting	61
Building	308
Pellet Section Physical Plant Cost	4,298

B. COPPER PRODUCTION

Capacity: 3,200 Tons of Copper/Year

Liquid Treatment (Cementation)	545
Piping	82
Insulation	16
Electrical	53
Painting	11
Building	55
Cement Copper Section Physical Plant Cost	762
TOTAL KOWA SEIKO SECTION PHYSICAL PLANT COST	5,060

TABLE VII-6

CAPITAL INVESTMENT SUMMARY

(Thousands of U. S. Dollars)

Capacity: 450,000 Tons/Year Pellets
3,200 Tons/Year Copper

	Pellets Only	Pellets and Copper
Physical Plant Cost		
Battery Limits		
Flotation: Sulfur Removal Section	1,725	1,725
Drying Section	286	286
Kowa Seiko Iron Oxide Pellet Section	4,298	4,298
Kowa Seiko Copper Recovery Section	-	762
Maintenance Facilities	38	40
Interconnecting Facilities		
Water, Pumping and Distribution	44	50
Steam Distribution	18	20
Electric Distribution	44	50
Fire Protection	31	35
Off-Sites		
Buildings	63	70
Fencing, Roads, Paving, Sewers	44	50
Total Physical Plant Cost	6,591	7,386
Engineering (13%)	860	960
Field Indirects (12%)	790	886
Construction Fee (7%)	461	517
Contingency (14%)	923	1,034
Land and Site Preparation	370	400
Development Costs	45	50
Starting Expenses @ 1/2 Costs for 6 Months*	1,060	1,350
TOTAL	11,100	12,583

*Based on operating costs and a share of fixed costs.

4. Operating Costs

a. Stockpile Reclamation: We have assumed a cost of $0.50 per ton for reclaiming the stockpile cinders with mobile equipment. As requested by BRPM, we have assumed that the cinders are available to the plant at zero cost.

b. Grinding-Flotation Drying: The grinding and metal wear costs are based on average "work index" values for the materials treated. The reagent requirements for flotation are from BRPM's experimental work.

c. Kowa Seiko: The reagent, power, fuel consumption, and labor costs are based on data supplied to BRPM by Kowa Seiko. The power consumption for grinding and kneading has been adjusted in order to compensate for grinding prior to flotation.

5. Profitability Summary

Table VII-7 presents our calculations on the profitability of this venture covering pellet production alone and pellet production with copper recovery.

a. Working Capital: The working capital has been estimated on the basis of 1-1/2 months' inventory of product involving a production cost, operating cost, plus a share of fixed costs, of about $520,000 for pellets and $106,000 for copper.

b. Revenue: The iron ore pellets containing 64% Fe are salable at 24¢/unit delivered European ports. We have used a value of 92¢/kg for copper contained in cement copper delivered to European copper smelters. This is based on a discount of 18¢/kg below a wirebar price of $1.10/kg. These discounts are consistent with cement copper purchase schedules around the world. A 90% recovery of copper in the cinders is assumed based on our experience.

c. Transportation Costs:

- Transportation of Plant to Port (10 km):

  BRPM has indicated that the cost of rail haul for large bulk shipments would vary between 35-59¢/ton which has been confirmed by Maroc Chimie and is in line with our experience. For our cost calculations, we have used a cost of 50¢/ton of pellets for transportation by rail from plant to port.

TABLE VII-7

OPERATING COSTS

Capacity: 450,000 Tons of Pellets/Year
3,200 Tons of Cement Copper/Year

	Unit	$/Unit	Units/Ton*	Pellets Alone	Thousand $/Year Pellets and Copper
I. Stockpile Reclamation	Ton	0.50	0.38	94.5	94.5
II. Grinding-Flotation-Drying Section					
Power	Kwh	0.02	17.50	157.5	157.5
Fuel Oil	Ton	20.50	0.011	99.0	99.0
Water	m^3	0.04	1.50	27.0	27.0
Amyl Xanthate	kg	0.77	0.12	40.5	40.5
Pine Oil	kg	0.33	0.05	9.0	9.0
Grinding Media	kg	0.33	0.70	103.5	103.5
Labor	Man-Hr.	0.40	0.20	36.0	36.0
Supervision	Man-Hr.	2.00	0.015	13.5	13.5
Overhead - 100% Labor & Supervision		-	-	49.5	49.5
III. Kowa Seiko Process					
Power	Kwh	0.02	60.00	490.0	540.0
Fuel Oil	Ton	20.50	0.061	567.0	567.0
Water	m^3	0.04	0.50	8.0	9.0
$CaCl_2$	kg	0.04	60.00	1,080.0	1,080.0
$Ca(OH)_2$	kg	0.01	11.00	49.5	49.5
$CaCO_3$	kg	0.004	40.00	-	72.0
Scrap Iron	kg	0.12	14.00	-	756.0
Grinding Media	kg	0.33	0.20	31.5	31.5
Misc. Chemicals	kg	0.05	1.00	22.5	22.5
Labor	Man-Hr.	0.40	0.36	58.5	63.0
Supervision	Man-Hr.	2.00	0.03	26.0	27.0
Overhead - 100% Labor & Supervision				84.5	90.0
IV. Maintenance Supplies @ 4% of Capital Investment				444.0	504.0
				3,491.5	4,441.5

* Metric tons of pellets

- **Storage, Reclamation, and Loading**: These costs are sensitive to the scale of operation. Based on our past experience, we have assumed a cost of $0.70/ton for stockpiling, reclamation, and loading of the pellets.

- **Ocean Freight**: Unless special contracts can be obtained from Japan, the sale of these pellets to Japan does not appear to be the most profitable alternative. In addition to a higher cost for ocean freight, we understand that the delivered price of pellets in Japan (mainly from Australia) is several cents/unit lower than that in Europe. Appendix B presents a summary of ocean freight costs developed for shipping the Safi pellets to European ports in 21,000-ton ships. Based on these costs, we have used an average figure of $2.55/ton for shipping the pellets to European ports.

- The small amount of cement copper would have much higher shipping costs. Based on our experience, we have used an average figure of U.S.$0.05/kg for shipping cement copper to European plants. This figure would adequately cover general cargo rates for ocean freight plus overland shipment to European smelters.

d. **Fixed Costs**: These have been estimated based on information supplied by BRPM and available in a booklet "Investment in Morocco", July 1969, published by the Investment Promotion Center of the Government of Morocco.

- **Depreciation**: Although the investment code provides for accelerated depreciation at up to twice the normal rate (i.e., 5 years), we have used a 10-year depreciation period for this plant.

  The possible impact of accelerated depreciation is considered in a subsequent section.

- **Taxes and Insurance**: Based on figures obtained from the Moroccan Investment Promotion Center, we have calculated the local taxes to be about 2% of the capital investment to which we have added 0.5% for insurance.

- **Cost of Sales**: We have assumed iron ore and cement copper marketing costs to be 0.5% of sales.

- **Interest on Working Capital**: We have assumed the interest rate to be 9%.

- Interest on Borrowed Capital: All profitability calculations in this report are based on 100% equity capital except for Table VII-9. In Table VII-9 we have used the same cost data as Table VII-8 except that financing is based on 60% borrowed capital (@9% per annum) and 40% equity capital. This increases the rate of return on equity capital from 17.9% to 26.4%. Average interest costs have been calculated by taking the average outstanding debt over the 10-year period and multiplying it by the interest rate.

e. Taxes: Ths business profits tax is 48% of the gross profit. We understand that there are no other taxes or duties that are payable on export commodities.

In Table VII-8 we have excluded the amount of net profits set aside for the purchase of equipment bonds. This would amount to 4% of the net profit or about $0.09/ton. This would decrease the return on investment from 17.9% to 17.6%.

f. Subsidy, Tax Holidays, and Accelerated Depreciation: An "equipment premium" is a direct subsidy available from the Government. This amounts to 15% of the cost of equipment and buildings of a directly productive nature. If this subsidy were available to this project, the amount of subsidy would be approximately $1,100,000. This would increase the rate of return on investment from 17.9% to 19.8%.

If a five-year depreciation is available from the Government, the rate of return would increase from 17.9% to 22.7%.

If both five-year depreciation and a five-year tax holiday are available from the Government, the rate of return would increase to 25.2%.

If financing is based on 60% borrowed and 40% equity capital and both five-year depreciation and a five-year tax holiday are available, the rate of return would decrease to 26.5%.

g. Return on Investment: We have calculated the return on investment as the cash flow (net profit plus depreciation) divided by the equity capital investment.

Table VII-8 indicates that a plant treating the Safi cinders would be profitable giving a return on investment of about 18% only if copper is recovered. As seen in Table VII-8, pellet production with no copper recovery is a marginally profitable venture. It should be realized that the profitability of this plant is a consequence of being able to utilize the low-silica cinders that will be available after 1971. In addition to copper values, these cinders produce high-grade pellets that are acceptable to the iron and steel industry, while requiring only a sulfur removal step

TABLE VII-8

PROFITABILITY SUMMARY

Capacity: 450,000 Tons of Pellets/Year
3,200 Tons of Copper/Year

		Pellets Alone	Pellets & Copper Production
I.	Capital Investment (millions of $)	11.1	12.6
II.	Working Capital (millions of $)	0.1	0.6
		Pellets Alone ($000/Year)	Pellets & Copper ($000/Year)
III.	Revenues		
	Iron Ore Pellets - $0.24/Unit x 64 Units	6,912.0	6,912.0
	Copper - $0.92/kg. x 7.18 kg	-	2,972.5
		6,912.0	9,884.5
IV.	Transportation Costs for Pellets		
	Shipping to European Port	1,147.5	1,147.5
	Storage and Loading	315.0	315.0
	Plant to Port	225.0	225.0
V.	Transportation Costs for Copper	-	160.0
VI.	Netback to Plant	5,224.5	8,037.0
VII.	Operating Costs		
	Direct Operating Cost	3,491.5	4,441.5
	Fixed Costs		
	Depreciation @ 10% of Capital Investment	1,110.0	1,260.0
	Taxes and Insurance @ 2.5% of Capital Investment	277.5	315.0
	Sales Cost @ 0.5% of Sales	34.6	49.5
	Interest on Working Capital @ 9%	45.0	54.0
	Total Operating Cost	4,958.6	6,120.0
	Gross Profit	265.9	1,917.0
	Less Business Profits Tax @ 48%	127.6	918.0
	Net Profit	138.3	999.0
	Add Back Depreciation	1,110.0	1,260.0
	Cash Flow	1,248.3	2,259.0
	Return on Equity Investment (100 x Cash Flow/C.I.)	11.2%	17.9%

TABLE VII-9

PROFITABILITY SUMMARY - 40% EQUITY

Capacity: 450,000 Tons of Pellets/Year
3,200 Tons Cement Copper/Year
40% Equity - 60% Debt - 10-Year Loan

I.	Capital Investment	12.6
II.	Working Capital	.6
		Thousands of $/Year
III.	Netback to Plant	8,037.0
IV.	Operating Costs	
	Direct Operating Costs	4,441.5
	Fixed Costs	
	Depreciation @ 10% of Capital Investment	1,260.0
	Taxes and Insurance @ 2.5% of Capital Investment	315.0
	Sales @ 0.5% of Sales	49.5
	Interest on Working Capital @ 9%	54.0
	Average Interest on Debt @ 9%	337.5
	Total Operating Cost	6,457.5
	Gross Profit	1,579.5
	Less Business Profits Tax @ 48%	756.0
	Net Profit	823.5
	Add Back Depreciation	1,260.0
	Cash Flow	2,083.5
	Less Payment on Principal	756.0
	Equity Cash Flow	1,327.5
	Return on Equity (Equity Cash Flow/Equity C.I.)	26.4%

prior to the Kowa Seiko process. Our calculations show that a similar plant producing low-iron pellets from the stockpiled high-silica cinders treated only for sulfur removal will be marginal and a plant based on high-silica cinder treated for silica and sulfur removal will be uneconomical.

6. Economics of Copper Recovery

The discussion in Chapter V shows that decopperizing of cinders is essential in order to produce iron oxide pellets that are acceptable in the market place. Copper is expelled from the pellets as volatile chloride in the rotary kiln during the Kowa Seiko process and trapped in the scrubber solution. One can easily evaluate the costs involved in recovering copper from the scrubber solution to determine if this incremental copper recovery step is economically justified. As shown in Table VII-6, thc copper recovery step will increase the capital investment from $11,100,000 to $12,600,000. Table VII-8 shows that the return on investment (all-equity cash flow basis) is increased from 11.2% to 17.9%. Clearly copper recovery (as cement copper) from the scrubber solution is a profitable venture. This is also seen by noting that the cement copper obtained is worth $0.88/kg at the plant. The incremental operating costs involved in obtaining the cement copper are:

	U.S.¢/kg Copper Recovered
$CaCO_3$	2.4
Scrap iron	25.7
Labor	.2
Miscellaneous	2.2
Total	30.5

With operating costs of $0.305 and capital charges of $0.05-0.06 a kilogram on the incremental investment (over an oxide pellet plant) on a product valued at $0.88, the recovery of copper from the kiln off-gases is a very profitable operation and the incremental costs involved in incorporating this step in the overall process are justified.

APPENDICES

APPENDIX A

SILICA REMOVAL

Removal of silica from the stockpiled cinders is necessary to produce high-grade pellets. There are two approaches that can be used:

1. Flotation: This is being investigated at BRPM laboratories and appears promising technically. This method would be used in conjunction with the Kowa Seiko process and would precede it.

2. Reducing Roast-Magnetic Separation: This method is based on reducing hematite to magnetite in a fluid bed and subsequently rejecting silica by grinding and magnetic separation. This method is being used on an industrial scale by Montecatini and has been tried on the Safi cinders only on a bench scale. This particular approach could be used in conjunction with fluid bed decopperizing and fluid bed desulfurization except that fluid bed decopperizing processes have not been proven commercially.

We have developed preliminary costs for removal of silica from the stockpiled high-silica cinders based on preliminary flotation data developed by BRPM on the flotation of hematite with sulfonate at an acid pH.

Table A-1 presents a cost summary for the hematite flotation step. We have considered only the incremental costs of incorporating hematite flotation, concentrate dewatering, and tailings disposal steps in a plant that uses flotation for desulfurization of cinders. It can be seen that the major component of the operating cost is the reagent consumed in flotation of hematite. This cost is relatively insensitive to the scale of operation. Should silica flotation with amines or soaps prove successful, we would expect the reagent costs to decrease from $1.63 per ton of feed to about $0.50 per ton.

Based on past experience, we believe that a reducing roast, grinding, and magnetic separation will cost about the same as sulfonate flotation. However, this processing step has not been used on a large scale for pyrrhotite cinders and we would expect the need for considerable process development efforts outside Morocco in order to prove the viability of this approach. For this reason, this approach is not recommended.

Table A-2 presents the economics for two pellet-making operations that produce 500,000 tons of pellets per year.

TABLE A-1

INCREMENTAL COSTS FOR SILICA REMOVAL BY FLOTATION

I. **Basis:** Hematite flotation with sulfonate 60% wt. recovery
Feed: 166,000 tons/year of high-silica cinders.
Product: 100,000 tons of low-silica (4%) cinders.

II. **Capital Investment:**

Physical Plant Cost	$180,000
Development Cost	20,000
	$200,000

III. **Operating Costs:**

	Unit	$/Unit	Units/Ton	$/Ton of Feed
Power	Kwh	0.02	5.0	0.10
Na Silicate	Kg	0.22	0.9	0.20
H_2SO_4	Kg	0.02	0.35	0.01
Collector	Kg	0.33	4.30	1.42
Water	m^3	0.04	1.00	0.04
Labor	Man-Hr.	0.40	0.07	0.03
Supervision	Man-Hr.	2.00	0.005	0.01
Overhead - 100% Labor & Supervision				0.04
Maintenance Supplies @ 4% Capital Investment				0.05
			Direct Operating Cost	1.90
Depreciation	- 10 years			.12
Local Taxes & Insurance - 2.5% Capital Investment				.03
			TOTAL COST PER TON OF FEED FOR SILICA REMOVAL	2.05

IV. **Total cost per ton of product for silica removal** = $\frac{2.05}{.6}$ = $3.42 per ton of product

TABLE A-2

ECONOMICS OF SILICA REMOVAL BY FLOTATION

Basis: 500,000 tons of pellets per year

I. Case X: 63% Fe pellets; sales price 23.5¢/unit or $14.80/ton

II. Case Y: 65% Fe pellets; sales price 24¢/unit or $15.60/ton
Incremental Capital Cost for SiO_2 removal = $200,000
Sales price advantage for high-grade pellets = $15.60 - $14.80 = $0.80 per ton

III. Economics:

	Thousands of $/Year
Sales price advantage for Case Y	400
Less incremental cost of moving 66,000 tons of high-silica ore @ $0.50/ton	33
Less incremental cost for silica removal	342
Gross Profit	25
Less incremental business profits tax @48%	12
Net Profit	13
Add Back incremental depreciation	20
Cash Flow	33

Rate of return (Cash flow/Capital investment) = 16.5%

Case X: 300,000 tons/year of low-silica (4%) cinders
from roaster

100,000 tons/year of low-silica (4%) cinders
from stockpile

100,000 tons/year of high-silica cinders

The pellets produced in this case would contain about 63% Fe and would suffer a penalty of 1/2¢/unit.

Case Y: 300,000 tons/year of low-silica cinders
from roaster

100,000 tons/year of low-silica cinders
from roaster

100,000 tons/year of low-silica cinders
from hematite flotation of 166,000
tons of high-silica cinders.

The pellets in this case would contain about 65% Fe.

The calculations in Table A-2 indicate that removal of silica by flotation might be economically attractive when the cinders treated in this manner form 20% of the feed to the pellet plant. By a similar calculation, it can be shown that when this type of material exceeds about 22% of the pellet plant feed, silica removal by flotation is no longer profitable.

The economics developed in Tables A-1 and A-2 are very sensitive to the quantities of reagents consumed in flotation, the flotation recovery and the cost penalites suffered for making high-silica, low-iron pellets. Because of this, we recommend that the economics of silica removal be reexamined after the reagent consumption is verified by larger scale tests and after firm offers for purchase of pellets have been received from prospective pellet customers.

The processing scheme proposed in this report is based on the blending of high-silica cinders without silica removal. A silica removal step should be available to the plant when the low-silica stockpile is exhausted, i.e., after about 10 years of plant operation. Because of this, research on silica removal should have a low priority at this point in time. After the full-scale plant is in operation, we suggest that the following approaches be investigated amongst others:

- Grinding and Liberation: Since the new beneficiation plant produces low-silica pyrrhotite with minimum grinding, we believe that the silica grains in the stockpiled cinders are probably relatively large and might be liberated with minimal grinding. Reagent consumption for hematite flotation might be decreased if it is conducted at a coarse mesh of grind.

- **Flotation:** We believe that flotation of silica from coarse ground cinders should be investigated using the following approaches:

  a) Use a primary amine collector for silica, starches, proteins, gums, or tannins as depressants for hematite and float in moderately alkaline circuit.

  b) Activate silica with calcium, barium, copper, lead, aluminum, or ferric ions and float with a carboxylic collector, using the same depressants for hematite as before in an alkaline circuit (pH of about 11).

If either of these steps is successful, it offers the following advantages over hematite flotation:

- Lower reagent costs for removing smaller amounts of silica from large amounts of hematite. Approximate reagent costs of about $0.50/ton versus about $1.60 with the present approach.

- Smaller equipment--short flotation times are typical of amine or soap flotation.

- Improved weight recovery--slime loss during silica flotation of coarsely ground cinders might be less.

The disadvantage of this approach would be the need for two stages of grinding and a thickener to dewater the tailings from silica flotation prior to grinding and sulfide flotation. Additional treatment might be necessary for removal of amine or carboxylic collector coatings.

It should be noted, however, that limited testing of the cationic (amine) silica flotation scheme, based on grinding cinders to -150 mesh, by L. H. Manderstam & Partners, Ltd., was unsuccessful and produced a cinder containing over 9% silica.

APPENDIX B

SHIPPING COSTS

The shipping costs used in the report are based on conversations with iron ore marketing specialists in the U.S. and Europe and the costs developed by Smith & Johnson, Steamship Operators & Brokers, in New York. Relevant portions of their letter are reproduced below.

> "The governing draft for single deck bulk carriers most suitable for carriage of the pellets is that of Safi where minimum draft at harbor entrance is about 29 feet, with tidal range varying from about 4-1/2 to 9 feet. The deepest draft vessel sailing from Safi is reported as 32'.
>
> "We understand that the subject project of your principals includes installation at Safi of a bulk loading facility for the pellets, and we have assumed that its capacity would be no less than that of the present phosphate loading belt and travelling gantry crane which together can handle 1000 tons per hour loading.
>
> "Assuming 30 hours laytime used for loading, the approximate average daily rate of discharge at each of the five mentioned possible discharge ports is as indicated in the rate table - all based on cargoes of about 21,000 tons each, which quantity can usually be carried on the governing Safi draft.
>
> "The following are our estimates of freight rate costs based on current market values of suitable size bulk carriers, FIOT basis, 1 berth load, 1 berth discharge, under a contract for consecutive voyages, and vessel returning in ballast from discharge port to Safi because the voyage distances are relatively short.

Safi	Days Allowed L & D	Freight Rate
to Port Talbot	4	$2.25 per M.T.
to Newport	5	$2.40 per M.T.
to Rotterdam	4	$2.45 per M.T.
to Immingham	7	$2.90 per M.T.
to Middlesbrough	5	$2.70 per M.T.

> "Vessel demurrage and despatch rates may currently be figured at about $2,000 and $1,000 daily, respectively.

Possible congestion at the pellet discharging port or berth should be reckoned by shippers in overall costs of ocean transportation - namely vessel demurrage and who pays it - shipper or consignee. The balance between incurring demurrage and earning despatch money is a matter that cannot be accurately estimated, and depends also upon the terms and conditions of the charter party negotiated in respect to definition of laytime and commencement of same. As example of congestion at Rotterdam last September and October, we have records of 21, 16 and 13 days spent in port by vessels with ore cargoes for discharge.

"If production and export of pellets at Safi then totalled 450,000 metric tons per annum, it can be seen that only one ship of about 21,000 tons cargo capacity would be required if on consecutive voyages contract.

"In short, we believe the freight rate costs indicated above represent a fair estimate of ocean transportation costs that can be expected."

APPENDIX C

BIBLIOGRAPHY

A. DOCUMENTS SUPPLIED BY BRPM

1. BRPM notes No. 197, 202, 215, 259, 282, 286, 296, 297, and 298 - Annexe 7.
2. Report by L. H. Manderstam & Partners, Ltd., July 1969.
3. Report by Dr. A. Colombini of Montecatini, September 6, 1966.
4. Report by CEEI, November 1968.
5. Description of CEEI Processes (in English) with Flowsheets.
6. BRPM-DVM Cost Calculations for Kowa Seiko Process.
7. Layout of the Installation at Safi Showing Location of Stockpiled Cinders.
8. Kowa Seiko Report, September 1970.
9. Brochure on BRPM Activities.
10. "Investment in Morocco", July 1969, published by the Investment Promotion Center (supplied by Mr. Dottridge of UNDP).

B. PERTINENT REFERENCES IN THE LITERATURE

a. Kowa Seiko Process

1. Anon., "Kowa Seiko Process for Overall Utilization of Pyrites", Sulphur, No. 69, 29-31, March/April 1967.
2. Anon., "The Purification and Pelletization of Pyrite Cinders", Sulphur, No. 77, 34-35, July/August 1968.
3. Y. Okubo, "Kowa Seiko Pelletizing Chlorination Process - Integral Utilization of Iron Pyrites", J. of Metals, 20-3, 63-67, March 1968.
4. R. Remirez, "Japanese Process Makes Blast Furnace Feed From Pyrite Concentrate", Chemical Engineering, 75-8, 114-116, April 8, 1968.
5. Anon., "Chlorine Roast for Iron-Furnace Feed", Chemical Week, 87-88, January 13, 1968.

b. DKH Process

1. F. Habashi, "The Recovery Empire Built on Fool's Gold", Engineering and Mining Journal, 12, 59-64, December 1969.

c. LDK Process

1. F. Habashi, loc. cit.

2. Anon., "The Chlorinated Volatilization Process for Pyrites Cinder Treatment", Sulfur, No. 79, 31-34, November/December 1968.

3. K. K. Lippert, et al., "Recovery of Non-Ferrous Metal Impurities From Iron Ore Pellets by Chlorination (CV or LDK Process)", Trans. Inst. of Mining and Metallurgy, 78(751), C98-C107, 1969.

d. Montecatini Process

1. V. Colombo, et al., "Montecatini's Revamped Pyrite Flowsheet Overcomes the Heat-Iron Sulphur Snags", Engineering and Mining Journal, 166-4, 94-97, April 1965.

2. V. Colombo, et al., "Fluo Solids Reduction of Hematite at Montecatini", J. of Metals, 17-12, 1317-1325, December 1965.

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