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Trevino, Andres A.

Madison, WI: [s.n.], December 1984

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LOWER STACKS

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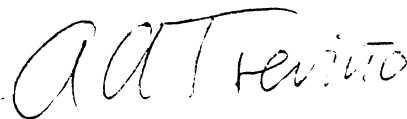
December 14, 1984

Dear Mr. Grefe:

Enclosed please find the final copy of my report summarizing my review of McKee's reports on Exxon's pyrite processing alternatives at Crandon.

Please feel free to contact me if you have any questions.

Sincerely.

A handwritten signature in cursive script that reads "AATrevino".

Andres A. Trevino

Review of the Crandon Project Reports Submitted
by Exxon Minerals Company Assessing Possible
Uses for Pyrite Tailings

FINAL REPORT

December 21, 1984

by:

Andres A. Trevino
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ABBREVIATIONS

Ag	Silver
Au	Gold
CRU	Commodities Research Unit
Cu	Copper
DAP	Diammonium Phosphate
DK	Duisburger Kupferhutte
EPA	Environmental Protection Agency
Fe	Iron
GIR	Gain/Investment Ratio
H ₃ PO ₄	Phosphoric acid
H ₂ SO ₄	Sulfuric acid
JBC	Jones, Bardelmeier and Company
LDK	Lurgi-Duisburger Kupferhutte
M	Thousand
McKee	Davy McKee
MWDF	Mine Waste Disposal Facility
NH ₃	Anhydrous Ammonia
p	Page
Pb	Lead
pg	Page
pgs	Pages
P ₂ O ₅	Phosphate
RO	Reverse Osmosis
ROI	Return On Investment (Discounted Cash Flow)
S	Sulfur
SO ₂	Sulfur dioxide
SO ₃	Sulfur trioxide
SO _x	Sulfur oxides (SO ₂ , SO ₃)
specs	Specifications
T	Metric tons
T/A	Metric tons per annum
T/D	Metric tons per day
TVA	Tennessee Valley Authority
U ₃ O ₈	Uranium oxide
VCE	Vapor Compression Evaporator
wt%	Weight %
Zn	Zinc

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SCOPE OF WORK ITEMS

EXCERPTS FROM:

CONTRACT FOR PROFESSIONAL SERVICES

Between The

State of Wisconsin Department of Natural Resources

And

Dr. Andres A. Trevino

I. AUTHORITY

This contract is entered into by and between the State of Wisconsin Department of Natural Resources, Box 7921, Madison, Wisconsin 53707 (hereinafter called "the Department") and Dr. Andres A. Trevino, 5118 Sherwood Road, Madison, WI 53711 (hereinafter called "the Consultant"), under the authority of Section 23.40(5), subject to the requirements of Section 16.87(2), Wisconsin Statutes.

II. PURPOSE

The purpose of this contract is to have the Consultant provide the Department with technical assistance in reviewing and verifying data concerning the potential for utilization of waste materials from a zinc-copper-lead mine and mill proposed by Exxon Corporation (hereinafter referred to as "Exxon") near Crandon, Wisconsin. This information will be utilized in the environmental and regulatory reviews of Exxon's submittals and in preparing draft (DEIS) and final (FEIS) Environmental Impact Statements, mine permits, and mine waste disposal facility (MWDF) approvals for the proposed Crandon mine project.

III. SCOPE OF WORK

- A. The Consultant shall perform for the Department in connection with its environmental impact analysis and regulatory reviews of the zinc-copper-lead mine proposed by Exxon (hereinafter referred to as "the project") the following services.
 1. Project Familiarity: The Consultant shall become familiar with the general aspects of the proposed project through discussions with Department staff and through reading of project related documents which will be made available by Department staff.
 2. The Consultant shall review and evaluate the following documents which Exxon and its Consultants prepared to document the reuse, sale, recovery, and processing of mining wastes resulting from the Exxon mining project. (These documents were prepared to comply with section NR 182.08(2)(b)3g and NR 182.11(2)(f), Wisconsin Administrative Code.)
 - a. Pyrite Processing Market Studies Final Report, Commodities Research Unit, Ltd., dated November 1979.
 - b. Transportation Rate Estimates for Davy McKee Project 2489 Exxon Minerals Co. USA, Jones Bardelmeier and Co., Ltd., dated September, 1979.
 - c. Crandon Project Pyrite Processing Study - Summary, Davy McKee, dated June, 1981.
 - d. Crandon Project Pyrite Processing Study - Phase I, Davy McKee, dated November, 1979.

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- e. Crandon Project Pyrite Processing Study - Phase II, Davy McKee, dated June, 1981.
 - f. Crandon Project Pyrite Processing Study - Appendix, Davy McKee, dated March, 1980.
 - g. Miscellaneous narrative and data supplied by Exxon in its Environmental Impact Report, mine plan, and MWDF feasibility study and assorted responses to Department letters regarding quality and reuse of saltcake derived from water treatment proposed for the Crandon mine and mill.
3. Utilizing the information contained in the documents listed in item III.A.2 a-f, the Consultant shall evaluate and address the following specific topics concerning pyrite processing:
- a. Adequacy, completeness and accuracy of data sources and calculations performed to support the conclusions reached by Davy McKee.
 - b. Adequacy and completeness of the survey of available technologies which Davy McKee evaluated for potential application to the Project.
 - c. Adequacy and correctness of conclusions reached by Davy McKee regarding potential for reuse and processing of the pyritic fraction of the mine tailings waste.
 - d. Adequacy of the conclusions of the Davy McKee studies when compared to updated data available since the studies were completed. (Study conclusions were reached during the period of 1979-1980).
 - e. Adequacy of definition of study area, distribution network, transportation modes, and product handleability as these factors relate to waste marketability.
 - f. Effects on pyrite and byproduct marketability caused by mine production variations and decisions to utilize total production of mill tailings in byproduct production.
 - g. Range of capital costs for construction of facilities to accomplish the various pyrite reprocessing alternatives. Costs are to be addressed on a feasibility study level.
4. Utilizing the information contained in documents referred to under III.A.2.g above, the Consultant shall evaluate and address the following topics concerning saltcake:
- a. Adequacy and completeness of evaluation of the suitability for reuse of saltcake in commercial processes.

- 4 -

- b. Availability and description of existing markets for saltcake.
 - c. Environmental effects and necessary processing or containerization required for land disposal of saltcake.
- 5. The Consultant shall evaluate and recommend, as necessary, additional studies on pyrite processing or reuse, pyrite byproduct production, and saltcake disposition.
 - 6. The Consultant shall review and evaluate additional studies performed by Exxon or the Department in response to recommendations under the Scope of Work item, III.A.5 above and shall provide the Department with a written summary, acceptable to the Department, of this review.
 - 7. The Consultant shall perform literature surveys and prepare written summaries of the state of engineering knowledge and engineering research on pyrite reprocessing and its potential applications to the waste generated by the project. Specific evaluations shall be made of their potential commercial application within the project life of the project. This shall include the reproduction or acquisition of key technical publications which support the written summaries which shall become the property of the Department.

Section III. A. 7. is hereby amended to specifically include the following document as one of the key technical publications in the literature survey:

"Alternative Solutions for Pyrite Mine-Waste Problems: Sulfur Markets, CO₂ Control in Pyrite Processing, and the Use of Fly Ash in Treating and Isolating Mine Waste", by John Strasma, et al., January 8, 1981.

Section III. A. 3 is hereby amended to add a new paragraph:

- h. Potential magnitude of environmental emissions resulting from the processing of the pyritic fraction of the mine tailings waste.

1. EXECUTIVE SUMMARY

1.1 Pyrite Processing.

Exxon Mineral Company's planned mill operations at Crandon are expected to generate 1,094,000 T/A of pyrite tailings. An impoundment area is proposed to dispose off the 267,000 T/A of fine fraction in these tailings. The remaining coarse fraction can be used as mine fill. Impounded pyrites, however, generate an acid leachate that could contaminate the groundwater. As an alternative to impoundment, further processing of the pyrites to marketable products is suggested. Potential products include sulfur, sulfuric acid, phosphoric acid, diammonium phosphate fertilizer, iron pellets and several nonferrous metals.

This review assesses the adequacy of the feasibility study conducted to evaluate the pyrite processing alternatives available to Exxon. The study is contained in six reports prepared by Exxon's consultants Davy McKee, Commodities Research Unit and Jones, Bardelmeier and Co. The assessment aims at establishing the conformation of these reports to industrial practice. For each report, a careful analysis of data sources, calculations, methodology, technology survey, site considerations and conclusions was conducted. Since the reports were finished in the period 1979-1981, the potential effect of updated information on the conclusions was estimated. An extensive literature survey was completed to detect relevant technology innovations.

The reviewer's conclusion is that the reports are professional and conform to feasibility studies used in industry. Minor errors and omissions detected in the reports do not affect the final conclusions. The study's more important flaw is the lack of justification for the elimination of Crandon as a potential processing center. Transporting pyrite to Green Bay adds \$3 million to the operating cost of processing fine tailings and \$13 million to the cost of processing also the coarse fraction. McKee's final conclusion is that the processing center is uneconomical at the time of the analysis. Their recommendation, therefore, is to impound the fine fraction and use the coarse fraction as mine fill. The conclusion is supported by the study results presented in the reports. Based on available current information on markets and technology it is the reviewer's belief that an updated study would not modify McKee's final conclusion.

1.2 Salt Cake.

The proposed water treatment system at Crandon will produce some 4620 T/A of salt cake (sodium sulfate). A review of the market potential for this byproduct, its suitability for kraft pulping use and its potential environmental impact if impounded is included in this review. This section of the review is, however independent from the pyrite processing sections.

Sodium sulfate's main uses are in the kraft pulping (44%) and the detergent industries (44%). The kraft pulping use has been

decreasing as stricter environmental regulations force pulp manufacturers to recover their waste sulfur and sodium values. This trend is expected to continue in the future. US sodium sulfate imports from Canada are estimated to reach 220,000 T in 1984. Exxon should not have any problem allocating its small production of sodium sulfate if willing to sell at Canadian price levels (2/3 of US price). This alternative is subject to acceptance of the technical specifications of Exxon's product by the kraft pulp manufacturers. Household laundry detergents can contain up to 75% of sodium sulfate. This use is expected to grow moderately in the future. This market would also be open to Exxon's sodium sulfate if it can meet the required specifications. There is no information available to determine the final technical specifications of Exxon's sodium sulfate. If the resulting product is unacceptable to either kraft pulp or detergent manufacturers Exxon would have to dispose off this byproduct.

Sodium sulfate's main environmental threat is its high solubility. Leachate carrying the dissolved sulfates would find its way to groundwater. Rough estimates indicate that at the conditions present at Crandon the impounded salt cake could disappear in as little as a century. No information on salt cake impoundments is available in the technical references. It is the opinion of consulted experts that Exxon would have to provide a lined pond to keep water away from the impounded salt cake.

2. INTRODUCTION

Exxon Mineral Company's (Exxon) expects to obtain 1,094,000 T/A of pyrite tailings as a by product of their mill operations at Crandon. The original plan called for impoundment of the fine fraction of these tailings, amounting to 267,000 T/A, while the remaining 827,000 T/A of coarse fraction is returned to the mine as mine fill. The impounded pyrites, however present an environmental nuisance as their leachate contains sulfuric acid that would find its way to contaminate groundwater. The DNR requested alternative forms to process the pyrite tailings to avoid or ameliorate their environmental impact. Exxon hired the engineering consulting firm Davy McKee to conduct the studies. McKee specializes in engineering plant design, construction, procurement, commissioning, etc. and acts as licensing agent for several chemical process technologies. They have wide experience in the fertilizer industry. Since McKee does not conduct market studies, they subcontracted Commodity Research Unit, firm dedicated to market analysis, and Jones, Bardelmeier and Co., a worldwide freight specialist firm to establish the product markets, raw material availability and transportation modes and costs for both products and raw materials.

The results of the study are presented in six reports:

- Market Study (by Commodities Research Unit)

- Transportation Rate Estimates (by Jones, Bardelmeier and Co.)
- Summary Report (by Davy McKee)
- Phase I Report (by Davy McKee)
- Phase II Report (by Davy McKee)
- Appendix Report (by Davy McKee)

The adequacy of these reports is analyzed in this review. The review is based exclusively on the information contained on the six reports. In a few cases, estimates based on their information were used to strengthen my conclusions. These cases are properly identified in this review. For each report, a careful analysis of the following factors was conducted when applicable.

- a. Data sources and calculations.
- b. Adequacy of technology survey.
- c. Adequacy of conclusions.
- d. Effect of current conditions on the conclusions.
- e. Study area, distribution network, transportation mode and product handleability.
- f. Effect of mine production variations and use of total tailings.
- g. Range of capital costs.

Section 3 summarizes the pyrite processing project. Section 4 presents the individual report reviews. The technology review offered by McKee in the Phase I Report was extended by means of a computerized literature search, as well as physical searches in the University of Wisconsin-Madison Libraries. Section 5 summarizes the extended technology review. Section 6 presents rough quantitative estimates of the environmental emissions generated by the proposed pyrite processing facilities. Section 7 summarizes my conclusions on the reports and their recommendations.

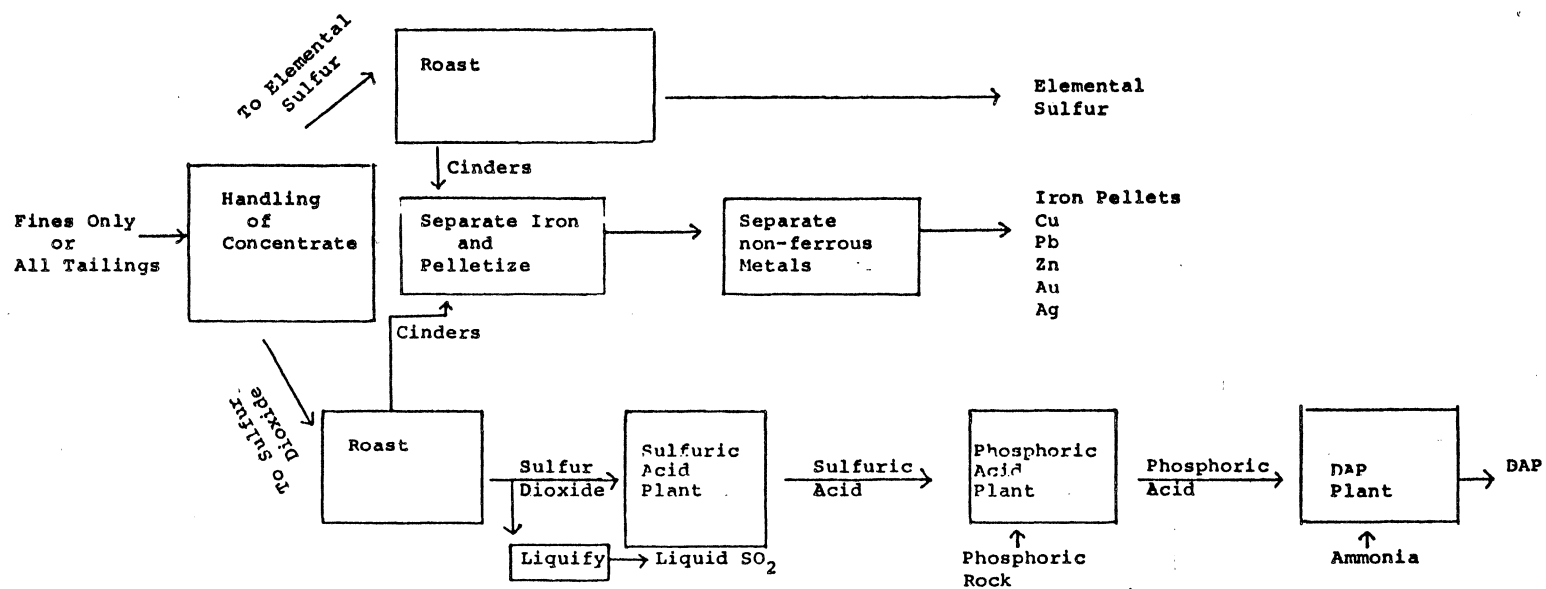
Section 8 is a review of the disposal problem posed by sodium sulfate generated at the mill's water treatment unit. This is a separate evaluation not related to the other sections in this report. Limited telephone interviews were conducted for this section. The purpose is to establish the potential markets for sodium sulfate, the suitability of Exxon's salt cake for kraft pulping purposes and the environmental implications of its impoundment.

Pyrites can be roasted to produce either elemental sulfur (S) or sulfur dioxide (SO_2). Although most sulfur is oxidized to SO_2 , the roast-to-sulfur alternative must be viewed as a source of sulfur to be sold as such. The two step process of pyrite roasting to S and S oxidation to SO_2 is bound to be more expensive than the one step process in which pyrite is roasted directly to SO_2 . The alternate processing "trains" for Exxon's pyrites are shown schematically in Figure 3.1. The by-product of both pyrite roasting processes is called "cinders", and it contains mostly iron minerals, but also non-ferrous metals: copper, lead, zinc, and some gold and silver. These cinders could be impounded (wasted), but would pose an environmental problem as their leachate is acid [22]. Alternatively, the iron can be separated and pelletized and sold to steel manufacturers, and the remaining non-ferrous metals recovered and sold to appropriate metal refiners. The environmental problem would thus be greatly diminished.

Should the pyrite roasting to SO_2 route be followed, the resulting SO_2 could be liquified and sold to manufacturers of sodium bisulfate or paper, or to sugarbeet refiners. These markets are too small compared to the roasting unit's output, and it is necessary to further process the SO_2 to sulfuric acid. Sulfuric acid is the largest volume chemical being manufactured in the world and could be sold to many markets. The main use, however, is to produce phosphoric acid for

Figure 3.1

PYRITE PROCESSING ALTERNATIVES



* Any of the products after roasting can be sold without further processing.

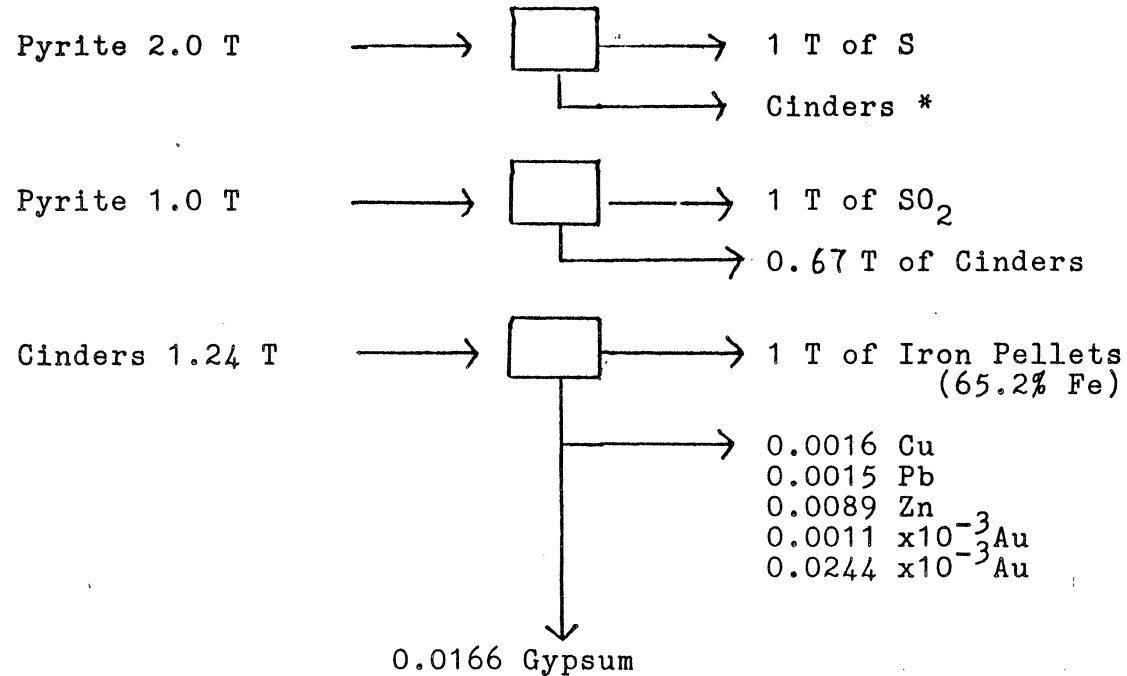
Source: Figure 2, Chapter 4, Phase I Report, Section 4.2, Phase I Report.

fertilizers, and the addition of a phosphoric acid plant to the processing train would increase the value added of the final product. A phosphoric acid plant requires phosphate rock that must be hauled from Florida or the western states region. By-product gypsum is manufactured in very large amounts, markets for this gypsum must be found or else its disposal might be a problem. Phosphoric acid can be further processed to manufacture diammonium phosphate (DAP). DAP is a very popular fertilizer widely used in the corn belt area. No further chemical processing is possible and DAP would be the highest value added product resulting from the pyrite processing train. Figure 3.2 presents the raw material requirements and by-product production for each processing step. Figure 3.3 shows the overall material balance for the alternative of processing pyrite fines to elemental sulfur and Figure 3.4 presents the corresponding balance when the pyrite fines are processed to DAP fertilizer. The necessary adjustments to take into account the processing of all the pyrite tailings (slimes and coarse) can be readily made using the material balances shown in Figure 3.2. All the annual production figures assume 350 operating days per year.

To take advantage of the lower costs of larger production units, (i.e., economies of scale), Exxon studied the alternative of processing additional 320,000 T/A of sulfuric acid generated by a zinc refinery. The additional acid calls for larger phosphoric acid and DAP units, and therefore, larger requirements

Figure 3.2

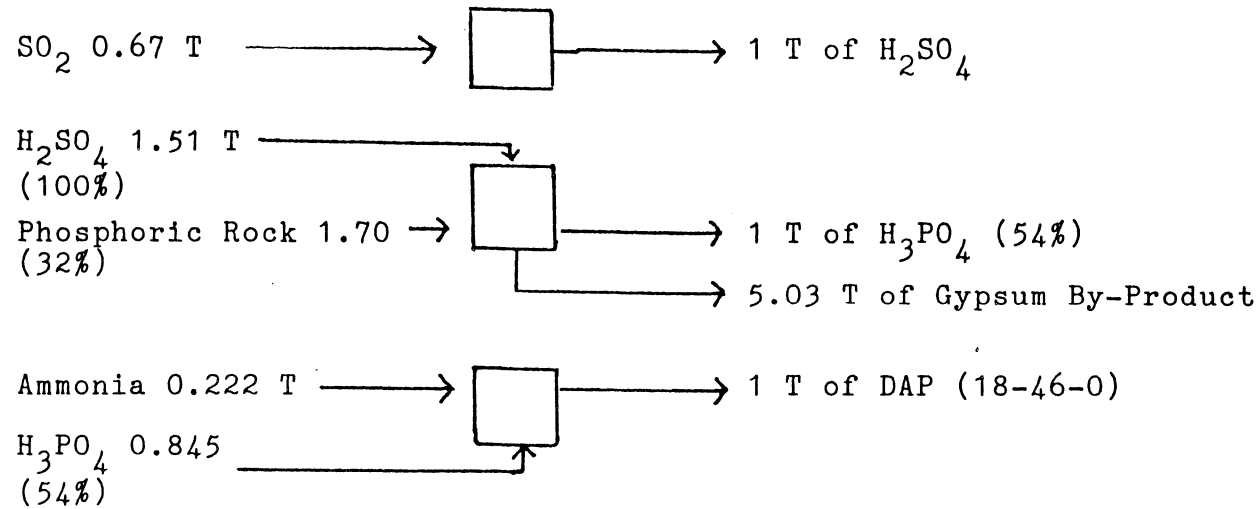
Simplified Individual Process Material Balances



* Not Estimated

Source: McKee's estimates, Phase I and Phase II Reports. (A published reference is available in McKee's Appendix Report, pg. 113).

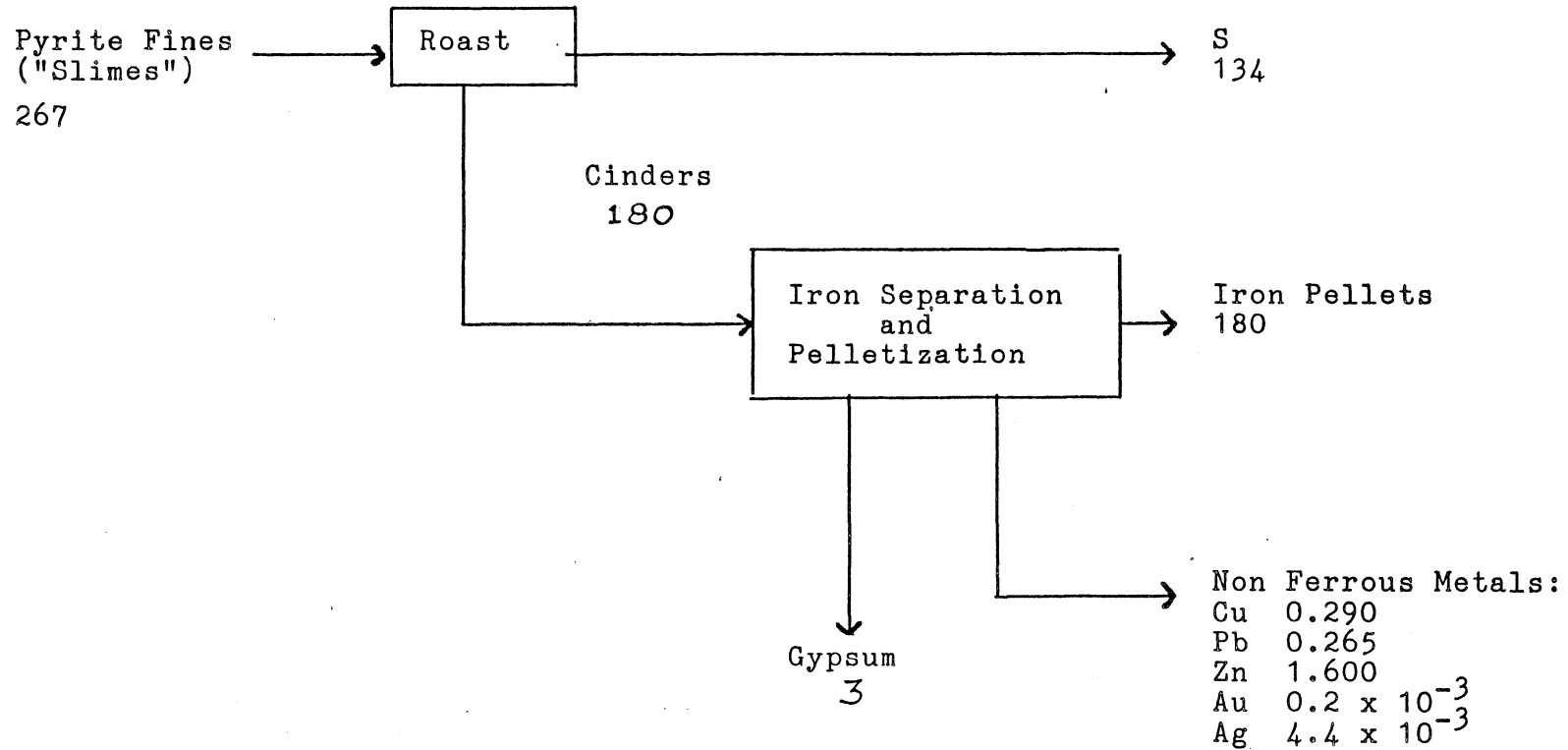
Figure 3.2 (Continued)



Source: McKee's Estimates, Phase I and II Reports. See also [11] p 13, [5] p 134, [10] p 301,302,305 for sulfuric acid, [5] p 246-250, [10] p 252-254 for phosphoric acid and [5] p 255-257, [10] p 255 for DAP.

Figure 3.3

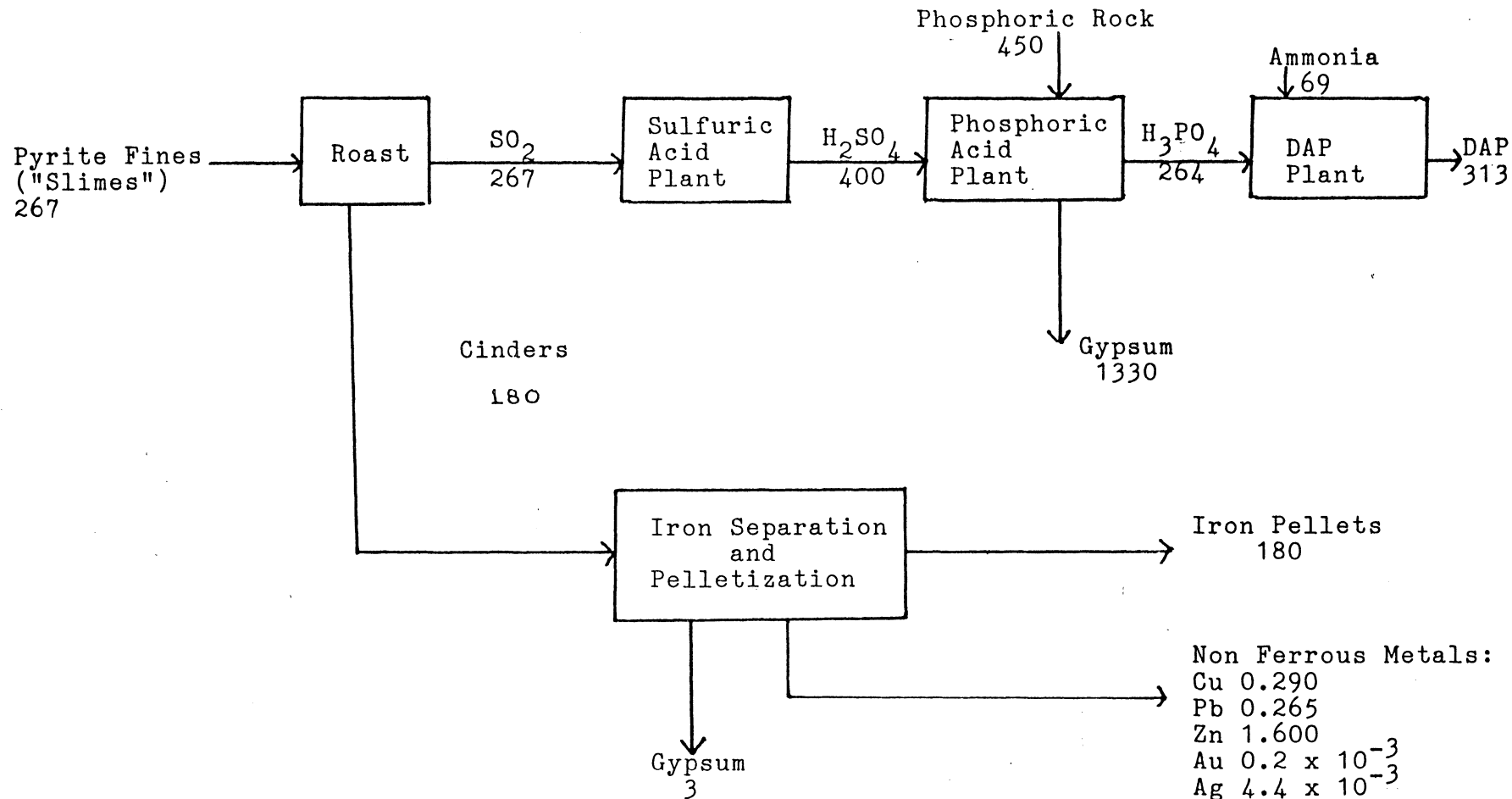
Overall Pyrite Processing Material Balance : Roast to S
(1000 T/A)



Source: McKee's estimates, Phase I and Phase II Reports (See Figure 3.2)

Figure 4

Overall Pyrite Processing Material Balance : Roast to SO_2
(1000 T/A)



Source: McKee's Estimates, Phase I and Phase II Reports (see Figure 3.2).

of phosphoric rock and ammonia. Although the zinc refinery is not expected to be available, the additional acid can be purchased from various sources and thus the evaluated alternative sheds light on the effect of economies of scale on the pyrite processing project. Table 3.1 summarizes all the production alternatives for Exxon's pyrite processing center studied by McKee. Table 3.2 presents the capital investment requirements for each case in 1980 dollars.

Table 3.1

PRODUCTION ALTERNATIVES
(1000 T/A)

Products:	No H ₂ SO ₄ from Zn Refinery		320,000 T of H ₂ SO ₄ from Zn Refinery	
	Only Slimes	All Tailings	Only Slimes	All Tailings
S SO ₂ H ₂ SO ₄ (100%)	134 ^a 267 ^a 400 ^{a,d}	547 ^b 1094 ^b 1694 ^{b,c}	134 ^a 267 ^a 720 ^{a,c}	547 ^b 1094 ^b 2014 ^{b,c}
H ₃ PO ₄ (54%) DAP Iron Pellets	264 ^{d,e} 313 ^d 180 ^{a,d}	1115 ^{d,e} 1322 ^d 718 ^{b,d}	480 ^{a,c} 562 ^{a,c} 180 ^a	1343 ^{b,c} 1572 ^{b,c} 718 ^b
Gypsum	1330 ^{d,f}	5610 ^{d,f}	2400 ^{a,c}	6713 ^{b,c}
Cu Pb Zn	0.290 ^g 0.265 ^g 1.600 ^g	1.870 ^h 1.050 ^h 3.740 ^h	0.290 ^g 0.265 ^g 1.600 ^g	1.870 ^h 1.050 ^h 3.740 ^h
Au Ag	0.2x10 ^{-3g} 4.4x10 ^{-3g}	0.84x10 ^{-3h} 18. x10 ^{-3h}	0.2x10 ^{-3g} 4.4x10 ^{-3g}	0.84x10 ^{-3h} 18. x10 ^{-3h}
<u>Raw Materials:</u>				
Phosphoric Rock (32%) Ammonia	450 ^d 70 ^d	1887 ^d 288 ^d	810 ^{a,c} 125 ^{a,c}	2268 ^{b,c} 350 ^{b,c}
Pyrite	267 ^{a,d}	1094 ^{b,d}	267 ^a	1094 ^b

Table 3.1
(cont.)

- (a) Summary Report, Pg. 1-2 and 2-7, "base case".
- (b) Summary Report, pg. 2-8, alternate case.
- (c) 320,000 Tons of H_2SO_4 are bought from the hypothetical Zn refinery or any other outside source, affecting all downstream processes.
- (d) Phase II, pg. 3-3.
- (e) H_3PO_4 reported as 100% P_2O_5 in source, 54% in this table.
- (f) Reported figure is 1,100,000 T/A for Only Slimes case and 6,000,000 T/A for All Tailings case, but these figures are inconsistent with their calculations for the added sulfuric acid cases. Actual gypsum production should be around 9.17 T/T of 100% H_3PO_4 , or 5.03 T/T of 54% H_3PO_4 . This error does not affect the outcome of the economic assessment since gypsum is assumed to be impounded. The effect on the cost impoundment facilities is small enough to be neglected at this level of analysis.
- (g) Phase II, Section 5, Figure 6.
- (h) Phase II, Section 5, Figure 7.

Table 3.2

BASIC ALTERNATIVES:
INVESTMENT REQUIREMENTS*
(\$ Million)

Process/End Product		NO H ₂ SO ₄ from Zn Refinery		320,000 T of H ₂ SO ₄ from Zn Ref.	
		Only Slimes	All Tailings	Only Slimes	All Tailings
Pyrites to Sulfur		58 f,k	170 g,k	58 f,k	170 g,k
Pyrites to Sulfur Dioxide	Liquid SO ₂	56 ¹	161 ¹	56 ¹	161 ¹
	H ₂ SO ₄	84 ^{a,b,h}	250 ^{b,h}	84 ^{a,b,h}	250 ^{b,h}
	H ₃ PO ₄	n.a. [≠]	n.a. [≠]	n.a. [≠]	n.a. [≠]
	DAP	133 ^{d,j}	392 ^{d,e,j}	145 ^{a,c,i}	400 ^{c,i}

≠ Included in DAP.

* All figures include recovery of iron pellets and non-ferrous metals. Off-sites cost included, but no working capital. All costs are in 1980, first quarter dollars.

Table 3.2 (Cont.)

- (a) Phase II, pg. 3-5.
- (b) Phase II, Figures 6 & 7 of Chapter 3.
- (c) Phase II, Figures 8 & 9 of Chapter 3.
- (d) Phase II, Figures 10 & 11 of Chapter 3.
- (e) By adding the individual plant investments together the resulting total investment is \$392 million, McKee rounded it up to \$400 million in Figures 10 & 11 (Chapter 3).
- (f) Phase II pg. 4-20 and 4-21.
- (g) Phase II, pg. 4-22 and 4-23.
- (h) Phase II, Figures 39 & 40, Chapter 5.
- (i) Phase II, Figures 41 & 42, Chapter 5.
- (j) Phase II, Figures 43, 44, Chapter 5.
- (k) Phase II, Figures 45, 46 Chapter 5.
- (l) Estimate based on Figure 5 of Chapter 3 (Phase II Report), leaving out the sulfuric acid plant and adding liquefaction facilities.

4. INDIVIDUAL REPORT REVIEWS

4.1 Pyrite Processing Market Studies Final Report, Nov., 1979

Data Sources and Calculations (Contract III.A.3.a.)

It is considered by the preparing company as a "preliminary" evaluation, implying extensive use of published and unpublished data and industry contacts, but limited field interviews.

All referenced public data sources are reliable and adequate (e.g. U.S. Bureau of Mines, U.S. Dept. of Agriculture, United Nations Statistics, United Kingdom Iron and Steel Statistics Bureau, Eissen und Stahl, American Iron Ore Assoc., Tennessee Valley Authority, U.S. Dept. of Commerce, Dept. of Energy, Minerals and Resources of Canada, U.S. Environmental Protection Agency, etc.). The referenced private sources include the preparing company's files (Commodity Research Unit) and Stanford Research Institute of California, both firms with wide experience in market analysis.

The information in these reports is adequate for the purpose of assessing the project's viability. The prices and potential markets for each of the following products is studied:

- Pyrite
- Sulfur
- Iron Pellets
- Sulfur Dioxide
- Sulfuric Acid
- Phosphoric Acid
- Gypsum
- Diammonium Phosphate (DAP) fertilizer

Also, the availability and price of the auxiliary raw materials:

- Phosphate Rock
- Anhydrous Ammonia

The analysis includes an overview of the World supply/demand status and trends, and the possibility for exports/imports based on the individual strengths of the countries involved. Then, the U.S. Domestic supply/demand is analyzed, by region, in great detail. All available sources and downstream user companies are detected and their plant capacity listed. The possibility of specific purchases/sales from or to the most relevant companies is established through direct or indirect interviews. Interviews are also used to establish the mode of commercialization, if different from the normal company-to-company scheme. This analysis results in a strong report.

Adequacy of Conclusions (Contract III.A.3.c)

Table 4.1 presents a summary of salient comments and conclusions. CRU's recommendations follow an adequate rationale. A few cases were presented weakly (See Table 4.1):

- i) Iron Pellets. A market opportunity was detected but dismissed on the grounds of a dropping price and "probable" unfavorable economies of scale. Such economic assessment was beyond their scope and they base it on interview comments. This is a very informal assessment, to say the least. Davy McKee conducted the actual economic assessment of manufacturing iron pellets, thus CRU's informal comment had no further consequences.

TABLE 4.1

SUMMARY OF MAIN CRU CONCLUSIONS AND
COMMENTS FOR EACH MATERIAL

MATERIAL

CRU SALIENT COMMENTS AND CONCLUSIONS

COMMENTS

Pyrite Concentrates
(pgs. 13-18)

- Only use is roasting to S mostly for H_2SO_4 production. Not profitable as a source of Iron
- World Market still substantial but cheap local sources available
- U.S. Market disappearing as cheaper Frasch S and by-product H_2SO_4 become widespread. Also roasting presents environmental problems
- Only potential clients: Copper Range (10% of Exxon's output), Cities Service (3 times Exxon's output).
- Buying subject to Exxon's product specs and then probably at low price.

This is a simple way of getting rid of the tailings, and if it is profitable Exxon will undoubtedly pursue it.

Iron Pellets
(pgs. 19-67)

- 90% goes to Steel
- U.S. Cap. approx. 82 million T, 75% in Great Lakes (pg. 58)
- Alternative of further processing pellets to produce "prereduced" pellets for Direct-Reduction-Steel unattractive since most regional capacity is Blast-Furnace-Steel.
- Exxon's Grandon facility would be ideally located for this market, and output small enough to be easily absorbed, but prices dropping and Exxon's small capacity will "probably" result in an economically unattractive process.

Certainly unnecessary, since blast-furnace-steel pellets require less processing and have a large regional market. Market assessment valid, but very informal economic assessment by CRU, with no other information than the "feeling" of their industry contacts.

MATERIAL

CRU SALIENT COMMENTS AND CONCLUSIONS

COMMENTS

Sulfur
(pgs. 69-119)

- Main use is production of H_2SO_4
- World use is growing mainly due to phosphate fertilizers
- Regional shortages exist, including the U.S.
- Prices maintained or increasing
- By-product S from refining and gas operations is increasing, but imports still necessary
- Diminishing H_2SO_4 market due to power-plant SO_2 recovery and smelter by-product not expected to affect demand in near future. Deficits in supply expected to continue through year 2000.
- Regional markets would easily handle Exxon's output. Optionally, Exxon Corp. is already a major recoverer and marketer of sulfur.

Sulfur Dioxide
(pgs. 121-125)

- Main uses are Na_2HSO_4 production, paper industry and sugarbeet refining
 - By-product SO_2 plentiful, but recovery/purification units must be installed
 - U.S. Market only 200,000T in 1978 (Table 4, pg. 124)
 - Regional consumption 16,000 T/A but Stauffer supplies 10,000 T/A (pg. 124)
 - Market too small for Exxon's output
-

MATERIAL

CRU SALIENT COMMENTS AND CONCLUSIONS

COMMENTS

H₂SO₄
(pgs. 127-193)

- 60% goes to fertilizers, other uses spreaded among wide range of industries (pg. 132)
- Growth spurred by phosphoric fertilizer industry
- Substantial price discounts due to presence of by-product ("fatal") and producers
- Capacity adequate
- Exxon will have difficulty entering North Central market, very competitive due to interest of Western States, regional and Canadian smelter acid producers ("fatal" acid, thus probable price punishment will bring net back to only \$10-15/T vs. list price of \$58/T in Midwest) (pg. 167)
- Sales through wholesaler (CIL Chemicals, Inc.) recommended since Exxon has no established channels for H₂SO₄. This implies acceptance of low net back (\$15/T).

Supporting argument for effect of "fatal" and on price not very solid (only 4 such producers in the region, only 10% of U.S. supply is "fatal" acid)

Phosphate Fertilizers
(pgs. 195-215, 227-241)

-
- World demand is growing, reached 28 million T of P₂O₅ in 1978. Trade is important, around 4 million T of P₂O₅ in the same year (Tables 4,5 pg. 200,201)
 - Price trend up
 - U.S. is net exporter (3 million T of P₂O₅ in 1978)
 - 75% of U.S. DAP market is absorbed by corn belt (2.2 million T). Regional growth not expected (Table 22, pg. 229)
 - Existing regional supply is limited (Mobil 218,000 T/A, Beker 380,000 T/A in Illinois and First Mississippi Chem. 380,000 T/A in Iowa). Demand met by Gulf Coast producers (pg. 232)

MATERIAL

CRU SALIENT COMMENTS AND CONCLUSIONS

COMMENTS

Phosphate Fertilizers
(continued)

- Exxon should sell to cooperative groups
- Exxon's plant ideally located to serve this market (Green Bay or Evansville), but unlikely to be able to meet the price.

CRU's "feeling" is that the venture would be uneconomic for Exxon, but this is not substantiated by the report.

H₃PO₄
(pgs. 216-226)

- 93% goes to fertilizers (pg. 220)
- Market improving. Export markets sustained at 600-750,000 T/A.
- Capacity utilization has been high and expected to continue through year 2000 (Table 19, pg. 224)
- Prices firm and expected to continue so.
- Most producers are integrated to fertilizers, thus Exxon should not seek entry in this market

After all positive indications this is a sudden change in perspective. Lack of merchant market not sufficiently supported in the report.

Phosphate Rock
(pgs. 243-267)

- Phosphoric acid is main use
- There will be ample supply for Exxon's project (Table 10, pg. 267)

Ammonia
(pgs. 269-288)

- Sufficient capacity exists
 - Imports are used if their price is low
 - Prices have been declining
 - Convenient Terminals available at Garner for Green Bay and Terre Haute for Evansville
-

MATERIAL

CRU SALIENT COMMENTS AND CONCLUSIONS

COMMENTS

Gypsum
(pgs. 289-300)

- Most important uses are plasters (75%) and cement retarder (19%). (Table 1, pg. 291)
 - Total demand 19.4 million T in 1978 (Table 1, pg. 291), imports accounted for 7.2 million T (5.4 from Canada, 1.4 from Mexico, pg. 295)
 - 30 million T/A of by-product gypsum are dumped, except for 500-600,000 T/A used in agriculture. (pg. 299)
 - Prospects to market Exxon's gypsum very poor
-

Iron Ore
(pg. 63)

- Main uses are cement and heavy media coal washing and pigments.
 - Cement users require lower grade ore, thus pay lower prices.
 - Coal washing requires magnetite (Fe_2O_3).
 - Pigments market small (65,000 T in 1973) and cheap scrap iron preferred raw material.
-

Source: Market Report

- ii) Sulfuric Acid. A limited but existing market was detected. CRU, however assumes that the competition from smelter acid producers will force Exxon to sell its sulfuric acid at a very low price (\$15/T). According to their own data, the effect of this competition on the shipment unit value for the midwest zone might not be as severe as in the examples that they analyze (there are 4 smelter acid producers in the area, and only 10% of US acid is "fatal"). Assuming a reasonable sales price of \$30/T, however, still results in a net annual loss for the sulfuric-acid-only alternative as shown in Table 4.2.
- iii) Diammonium Phosphate A market opportunity is established, but CRU speculates that Exxon's cost will be higher than the market price, thus making the venture uneconomic. This unsupported judgement is again beyond the scope of CRU's study. Since Davy McKee assessed the economic viability of manufacturing DAP CRU's comment has no further effect.
- iv) Phosphoric Acid. The report builds up to establish what seems a reasonable market opportunity, then turns around indicating that this market is mostly captive and therefore Exxon would not gain access to it. The importance of the captive market is not sufficiently supported. Based on CRU's recommendation the alternative to manufacture and sell phosphoric acid without further processing was not assessed.
- v) Non-ferrous Metals. No market analysis is provided. Davy McKee's economic assessment assumed that all of Exxon's production could be sold if they were recovered. Since also the case where they are not recovered was assessed, the lack of this market analysis is not important.

Effect of Current Conditions on the Conclusions (Contract III.A.3.d)

1979 was a peak year for most industries. Since, the US experienced a recession that lasted until the second half of 1983. Demand dipped while additional capacity was postponed. The demand is just returning to 1979 levels and capacity rationalization eliminated some of the overcapacity, thus changes in supply/demand conditions are minor and do not have a strong impact on the market size estimated in CRU's report. Both raw materials

TABLE 4.2

EFFECT OF HIGHER H_2SO_4
SALES PRICE ON PROJECT CASH FLOW
 (\$ Millions)*

	Green Bay		Evansville	
	Only Slimes	All Tailings	Only Slimes	All Tailings
Revenue @ \$15/T	6.0 (a)	25.4 (a)	6.0 (a)	25.4 (a)
Revenue @ \$30/T	12.0 (b)	50.8 (b)	12.0 (b)	50.8 (b)
Operating Cost	16.0	52.8	20.1	70.5
(Loss) @ \$15/T (d)	(10.0)	(28.4)	(14.1)	(45.1)
(Loss) @ \$30/T (d)	(4.0)	(2.0)	(8.1)	(19.7)

(a) Phase II report, p. 5-4

(b) $400,000T \times \$30/T = \$12,000,000$

(c) $1,694,000T \times \$30/T = \$50,800,000$

(d) Loss = Revenue - Operating Cost

* 1980 dollars

and product prices have undergone changes in the past 5 years. Inflation, energy costs, tend to increase the cost indexes, but recession forces manufacturers to hold prices down. The net effect has been known as "experience" and tends to decrease the profit margin. CRU's conclusions on price changes are irrelevant to the economic analysis since the assessment is worked on constant terms. The price and cost structure, that is, the relative prices of products, raw materials, and the investment costs have a marked influence on the economic assessment, but since all of them were subjected to the same changes the final assessment is not expected to vary substantially.

Study Area, Distribution Network, Transportation Mode and Product Handleability (Contract III.A.3.e)

The preparing company was apparently handed-down the two selected processing centers. Then their task was to define the potential markets for each of these. Their market analysis includes commercial distribution networks when they exist. This information was apparently derived from industrial contacts through interviews.

The transportation modes are clearly determined in the Transportation Rate Estimates Report. The handleability of the products was not pertinent to the Market Studies Report. The technical compliance of the products with required specifications was established through published data and interviews. This is sufficient at this stage.

Effect on Marketability caused by Mine Production Variations
and Decisions to Utilize Total Production of Mill Tailings
(Contract III.A.3.f)

The alternate potential products are presented in Table 4.3. For a given plant capacity, operating at levels below maximum utilization results in increased costs, and, therefore, decreased profitability (Revenue - Costs). The profitability of all the manufacturing options being considered is increased by building a bigger facility. This is evident from Table 4.7 where the option where additional 320,000 T/A of H_2SO_4 are available is always more profitable (shows higher gain or lower loss). However, if the plant is too big it could be more difficult to sell the entire production, thus forcing the plant to operate below capacity and thus decreasing the profitability. The net change in profitability depends on each individual case and in how far below maximum capacity the unit has to operate. In Table 4.3, Sulfur, iron pellets and DAP have good market opportunities since the project production is only a fraction of the potential regional market. Should a bigger facility be built (Max. Prod. column), sulfur and DAP would face potential market saturation, thus creating a lower-than-maximum utilization case. Failure to sell 35% of the 1,572,000 T/A of DAP under the max. production case would totally offset the gain reported in Table 4.7 (555,000 T @ \$220/T = \$122 million). The case for sulfur is more drastic, since a mere 4.6% reduction in the expected sales of 547,000 under maximum production would offset the corresponding gain reported in Table 4.7 (25,200 T @ \$75/T = \$1.9 Million).

TABLE 4.3
Project Production vs. Potential Market
(1000 T/A)

31

	Project Production		Size of Potential Market
	Min. Prod. (a)	Max. Prod. (b)	
Pyrite	267	1094	500 (c)
Sulfur	134*	547	1500 (d)
Iron Pellets	180*	718	60,000 (e)
Sulfur Dioxide	267	1094	6 (f)
Sulfuric Acid	400	1694	2600 (g)
Phosphoric Acid (54% P ₂ O ₅)	264	1343	1300 (h)
Gypsum	1330	6713	600 (i)
Diammonium Phosphate	313*	1572	2200 (j)
Non ferrous metals	-	-	n.a.

(a) Table 3.1 Column 1

(b) Table 3.1 Column 4

n.a. Not Available

* Products with attractive market.

TABLE 4.3 (Cont.)

- (c) 1977 estimated U.S. production was 420,000T (CRU Report, Chapter 1, Table 1, pg. 15, Table 1, Phase I Report, pg. 2-3, Table 1, Summary Report pg. 3-3). Assume current U.S. consumption grew to 500,000T.
- (d) Assume Canada's and Mexico's exports to U.S. can be substituted by Exxon's sulfur. (CRU Report, Chapter III, Fig. 3, pg. 90, pg. 106, Mineral Industry Surveys, U.S. Dept. of the Interior, Bureau of Mines, Sulfur, Monthly; March 1984)
- (e) U.S. pellet demand approximately 82,000,000T. Great Lakes area capacity to process pellets is approximately 75% of U.S. Assume demand keeps same ratio. (CRU Chapter II Report, pg. 58)
- (f) Regional consumption 16,000 T/A, but Stauffer controls 10,000 T/A (CRU Report Chapter III, Appendix A, pg. 126)
- (g) North Central States Market (CRU Report Chapter IV, Table 19, pg. 156)
- (h) Merchant market (CRU Report Chapter V, pg. 221)
- (i) By-product gypsum market (CRU Report Chapter VII, Table 4, pg. 295)
- (j) Cornbelt market (75% of U.S.) (CRU Report Chapter V, Table 22, pg. 229)

For the sulfuric acid case, failure to allocate all the output would force the pyrite processing train to halt while the pyrites impounded until sales of the acid resume.

The marketability of each product depends mostly on its price and potential market. These are not affected by the level of utilization of the plants, but are affected by the plant size. As mentioned above, a bigger plant would result in lower costs, thus providing room for price cuts to make the product more "marketable." On the other hand, a big plant might saturate the potential market and thus make the products less marketable.

Sections III.A.3.b. and g of the Contract do not apply to this report.

4.2 Transportation Rate Estimates, Sept. 1979

Data Sources and Calculations (Contract III.A.3.a)

The public sources of information referenced in the report are reliable organizations, e.g. U.S. Dept. of Transportation, Bureau of Mines, Bureau of Census, Corps. of Engineers, Dept. of Agriculture, etc. Private data was acquired mainly from the preparing company's files and from the Consulting Center, U.S.A. No direct rate quotations were obtained for the proposed movements. Instead, the following sources were used:

- published commodity cost and rate data by mode,
- published commodity point-to-point rates,
- class and annual volume trainload rates
- interviews with barge carriers, rail equipment suppliers and inland waterway experts.

These are adequate data sources for this stage of project planning. The information was further processed as follows:

- Using transportation maps, distance tables and commodity statistics a hypothetical mode or combination of modes to be employed was established.
- Transport rates per ton-mile for each mode were developed.
- Each mode's transfer and terminal points and charges for each movement were determined, and converted to rate per ton-mile.
- For each mode for each movement, the transport turn-around times and the required equipment and facility costs were computed and converted to cost per ton-mile.
- The optimal mode or combination of modes for each commodity movement was determined.
- The effect of external problems (e.g. weather), logistical attributes, equipment limitations and other special factors was evaluated.

Rail, inland waterways, private truck and ocean and Great Lakes modes are studied. The consolidation steps provide

adequate costing information needed to compute individual transportation costs for each desired route. Calculations are thence very detailed, including proforma trip cost-sheets for ship and truck modes.

The level of detail of the resulting cost estimates is adequate, in fact, it exceeds the requirements of the project at this stage. The results are summarized in page 4 of JBC's report. Table 4.4 presents a summary of the estimated transportation costs and mode for the raw materials. The main flaw of JBC's Report is the failure to present the cost of transporting ammonia to Green Bay from the nearby terminals located in Iowa: Garner, Algoma, Marshalltown or Washington, relying instead in far away terminals as St. Louis, and Terre Haute. These two terminals are closer to Evansville, but farther from Green Bay (see Figures 1 and 2 and Table 11 in Chapter VII of CRU's Market Report, pp. 285-287). The distance from the Garner terminal to Green Bay is roughly equivalent to that between Terre Haute and Evansville. The economic assessment study by McKee, however, used the same delivered ammonia price for both Green Bay and Evansville. This implicitly recognizes that both processing centers have access to a corresponding nearby terminal.

Adequacy of Conclusions (Contract III.A.3.c)

Conclusions concentrate on the choice of modes of transportation.

TRANSPORTATION LOWEST ESTIMATED COSTS AND
PREFERRED MODES FOR RAW MATERIALS

<u>Commodity</u>	<u>Origin</u>	<u>Destination</u>	<u>Rate U.S.\$/T</u> <u>Mid'79</u>	<u>Mode</u>
Pyrite	Crandon	Green Bay	11.44	Rail
		Evansville	24.43	Rail
Phosphate Rock	Tampa	Green Bay	15.08	Ocean/Lake
		Evansville	12.16	Ocean/River
Ammonia	Terre Haute	Green Bay	23.65	Rail
		Evansville	13.05	Rail

Source: Transportation Rate Estimates Report, pg. 4

The selection is based on the most economic alternative, but alternative choices are also assessed. The analysis is very complete including a conservative factor calling for rail transportation in the event that the Great Lakes traffic is constrained by freezing.

To account for future potential cost changes due to external factors, an analysis of capacity constraints and expected regulatory changes, as applied to transportation is provided.

The conclusions on expected changes due to regulation are presented in Appendix A (p 73) of the Transportation Report. The anticipated changes for motor carriers do not affect the project since the selected modes are rail and inland waterways. For rail transport, higher fares are predicted. For inland waterways, the effect of tax changes are not expected to be out of line with taxes imposed on other modes of transportation.

JBC's comments on the precarious financial condition of several rail carriers are more operational in nature and would only be of relevance if there were a risk for the rail mode option to disappear.

The report's conclusions establish the transportation factors and costs adequately.

Effect of Current Conditions on Conclusions (Contract III.A.3.d)

The main factors affecting the transportation costs and conclusions are inflation and regulatory changes. The cost variations brought about by these factors are too minor to justify an updated analysis. JBC's report conclusions can be safely considered valid under current conditions.

Study Area, Distribution Network, Transportation Modes and Product Handleability (Contract III.A.3.e)

The preparing company was obviously handed-down the required origins (processing centers) and destinations (markets). There is no account in any of the reviewed documents on how the processing centers were selected. The markets, however, are clearly defined in the market study and are chosen as to be close to each of the processing centers.

The transportation modes are carefully selected using the methodology outlined in III.A.3.a above. Temporary changes in the selected mode are clearly specified for the winter.

The handleability of the products is not addressed in this report. However, all but the pyrite concentrates are currently being moved by existing transportation facilities and therefore no new problems are expected. The pyrite concentrates are to be partially dried before shipping to the processing centers and their transport is not expected to pose unsurmountable problems.

Experts consulted by Davy McKee concur in this expectation.

The distribution networks are established satisfactorily in the market study.

Sections III.A.3.b, f and g of the Contract are not applicable to this report.

4.3 Crandon Project Pyrite Processing Study-Summary, June, 1981

Data Sources and Calculations (Contract III.A.3.a)

The only sources for the Summary Report are the following reports:

- Pyrite Processing Market Studies Final Report, Nov. 1979, by Commodities Research Unit (CRU).
- Transportation Rate Estimates, Sept. 1979, by Jones, Bardelmeier and Co. (JBC).
- Crandon Project Pyrite Processing Study - Phase I, Nov. 1979, by Davy McKee.
- Crandon Project Pyrite Processing Study - Phase II, June 1981, by Davy McKee.
- Crandon Project Pyrite Processing Study - Appendix, March 1980, by Davy McKee.

The preparing companies are specialists in their field and conducted professional adequate studies. Each report is discussed in further detail in its appropriate section.

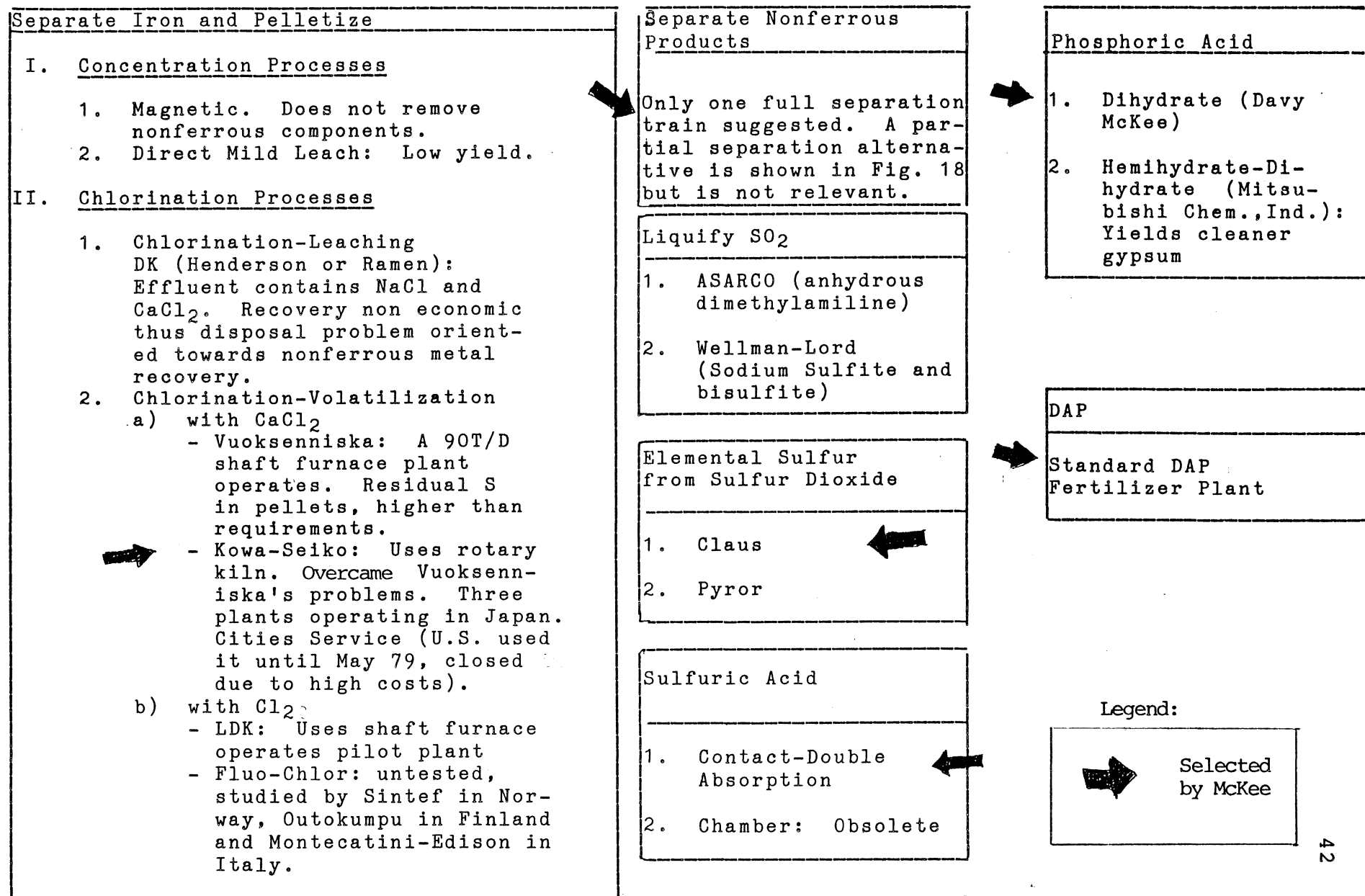
Adequacy of Technology Survey (Contract III.A.3.b)

Their technology summary (Chapter 5) is extracted from Davy McKee's Phase I Report. Table 4.5 presents a summary of the technology alternatives studied by Davy McKee. The survey is complete and adequate for all processing alternatives, but included old documentation (up to 1969) for pyrite roasting, iron pelletization and extraction of non-ferrous metals. An extensive computer search for further technical activity in these processes and sulfuric acid, phosphoric acid, DAP and sulfur from sulfur dioxide was conducted. The detailed results are presented in Section 5 below. The search did not find any other alternative technologies up to 1983.

Table 4.5
TECHNOLOGY ALTERNATIVES

Handling of Concentrate (Phase I, Ch. 4, p 4-3, 4-4)	Roasting Pyrite to Elemental Sulfur (Phase I, Ch. 4, p 4-4/4-12)	Roasting Pyrite to Sulfur Dioxide (Phase I, Ch. 4, p. 4-13/4-14)
1. <u>Total Slurry</u>: Minimizes risk of oxidation but has higher freight and may freeze in winter. ➔ 2. <u>Reduced Moisture</u>: Lower freight cost than (1) but must use covered storage. 3. <u>Dry</u>: Lowest freight cost, but high investment and energy cost. Legend: ➔ Selected by McKee	1. <u>Thermal Processes</u> a) Orkla: Plant based on blast furnace closed down in 1962. Causes were low SO_2 prices, high coke prices and wasted iron slag. b) Outokumpu (Kokkola): Flash smelter operating in Finland. ➔ c) Electric Furnace (Pryor): Pilot plant in Norway. Highest S recovery. Electrolytic iron hard to sell. d) Fluidized Bed (Dorr-Oliver, Rosenquist): no pilot plant or commercial application. 2. <u>Hydrometallurgical Oxidation Processes</u> a) Sheritt-Gordon: operating on Ni-Co b) Anaconda: operating on Cu c) Amax: Operating on Cu-Ni-Co. No commercial experience with pyrite 3. <u>Chlorine Processes</u> A pilot plant had difficulty recovering non-ferrous metals (Mitterberg Kupferbergbar of Australia). Others investigated the process in the 1950's: Comstock & Westcott, Texasgulf in U.S., Outokumpu in Finland, A/S Norsk Bergverk/Kisfiredlingen in Norway. 4. <u>Halvorsen Process</u> DK built pilot plant, but abandoned it later. It uses sulfur dioxide to oxidize pyrrhotite to iron oxide.	1. <u>Rotary Kiln</u> 2. <u>Multiple Hearth Furnace</u> ➔ 3. <u>Turbulent Bed Reactor</u>: Newest

TABLE 4.5 (Continued)



Alternate uses for gypsum and sulfur were also searched for. Commercial uses of sulfur in sulfur extended asphalt, road patching and sulfur concrete already exist [8] Molded sulfur blocks are moving into commercialization. These uses are briefly dealt with in McKee's Summary Report. New byproduct gypsum uses in Japan are also mentioned in their market summary.

Adequacy of the Conclusions (Contract III.A.3.c)

Conclusions and recommendations for the whole study are summarized in p. 1-2 through 1-7 of McKee's Summary Report. Table 4.6 presents their final conclusions and recommendations.

The lack of markets detected for sulfur dioxide, gypsum and pyrites (Alternatives 1,2 and 4 in Table 4.6) are adequately supported by the information contained in CRU's Market Report. The market for miscellaneous iron products (Alternative 3 in Table 4.6) is only briefly addressed by CRU. Their conclusion, however is justified at this level of analysis. The need to sell sulfuric acid at "fatal acid" discounted price of \$15/T is not fully established (Alternative 5 in Table 4.6). My sensitivity calculations in Table 4.2 show that even at a reasonable price of \$30/T the sulfuric acid production would not be profitable. McKee's recommendation, therefore, is not affected by the weakness of the analysis in CRU's report. The addition of an iron pellet and nonferrous metals recovery train (Alternative 6 in Table 4.6) is only discussed as an option in the sulfuric acid production case. Their assessment studies show that the addition of the iron pellets/nonferrous metals facility improves the economics of

TABLE 4.6

McKEE'S CRANDON PROJECT FINAL CONCLUSIONS AND RECOMMENDATIONS

Alternative	Conclusion	Recommendation
1 Sulfur Dioxide	Market too small, does not justify cost analysis	—
2 Gypsum	Cannot be sold. Impurities costly to remove. Does not justify cost analysis	—
3 Miscellaneous Iron Products (pigments, iron powder, etc.)	Lack of markets or production considerations. Does not justify cost analysis	—
4 Pyrites	Market does not exist	Use coarse portion as mine fill and fines to settle in ponds for later reclamation of minerals, if and when economics are favorable
5 Sulfuric Acid with Pyrite Cinders to Discard	Pyrite acid more costly than available acid. Must sell at "fatal" acid price level (less than half the listed price)	Production uneconomical
6 Sulfuric Acid, Recover Iron Pellets and Nonferrous Metals from Pyrite Cinders	The quantity of pellets do not warrant the capital intensive installation costs. Recovery of non-ferrous and precious metals insufficient to make alternative viable	Production uneconomical
7 DAP, Recover Iron Pellets and Nonferrous Metals from Pyrite Cinders	A market exists but disposal of by-product gypsum greater environmental problem than original fine tailings	Marginally attractive, but gypsum disposal problem important. Must subject to close scrutiny before considering it viable
8 Sulfur, Recover Iron Pellets and Nonferrous Metals from Pyrite Cinders	Production costs higher than other sulfur sources	Not recommended due to high energy consumption and production costs

all the processing alternatives for pyrites, that is, it increases the annual gain or decreases the annual loss (see Table 4.7 below). Their conclusion stating that the quantity of pellets do not warrant the investment is thus not supported by the results in their report. The added revenues due to the recovery of iron pellets and nonferrous metals, however, fail to increase the ROI of any of the processing alternatives to acceptable levels as shown in Table 4.9, and this part of McKee's conclusion is supported by their results. Their final recommendation is then adequate. The market for DAP was found attractive (Alternative 7 in Table 4.6) and a marginal profitability reported. The calculated ROI is 5.3%, well under acceptable levels (industry typically requires ROI values better than the interest paid by banks). Also, gypsum disposal is a problem. Potential contaminants include fluorides and radioactive materials (Florida phosphoric rock contains 0.5 Kg of U_3O_8 per T of P_2O_5 , [5,26]) The estimated production of gypsum over the life of the project would require a minimum of 44 million m^3 (36,000 acre-ft) of impoundment facilities (222 million m^3 if all tailings are processed and additional 320,000 T/A of external sulfuric acid are available). These impoundment requirements are much larger than the estimated 6-7 million m^3 (5340 acre-ft) required for the pyrite slimes. In fact, they are larger than the whole mill's impoundment facility of 23 million m^3 (19,000 acre-ft). McKee's conclusion and recommendation on this alternative seem then justified. The study's conclusion on sulfur production (Alternative 8 in

Table 4.6) is consistent with the report's results (see Tables 4.7 and 4.9 below). High energy consumption is not a strong enough reason to declare a process uneconomical, but the actual economic assessment does turn out the same conclusion.

The overall study conclusion is that it is uneconomical to process pyrite at the time the report was finished. The impoundment of the fine tailings is therefore recommended, while the coarse fraction is used as mine fill. These conclusions and recommendations are adequate.

Effect of Current Conditions on the Conclusions (Contract III.A.3.d)

Markets

1979 was a peak year for the chemical industry. A subsequent recession dropped the industry's output and last year's recovery was barely able to bring it back to 1979 levels. No new market opportunities were detected in the literature survey. The market conditions, therefore, do not merit update.

Assessment.

The prices of products and raw materials have been subjected to substantial increases since 1980. Also investment and transportation costs have been incremented. McKee's study was using a constant basis for prices and costs. This approach

minimizes the impact of normal price and cost fluctuations. Their results would only be invalidated by substantial relative changes in prices and costs. Since no such changes were detected in the industrial information sources it is not considered necessary to update the assessment studies at this time.

Study Area, Distribution Network, Transportation Mode and Product Handleability (Contract III.A.3.e)

The preparing company was apparently handed-down the two selected processing centers. Then their task was to define the potential markets for each of these. Their market analysis includes commercial distribution networks when they exist. This information was apparently derived from industrial contacts through interviews.

The transportation modes are clearly determined in the Transportation Rate Estimates Report. The handleability of the products was not pertinent to the Market Studies Report. The technical compliance of the products with required specifications was established through published data and interviews. This is sufficient at this stage.

Effect on Marketability Caused by Mine Production Variations
and Decisions to Utilize Total Production of Mill Tailings
(Contract III.A.3.f)

Reviewed in the Market Report (Section 4.1 above).

Range of Capital Costs (Contract III.A.3.g)

Reviewed in the Phase II Report (Section 4.5 below).

4.4 Crandon Project Pyrite Processing Study-Phase I, Nov. 1979

This report comprises three main sections:

- i) Marketing (Chapter 2)
- ii) Transportation (Chapter 3)
- iii) Process Technology (Chapter 4)

The Marketing chapter is an abstracted version of the Market Study Report (III.A.2.a) and it is reviewed in Section 4.1. The Transportation chapter is a summary of the Transportation Rate Estimates Report and is dealt with in Section 4.2.

The Process Technology analysis is reviewed below.

Data Sources and Calculations (Contract III.A.3.a)

This report concentrates on the qualitative identification of available technologies to accomplish each of the downstream processing steps for pyrite. The information sources include technical publications like the Journal of Metals, specialized symposia proceedings, technology licensors private and public information, U.S. and foreign patents and technical encyclopedias. These technical sources are adequate to determine available process technology.

Davy McKee is a large worldwide engineering firm with vast experience in process design. They act as licensors for phosphoric acid processes (Pryon process). They designed and have built many plants around the world, including phosphoric acid, sulfuric

acid, diammonium phosphate plants among others. This experience has been accumulated in their engineering departments and was utilized as an additional source for technology and process economics information. This is adequate for the Crandon project. It is likely that Exxon selected Davy McKee as consulting firm based on McKee's in-house experience in the fertilizer industry.

Adequacy of Technology Survey (Contract III.A.3.b)

This report presents technology alternatives for the following processes:

- Pyrite handling facility (3 alternatives)
- Pyrite roasting to elemental sulfur (9 alternatives)
- Pyrite roasting to sulfur dioxide (3 alternatives)
- Cinder Reclamation of ferrous products (7 alternatives)
- Reclamation of non-ferrous products (1 alternative)
- Sulfur recovery from sulfur dioxide (2 alternatives)
- Sulfur dioxide liquefaction (1 alternative)
- Sulfuric acid from sulfur dioxide (2 alternatives)
- Phosphoric acid (2 alternatives)
- Diammonium Phosphate (1 alternative)

Table 4.5 presents a summary of the technology alternatives studied by McKee. The survey is complete and adequate for all the processes listed above. McKee included copies of a few relevant technical publications in the Appendix Report (See Section 4.6 below). Pyrite roasting, iron pelletization and

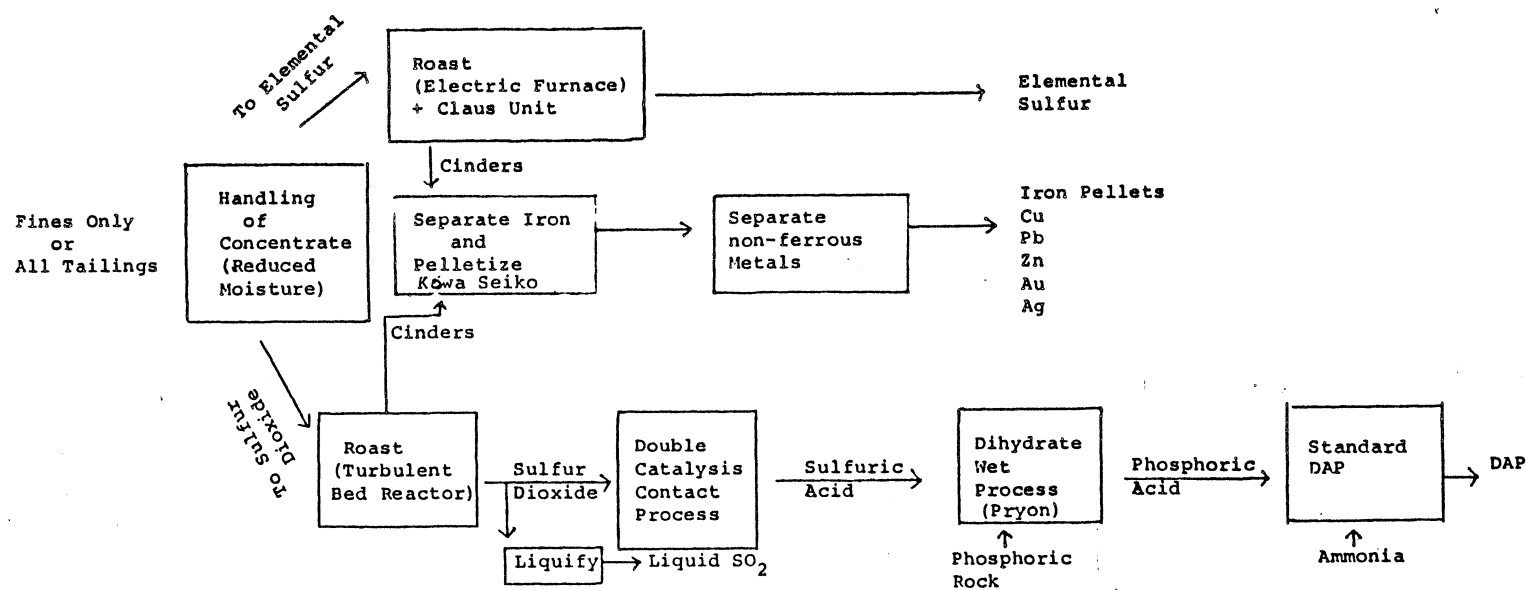
extraction of non-ferrous metals technologies are covered in these papers. These references, however, are old, dating at least from 1969. An extensive computer search was conducted to detect further technical publications on the processes listed above, except for the pyrite handling facility and the liquefaction of sulfur dioxide. These two processes are physical operations in which no important technological breakthrough is expected. A detailed analysis of the results of this search is presented in Section 5 below. The search did not find any additional important development for the studied processes up to 1983.

Alternate uses for gypsum, namely as a source of sulfur or as feedstock for sulfuric acid and cement are not dealt with at any length.

Adequacy of Conclusions (Contract III.A.3.c)

McKee's conclusions on process selection are presented in Sections 4.2 and 5.3 of the Phase I Report (pg. 4-33 through 5-3). The selected technologies are clearly identified in Table 4.5 above. Figure 4.1 displays how these technologies are connected to form processing alternatives. In the case of phosphoric acid and sulfuric acid, McKee selected those processes in which it has in-house experience. This is adequate since the processing cost from different licensors would not make a measurable impact in the project assessment (at this level, investment costs are typically estimated with 25-30% tolerance). Also, by using its in-house experience, McKee was able to reduce the error in processing cost estimates for these technologies.

Figure 4.1
SELECTED PROCESSING TECHNOLOGIES



* Any of the products after roasting can be sold without further processing.

Source: Figure 2, Chapter 4, Phase I Report, Section 4.2, Phase I Report.

For DAP, a standard technology (TVA, see [5] p 255) was preferred to the yet untested Pircon-Peck process developed by Arthur McKee and Co. to manufacture fertilizers from low-concentration sulfur dioxide streams. This decision again takes advantage of Davy McKee's in-house experience. The Pircon-Peck process was designed to upgrade sulfur dioxide present in waste gases, and producing a low-grade, 9-30-0 DAP fertilizer (Appendix Report pg. 170, TVA's process yields 18-46-0 DAP). A low grade DAP would be more difficult to sell and would have to be upgraded using the standard granulation process anyway (Appendix Report, pg. 166). Also, the Pircon-Peck process has only been tested at a pilot plant level. McKee's decision is thus adequate.

The selected electric furnace process to roast pyrite to elemental sulfur has not been commercialized, but it is the only route that can achieve almost full recovery of the sulfur when combined with a Claus unit. A less energy-intensive process would result in a lower yield, but also lower operating cost. This is not clearly demonstrated in the report. The selection, however should not considerably affect the project assessment results at the level of the current analysis.

Reclaiming and pelletizing the cinder resulting from roasting pyrite can be done by 7 technologies. The selected process (Kowa Seiko) is in commercial operation in Japan. The selection

of either of the other 3 chlorination-volatilization routes would not, in all likelihood, affect the outcome of the assessment. The chlorination-leaching and the concentrate routes appear to have substantial cost disadvantages, thus the Kowa Seiko technology is a reasonable and adequate choice.

The selection of a reduced-moisture facility for handling the pyrite is an adequate decision at this level of assessment.

Effect of Current Conditions on the Conclusions (Contract III.A.3.d)

An extensive computer and physical search was conducted to identify new technological developments. The results indicated engineering and scientific interest in improving the technologies reviewed by McKee, but no actual change in commercialization. The results of the search are presented in Section 5 below.

Study Area, Distribution Network, Transportation Modes and Product Handleability (Contract III.A.3.e)

Only the handling of the pyrite concentrates is of interest here. The behavior of the fine tailings in the roasting furnace is not known, but the processes selected for roasting to either elemental sulfur or sulfur dioxide can handle fine concentrates according to McKee's in-house expertise and their contact in Spain Tecnicas Reunidas, S.A. (Spain mines pyrites for their sulfur, see Appendix Report, pgs. 1,2). Also, Denver Equipment Co. [6] offers a process to produce pyrite concentrate suitable for roasting from fine tailings.

The final location of the pyrite processing center should be taken into account when selecting a technology. The specific factors to consider are availability of raw materials, utilities, labor, access to markets, weather conditions, waste disposal regulations, etc. Exxon selected two industrially developed areas that can provide the required production and transportation infrastructure to support the pyrite processing center: Evansville, IN and Green Bay, WI. Although the site selection rationale, including the dismissal of the Crandon Area is not explained anywhere in the Crandon project reports, it is evident that both areas do offer the necessary industrial infrastructure. In fact, at this stage of analysis both areas offer equivalent infrastructure, and no adjustments are required to McKee's technology selection.

III.A.3.f of Contract is discussed in the Marketing Report Review (Section 4.1 above).

III.A.3.g of Contract is discussed in the Phase II Report Review (Section 4.5 below).

4.5 Crandon Project Pyrite Processing Study-Phase II, June, 1981

Data Sources and Calculations (Contract III.A.3.a)

This report includes the process diagrams, description, investment estimates, operating costs and revenues for the processing alternatives.

The process diagrams were obtained from published and private sources, including McKee's in-house experience. For those processes with no available diagram, the engineering group at McKee designed one based on published specifications. The description is then adjusted to follow the process path and the material balances. Investment costs for the sulfuric acid, phosphoric acid and DAP plants was based on McKee's in-house data for recently built similar processes. For the remaining processes, the main pieces of equipment are identified and quotes are solicited. The investment is then calculated by adding all the units of equipment with provisions for installation and other indirect costs. All these procedures are standard in engineering practice and are within McKee's expertise. Table 3.2 presents the investment for each alternative.

The processing and investment costs for the iron pelletizing process and subsequent nonferrous metals recovery train were based on published information of companies operating in Europe

and are likely to have less accuracy than the stated $\pm 25\%$. This would suggest the need to carry out sensitivity studies on the investment to realize its effect on process profitability. The size of the required investment, however is small compared with the rest of the plant, thus eliminating this need. No detailed cost and investment information is provided for the roasting plant to elemental sulfur, although it appears that McKee assumed it equivalent to the roasting plant to sulfur dioxide. My figures for their estimated investment cost are very close to McKee's.

Sources for estimating revenues and operating costs include the raw material prices determined in the Market study, the transportation costs determined in the Transportation Rate study, prevailing costs for utilities and an estimate of investment related fixed costs. The engineering material balance provides the required production and consumption volumes to be multiplied by prices. These procedures are also standard in engineering practice.

The operating costs depend on the location of the processing center. Thus, different labor costs, utilities and investment-related costs change the economics of a process in addition to the expected variations caused by freight costs for raw materials and products. The freight costs differences between Green Bay and Evansville are adequately dealt with in McKee's report.

Labor, utilities and investment-related costs are assumed to be equal at both sites. The actual variations between both locations are indeed negligible at this stage of analysis and McKee's assumption is based in common project assessment practices. Crandon's mill location was ruled out as a potential site for the pyrite processing center. The rationale behind this decision is not contained in any of the Crandon Project reports, and must be explained. The selection of Green Bay is not, however, arbitrary, considering that markets for iron pellets are best accessed via Lake Michigan. Evansville makes sense mainly when the production of phosphoric acid or DAP are included as alternatives. In this case, phosphoric rock must be hauled from Tampa, FL, while the markets for DAP and iron pellets remain in the corn belt and Great Lakes areas respectively. Evansville is a middle point with ready access to ammonia raw material and additional DAP markets.

A few errors/omissions were detected in the Phase II Report:

1. Despite the fact that the text of the report claims that pyrite is charged at \$0/T over the freight cost, it is actually charged at \$2.02/T over freight cost (\$4.31/T for Evansville) (p. 4-1 and 4-6 to 4-9).
2. The suggested price for DAP in the Marketing Report is \$280 - 300/T f.o.b. Midwest (Market Report, p. 240), however, the price of \$220/T f.o.b. Tampa was used instead (Phase II Report, p 5-2). This lowers the profitability of the project.
3. The suggested price for ammonia is \$138/T delivered (Phase II Report, p 4-1). This assumes some base price \$111--114/T plus an estimated freight of \$24 - 27/T, as estimated by the Transportation Rates Report (p 4). However, the

Marketing Report estimates the 1977 price of ammonia in \$98.21/T (Market Report, p 277), and there is an ammonia terminal in Garner, Iowa very close to Green Bay (Market Report, p 285 - 287). The freight from this terminal would be similar to the Terre Haute - Evansville (i.e. \$13/T).

4. Sulfuric Acid does not seem to be charged at the production cost price in the DAP process, but at a price \$1.5 - 2.7/T lower (Phase II Report, p 4-10 to 4-17).
5. By an error in transferring the estimated investment for the nonferrous recovery section, a cost of \$1.6 million was entered instead of the estimated \$3.6 million (Appendix Report p 266).
6. There are no computer output results for all the cases. The four DAP cases are supposed to include the recovery of nonferrous metals, but the revenue does not show them. I also do not have clear whether the depreciation cost was left in the fixed costs, thus resulting in a partial double counting.
7. Even though a cost of \$2.50/MMBTU was assumed for fuel, the roasting unit that produces elemental sulfur shows a natural gas cost of \$3.00/MSCF or approximately \$3.00/MMBTU (Phase II Report, p 4-20 to 4-23).
8. No diagram for the pyrite to sulfur plant is provided.

These errors do not affect the assessment conclusions.

Each of the processing alternatives was evaluated using a Discounted Cash Flow (DCF) program apparently in McKee's computer. The DCF program is very standard in project assessment and a simplified version can perform the necessary calculations for this study. Companies usually require that the Return on Investment (ROI) of a potential project be above the interest paid by banks on long-term deposits to consider the project attractive. Depending on the economic assumptions, the ROI value can vary. An optimistic set of assumptions including high sales revenues (either from high projected sales price or sales volume or both), low investment costs

and low raw material costs results in a high ROI value, say above 25%. A pessimistic counterpart, with correspondingly low estimates can drop the ROI value to 10%. Since it is impossible to predict the future, it is common practice to either establish worst-case and best-case situations, or a most-probable case situation. In our fictitious example above, the ROI value for such most-probable case would be around 18-20%. Although I prefer to see a worst-case/best-case analysis, McKee's most-probable case approach is also adequate and used in industrial practice.

Adequacy of the Conclusions (Contract III.A.3.c)

The possible processing combinations yield 40 processing alternatives for Crandon's pyrites. Since two sites are assessed (Green Bay and Evansville), a total of 80 project alternatives must be assessed. Table 4.7 presents the estimated annual gain, in terms of total annual sales revenues minus total annual operating costs, for the assessed alternatives. 32 alternatives, involving the production of liquid sulfur dioxide and of phosphoric acid for direct sales were dismissed on the basis of unexistant markets. Of the remaining 48, only 18 show a positive annual gain. The roasting of all pyrites (slimes and coarse) to elemental sulfur shows a marginal gain of \$1.9 million if the facility is located in Green Bay and iron pellets and non-ferrous metals are recovered from the cinders. This gain is small considering the investment outlay of \$170 million

Table 4.7

		PROJECT ALTERNATIVES							
		ANNUAL GAIN = REVENUES - OP COST \$ MILLION							
		GREEN BAY				EVANSVILLE			
Final Product		No H ₂ SO ₄ from Zn Ref. Only Slimes		320,000 T/A H ₂ SO ₄ from Zn Ref. All Tailings		No H ₂ SO ₄ from Zn Ref. Only Slimes		320,000 T/A H ₂ SO ₄ from Zn Ref. All Tailings	
Elemental Sulfur	Recover Iron Pellets & Nonferrous Metals	④ (6.6)	⑧ 1.9	④ (6.6)	⑧ 1.9	(10.8)	(14.8)	(10.8)	(14.8)
	Waste Cinders	(9.6)	(24.2)	(9.6)	(24.2)	(13.7)	(40.9)	(13.7)	(40.9)
Liquid SO ₂	Recover Pellets & Metals		NOT ASSESSED *						
	Waste Cinders		NOT ASSESSED *						
Sulfuric Acid	Recover Pellets & Metals	② (6.3)	⑥ (2.4)	② (6.3)	⑥ (2.4)	(10.4)	(19.0)	(10.4)	(19.0)
	Waste Cinders	① (10.0)	⑤ (28.5)	① (10.0)	⑤ (28.5)	(14.1)	(45.1)	(14.1)	(45.1)
Phosphoric Acid	Recover Pellets & Metals		NOT ASSESSED **						
	Waste Cinders		NOT ASSESSED **						
DAP	Recover Pellets & Metals	⑨ 15.3	⑩ 98.6	③ 34.5	⑦ 121.8	12.8	89.3	33.6	113.9
	Waste Cinders	11.6	72.5	30.8	95.7	9.1	62.5	29.9	87.8

() = loss ○ Process No. on p. 1-6 of Summary Report

Source: Chapter 5 in Phase II Report.
(pgs. 5-2 to 5-6, Figures 27 to 34 and 37 to 46). "Waste Cinders" cases not explicitly reported, but calculated from Ch.4 and 5 of Phase II Report.

* Eliminated in Preliminary Screening because of small market.

** Eliminated in Preliminary Screening because of captive market.

required to set-up the roasting facilities (see Table 4.8), and further considering that administrative, financial and other operating costs are not included in the gain. All the DAP manufacturing alternatives yield a positive gain, with the recovery of iron pellets and non-ferrous metals always increasing the profitability and the Green Bay site always more attractive than the Evansville site.

From all the 48 assessed alternatives, however, only three exhibit a positive ROI (see Table 4.9). All three include the production of DAP in the Green Bay site with recovery of iron pellets and non-ferrous metals. The highest ROI (5.3%) corresponds to the case when all the pyrites are processed (fines and coarse) and additional 320,000 T/A of H_2SO_4 are available from external suppliers, (either from the Zn refinery or any other smelter and producer). The second highest ROI (2.8%) corresponds to the case where all the pyrites are processed, but no additional H_2SO_4 is brought in from external suppliers. A ROI of 2.5% is obtained for the case when only fine pyrites are processed, but 320,000 T/A of H_2SO_4 are bought from external suppliers. All of these ROI values are well below bank interest payments. Also, for the highest ROI case, the required investment is \$400 million (see Table 4.8), which would constitute a substantial increase in Exxon's proposed investment of \$900 million in the mill facilities. McKee's conclusions are thus justified.

Table 4.8

PROJECT ALTERNATIVES
INVESTMENT \$144 MILLION, 1980 Dls.

Final Product		GREEN BAY (a)				EVANSVILLE (b)			
		No H ₂ SO ₄ from Zn Ref.		320,000 T/A H ₂ SO ₄ from Zn Ref		No H ₂ SO ₄ from Zn Ref.		320,000 T/A H ₂ SO ₄ from Zn Ref	
		Only Slimes	All Tailings	Only Slimes	All Tailings	Only Slimes	All Tailings	Only Slimes	All Tailings
Elemental Sulfur	Recover Iron Pellets & Nonferrous Metals	④ 58	⑧ 170	④ 58	⑧ 170	58	170	58	170
	Waste Cinders	39	131	39	131	39	131	39	131
Liquid SO ₂	Recover Pellets & Metals		NOT ASSESSED *						
	Waste Cinders		NOT ASSESSED *						
Sulfuric Acid	Recover Pellets & Metals	② 84	⑥ 250	② 84	⑥ 250	84	250	84	250
	Waste Cinders	① 65	⑤ 211	① 65	⑤ 211	65	211	65	211
Phosphoric Acid	Recover Pellets & Metals		NOT ASSESSED **						
	Waste Cinders		NOT ASSESSED **						
DAP	Recover Pellets & Metals	⑨ 133	⑩ 392	③ 145	⑦ 400	133	392	145	400
	Waste Cinders	114	353	126	361	114	353	126	361

○ Process No. on p. 1-6 of Summary Report

* Eliminated in Preliminary Screening
** Eliminated in Preliminary Screening because of captive market.

(a) The Recover-Pellets-and-Metals case corresponds to Table 3.2 in this review. The Waste-Cinders cases are not provided by McKee. From their data, to obtain the Waste-Cinders investment subtract \$18.5 million from Recover-Pellets-and-Metals case in the "Only Slimes" columns and \$39.2 million in the "All Tailings" columns.

(b) Evansville's investment is assumed identical to Green Bay's by McKee.

Table 4.9
PROJECT ALTERNATIVES
ROI %

Final Product		GREEN BAY				EVANSVILLE			
		No H ₂ SO ₄ from Zn Ref.		320,000 T/A H ₂ SO ₄ from Zn Ref.		No H ₂ SO ₄ from Zn Ref.		320,000 T/A H ₂ SO ₄ from Zn Ref.	
		Only Slimes	All Tailings	Only Slimes	All Tailings	Only Slimes	All Tailings	Only Slimes	All Tailings
Elemental Sulfur	Recover Iron Pellets & Nonferrous Metals	④ N	⑧ N	④ N	⑧ N	N	N	N	N
	Waste Cinders	N	N	N	N	N	N	N	N
Liquid SO ₂	Recover Pellets & Metals		NOT ASSESSED		*				
	Waste Cinders		NOT ASSESSED		*				
Sulfuric Acid	Recover Pellets & Metals	② N	⑥ N	② N	⑥ N	N	N	N	N
	Waste Cinders	① N	⑤ N	① N	⑤ N	N	N	N	N
Phosphoric Acid	Recover Pellets & Metals		NOT ASSESSED		**				
	Waste Cinders		NOT ASSESSED		**				
DAP	Recover Pellets & Metals	⑨ N	⑩ 2.8	③ 2.5	⑦ 5.3	N	N	N	N
	Waste Cinders	N	N	N	N	N	N	N	N

○ Process No. on p. 1-6 of Summary Report

N = Negative. All negative gains in Table 4.7 yield a negative ROI. Several of the values do not appear in McKee's reports, but by comparing the gains in Table 4.7 with the reported ROI values it is evident that they are negative or negligible.

* Eliminated in Preliminary Screening because of small market.

** Eliminated in Preliminary Screening because of captive market.

Effect of Current Conditions on the Conclusions (Contract III.A.3.d)Markets

1979 was a peak year for the chemical industry. A subsequent recession dropped the industry's output and last year's recovery was barely able to bring it back to 1979 levels. No new market opportunities were detected in the literature survey. The market conditions, therefore, do not merit update.

Assessment.

The prices of products and raw materials have been subjected to substantial increases since 1980. Also investment and transportation costs have been incremented. McKee's study was using a constant basis for prices and costs. This approach minimizes the impact of normal price and cost fluctuations. Their results would only be invalidated by substantial relative changes in prices and costs. Since no such changes were detected in the industrial information sources it is not considered necessary to update the assessment studies at this time.

III.A.3.b, e and f of Contract not applicableRange of Capital Costs (Contract III.A.3.g)

McKee's investment costs were estimated using in-house information, equipment manufacturers' quotes and engineering estimates. The accepted tolerance for project assessment at this level is around 30%. McKee claims a margin of error of $\pm 25\%$ in their investment costs. The actual error in the phosphoric acid, sulfuric acid and DAP plants investment estimates is likely to be less due to McKee's in-house experience with these processes. The investment estimates for the pyrite roasting, iron-pelletization and non-ferrous metals recovery units are likely to include an error closer to 30%. The resulting estimates are within industrial practices. Further improvement of the investment figures would only be undertaken for those alternatives that showed positive economics. None of the alternatives evaluated seem attractive enough to justify further engineering work.

4.6 Crandon Project Pyrite Processing Study - Appendix, March, 1980

This report can be divided into two parts:

I. 14 technical references

- 3 on pyrite roasting (pg. 1, 3 and 5),
- 5 on recovery of non-ferrous metals from pyrite cinders (pg. 8, 15, 21, 31 and 57),
- 5 on roasting of pyrites to elemental sulfur,
- 1 on the Pirson-Peck Process for DAP from flue gas desulfurization.

II. Davy McKee communications, equipment cost estimates and manufacturer quotes.

The equipment cost estimates are repeated after page 291 (i.e. 291-381).

The technical references present a good review of the pyrite roasting and subsequent recovery of non-ferrous metals. The most recent publication, however, is dated in 1969. An extensive computer and library search was conducted to update the technical references. The results are presented in Section 5 below.

The supporting data for equipment cost estimates is pertinent, although the bases for the following processes are not provided:

- Pyrite Roasting to Elemental Sulfur (no diagram is provided, nor equipment cost details).
- Sulfuric Acid Plant (a diagram is provided, but no equipment cost details).

- Phosphoric Acid Plant (a diagram is provided, but no equipment cost details).
- DAP Plant (a diagram is provided, but no equipment cost details).

5. TECHNOLOGY UPDATE

As documentation for the process technology survey, McKee provided a series of articles describing alternate processing routes for pyrite roasting and cinder treatment for iron and nonferrous metals recovery.

An extensive survey of technology publications was conducted to update McKee's own survey. The update is aimed at detecting technological developments that might affect McKee's technology choice, and, ultimately, the project's conclusions. The survey included a physical search at the University of Wisconsin library system and a comprehensive computer search with access to world-wide data bases. The following processes were surveyed:

- a. Pyrite roasting
- b. Sulfur from other sources (SO_2 , flue gas, gypsum)
- c. Iron recovery from pyrite cinders (including pelletization)
- d. Nonferrous metals recovery from pyrite cinders.
- e. Sulfuric acid
- f. Phosphoric acid
- g. Diammonium Phosphate (DAP)

The computer search output is included in Appendix B. In excess of 700 references were initially found by the computer. Many were not related to the processing aspects of the technology, while others dealt only with theoretical aspects such as kinetics, thermodynamics, chemical analysis, computer models, control, etc. A few reported results on pilot plant tests and a good number were patents. Since only commercial manufacturing applications were of interest all these references were eliminated. Further, those references written in a language other than English were not

investigated. The following regional interests were detected in this last group of references:

Pyrite processing

Spain, South Africa, India, Russia, France, West Germany and the Scandinavian countries all report some degree of commercial applications of pyrite roasting to either sulfur or sulfuric acid.

Recovery of metals from pyrite cinders

South Africa and Russia show great interest in this technology, especially on the recovery of gold. Japan, the Scandinavian countries, India and Spain all report work on iron, copper and other nonferrous metals. West Germany's interest is on zinc, nickel and cobalt.

Phosphoric acid

Japan holds the highest number of publications on the hemihydrate process. Their lack of indigenous reserves for gypsum account for this interest.

Finally, those references dated before 1975 were dropped leaving a total of 47 to be analyzed. These are listed in the Bibliography ([43-79] and [94-103]).

The technology alternatives presented by McKee for each processing step are shown in Table 4.5, with the final selection clearly highlighted. The results of the updated survey are summarized below.

5.1 Pyrite Roasting [8,11,18,47,49,50,51,57,58,59,60,61].

Includes roasting to sulfur and sulfur dioxide. For roasting to sulfur, McKee selected the electric furnace process because of its high sulfur recovery. No new developments were reported in the update for the Thermal-, Chlorine- or Halvorsen-type processes. Production by a hydrometallurgical technology was reported but the recovered sulfur was too impure to be marketed. The only alternative market for the impure sulfur would be as asphalt aid. For roasting to SO_2 , the turbulent bed reactor is the latest technological development reported in the literature.

Competing sources of sulfur such as recovery from natural gas, oil refineries, utility plants, etc., are discussed in several additional references [5 p137, 13, 77, 78, 79].

5.2 Sulfur from Sulfur Dioxide [98,101,102,103]

This process is needed to convert hydrogen sulfide and sulfur dioxide generated in the pyrite roasting process to elemental sulfur. Although design improvements have been reported, the Claus process selected by McKee is the preferred route to recover this sulfur.

5.3 Metals recovery from Cinders [43-46,48,49,51,53-56,95-97].

Several commercial routes to recover iron from pyrite cinders were reported in the literature. They differ mainly in the type of furnace

utilized to oxidize the iron. The reported cases are all competitive technologies and no change in the conclusions is expected by modifying McKee's selection (Kowa-Seiko). The separation of nonferrous metals is now an integral part of most pyrite roasting plants. The main reported development is Duisburger Kupferhuetten's electrowinning process to enhance the purification (refining) of copper already recovered from pyrite cinders. McKee's selection of a separation train for nonferrous metals does not include the final refining step, and is thus not affected by this type of development.

5.4 Sulfuric Acid [5 p134, 10 p301, 12,13,94,8].

New developments in the manufacture of sulfuric acid concentrate on the design of more energy efficient plants and improving pollution control. The preferred process is McKee's selection : Contact- Double Absorption.

5.5 Phosphoric Acid [5 p242, 10 p252,12,26,62,68-76].

The wet-process selected by McKee is still the preferred route to phosphoric acid in the US. In the updating survey several reports deal with the hemihydrate process. Occidental started a plant in Florida. This technology reduces the impurities in the resulting byproduct gypsum, but it is still manufactured in great amounts. The adoption of this process in Crandon's case would not result in a significant improvement over the wet-process selected by McKee.

5.6 DAP [5 p255,63-67].

The development efforts in DAP manufacturing technology have been towards improvement of operating efficiency. The standard process was developed by TVA and they remain the main contributors to its development.

5.7 Strasma Report Review.

The report by J. Strasma et al. was reviewed as part of the technology update [107]. The report presents an analysis of potential uses of mine tailings to manufacture marketable products. The report's main finding is the attractiveness of the Pircon-Peck process to manufacture DAP fertilizer from flue gas. Flue gas contains very small amounts of SO_2 . The Pircon-Peck process is not attractive under the conditions at Crandon because:

- (a) SO_2 is readily available in high concentrations from the pyrite roasting unit, and
- (b) the resulting DAP fertilizer is low-grade (9-30-0 vs. 18-46-0 obtained in the TVA process). It is unlikely that the farmers in the corn belt would accept low-grade DAP. Upgrading this fertilizer requires a conventional TVA unit, thus defeating the purpose of utilizing the Pircon-Peck process in the first place.

In general the report provides very basic information and very vague support for its analyses. It gives the impression of being an initial study to establish the issues at stake, that is a proposal to justify further work.

6. ENVIRONMENTAL EMISSIONS OF THE PYRITE PROCESSING CENTER

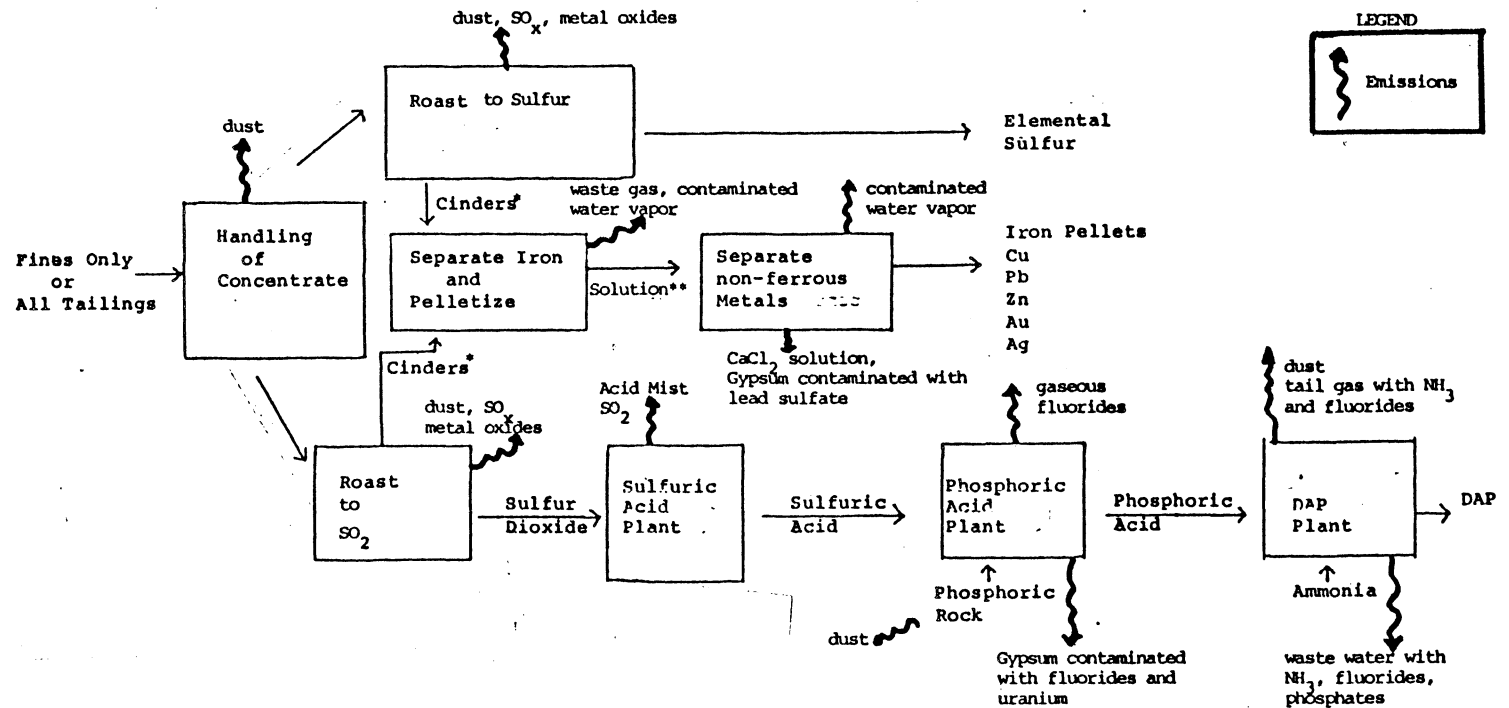
The concept behind the pyrite processing center is the avoidance of the environmental damage incurred by the impoundment of Exxon's mill tailings. The impoundment area required to hold the estimated 33 million T of tailings produced over the 30 years of mill operations is 22.1 million m³ (MWDF Feasibility Report). The processing alternative involves the separation of these tailings into 8 million T of pyrite concentrate (slimes) and 25 million T of coarse fraction. By processing the slimes, the impoundment area and containment specifications can be reduced. If all the tailings are processed the need for impoundment is eliminated. The pyrite processing train, however, is not pollution-free. Figure 6.1 shows the main emissions present in the pyrite processing alternatives. This Section presents a general overview of these emissions. The approach is qualitative for the most part, but quantitative estimates are provided when sufficient information is available.

6.1 Pyrite Handling.

Includes pyrite separation from gangue. This operation involves little chemical processing. The emissions from this step are better studied as part of the mill operations or the roasting facility.

Figure 6.1

PYRITE PROCESSING MAIN EMISSIONS



Source: Figure 2, Chapter 4, Phase I Report, Section 4.2, Phase I Report, Chapters 1 and 2, Phase II Report.

* Solid waste if not further processed to recover iron pellets.

** Liquid waste if not further processed to recover nonferrous metals.

The physical handling of the pyrite concentrate will result in minor particulate fugitive emissions.

6.2 Pyrite Roasting.

The main contaminants emerging from this process are the cinders if they are not further processed to recover iron pellets. An estimated 180,000 T/A of cinders are produced by the roasting unit. These cinders yield an acid leachate and a protected pond must be provided for their impoundment. The resulting environmental impact is only slightly less than that of impounding the pyrite tailings.

Gaseous emissions include sulfur and metal oxides (iron, zinc, lead, etc.) An emission limit of 2 Kg of SO_x /T of sulfuric acid was referenced by McKee (Phase II, p2-1, also [9]). If a limit of 2 Kg of SO_x /T of sulfur is imposed on the roasting facility the annual emissions of sulfur oxides will amount to 268 T/A. For the pyrite to sulfur dioxide facility, a similar limit will result in emissions of 534 T/A. These figures increase fourfold if all the tailings are roasted (slimes and coarse fraction).

As in any solids-handling unit, fugitive dust emissions are to be expected in the roasting facilities.

6.3 Sulfuric Acid Plant.

The most important emissions in the sulfuric acid plant are sulfur oxides and acid mist. For sulfur oxides the existing limit is 650 ppmV (Phase II, p2-2). This limit is readily achieved with current technology. For a typical emission of 2 Kg/T of sulfuric acid (Phase II, p2-1, also [9]), the proposed 400,000 T/A facility would discharge 800 T/A of sulfur dioxides. This emission increases to 3388 T/A if the 1,694,000 T/A plant is built to accomodate the coarse tailings also.

The emission limit for acid mist is 0.075 Kg/T of sulfuric acid (Phase II, p2-2). This limit results in emissions of 30 T/A and 127 T/A for the 400,000 T/A and 1,694,000 T/A plants respectively.

6.4 Phosphoric Acid Plant.

The main waste emission in this unit is solid gypsum contaminated with fluorides and uranium. There are no markets for this gypsum. The smallest processing alternative produces 1.3 million T of byproduct gypsum requiring some 44 million m³ of impoundment facilities. The largest processing alternative manufactures 6.7 million T of gypsum requiring a 222 million m³ pond. This is ten times the requirements for the mill's tailings.

Contaminating fluorides appear as sodium fluosilicates in the waste gypsum. These are not very soluble but preclude the use of the gypsum in construction. Silicon tetrafluoride and hydrogen fluoride are present in tail gas. The fluorides originate in the phosphoric rock required to manufacture phosphoric acid. Phosphoric rock contains as much as 3-4% fluorine [9]. This represents 13,500 T/A of fluorine for the small processing alternative and 68-90,000 T/A for the large one. These amounts are not expected to appear as emissions in Crandon's unit. Fluoride emissions are likely to be limited by EPA's standard of 0.01 Kg/T of P_2O_5 fed (Phase II, p2-3). The emissions under this standard are only 1.44 T/A for the small processing alternative and 7.26 T/A for the large one. The rest of the fluorides, however, must be removed and disposed off.

Florida phosphoric rock contains typically 0.03% of U_3O_8 [9]. Some of this uranium oxide remains in the gypsum, but most appears with the phosphoric acid. The smallest processing alternative generates 135 T/A of uranium oxide, while the largest one generates 680 T/A.

Particulate fugitive emissions are present in the physical handling of the phosphoric rock. These are not a major problem in the phosphoric acid plant.

6.5 Diammonium Phosphate Plant.

Ammonia and fluorides are present in tail gas and waste water streams of the fertilizer plant. Waste water contains also phosphate contaminants. The DAP product may contain fluorides and uranium from the phosphoric acid plant. EPA's standards limit fluorine emissions in DAP plants to 0.03 Kg/T of DAP (Phase II, p2-5). Crandon's emissions would then be limited to 9 T/A in the small processing alternative and 47 T/A in the largest case.

6.6 Iron Pelletization.

The main emission in the iron pelletization unit is the calcine dust containing nonferrous metals if these are not recovered downstream. Some 6,800 T/A of calcine dust are produced in the small processing alternative (only pyrite slimes). The calcine dust is cooled and washed with water yielding 53,460 m³/A of solution containing all the nonferrous metals plus 3,200 T/A of hydrochloric acid and 1,337 T/A of sulfuric acid.

Water vapor contaminated with metals (Cu, Pb, Zn, Cl and SO₃) is emitted when the hot pyrite cinders are cooled down by the direct use of recycle streams from the iron removal and zinc recovery operations (See Appendix C). 6-8,000 T/A of contaminated water are generated in the small processing alternative.

All the figures in this section increase fourfold if all the tailings are processed.

6.7 Nonferrous Metals Recovery.

Some 3,000 T/A of solid gypsum contaminated with lead and other metal sulfates are manufactured in this unit under the only-slimes processing alternative (see Appendix C). This is the main emission. The waste increases to 12,000 T/A for the all-tailings processing alternative.

50,100 T/A of a 10% solution of CaCl_2 in water are obtained in the zinc recovery unit. This stream is recycled to the iron pelletization unit to take advantage of the CaCl_2 as chlorination agent. Also, 6-8,000 T/A of a slurry containing some 820 T/A of $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$ are recycled to the iron pelletization facility to recover the iron (see Appendix C). These figures increase fourfold for the alternative of processing all the tailings.

6.8 Conclusion.

The most attractive alternative in McKee's study includes processing all tailings to DAP with total recovery of iron pellets and nonferrous metals and using 320,000 T/A of external sulfuric acid. Table 6.1 summarizes the estimated quantifiable emissions for this alternative. It is evident that the environmental problem created by the pyrite processing train is far more complex than the original impoundment of mill tailings.

Table 6.1

Estimated Emissions for Most Attractive
Processing Alternative

Processing Unit	Emissions	
	T/A	Type
Pyrite Roasting	2190	SO _x .
Sulfuric Acid	3388	SO _x .
	127	Acid mist.
Phosphoric Acid	6.7 million	Gypsum (222 million m ³ pond).
	7	Fluoride.
	680	Uranium oxide in Phosphoric acid.
DAP	47	Fluoride.
Iron Pellet.	200-210,000	Contaminated water vapor.

7. REVIEW CONCLUSIONS AND RECOMMENDATIONS.

Conclusions

The reports issued by Exxon's consultants are professional and conform to accepted project assessment practice. Their overall conclusion is that further processing of the pyrite tailings is uneconomic. Their final recommendation is to impound the pyrite fines and use the coarse fraction as mine fill. The conclusions and recommendations are supported by the results obtained in the reports. Current economic conditions have not changed enough to modify the conclusions. The comprehensive literature search did not uncover any technology development that could invalidate the process selection presented in the reports.

The reports address the potential environmental impact of the pyrite processing center in a rather sketchy manner. The case is that all processing alternatives will generate some degree of emissions. The specific case of gypsum obtained as a byproduct of the phosphoric acid/DAP processing alternatives is illustrative. This byproduct gypsum contains fluoride and uranium contaminants. Also, the required impoundment area to dispose off it is 44-220 million m^3 (36,000-180,000 acre-ft) in addition to Exxon's current planned facility of 23 million m^3 (19,000 acre-ft). The potential environmental damage of this pond seems larger than the pyrite fines impoundment. The

least environmentally damaging alternative appears to be the roasting of the pyrites to sulfur, including the recovery of iron pellets and nonferrous metals from the cinders. This alternative proved uneconomical under current conditions but should be kept in mind for future assessments.

The reports present the assessment of the "most probable" case for each alternative. Sensitivity studies including investment costs and product prices for the most economically attractive alternatives would contribute to strengthen the final conclusions. Apparently, Exxon's consultants had to work under tight time constraints. The resulting rush is probably the cause for the errors and omissions detected in the individual reports. The study's main flaw is the absence of a justification for the elimination of Crandon as a potential processing center.

My rough calculations show improved economics for such case, although still unacceptable ROI. This is demonstrated with a simplified version of the ROI, namely the gain/investment ratio GIR. Table 7.1 shows the GIR for the project alternatives. Notice that a GIR of 30.5% corresponds to the most attractive alternative of manufacturing DAP from all the tailings and including 320,000 T/A of additional external sulfuric acid, plus recovering iron pellets and nonferrous metals. This best case has a ROI of 5.3% in Table 4.9. Roughly there is a maximum equivalency of 0.17 percentage points of ROI per percentage point of GIR. Application of this equivalence factor to GIRs lower

TABLE 7.1
PROJECT ALTERNATIVES
GAIN/INVESTMENT RATIO

(%)

Final Product		GREEN BAY				EVANSVILLE			
		No H ₂ SO ₄ from Zn Ref. Only Slimes All Tailings		320,000 T/A H ₂ SO ₄ from Zn Ref. Only Slimes All Tailings		No H ₂ SO ₄ from Zn Ref. Only Slimes All Tailings		320,000 T/A H ₂ SO ₄ from Zn Ref. Only Slimes All Tailings	
Elemental Sulfur	Recover Iron Pellets & Nonferrous Metals	④ N	⑧ 1.1	④ N	⑧ 1.1	N	N	N	N
	Waste Cinders	N	N	N	N	N	N	N	N
Liquid SO ₂	Recover Pellets & Metals		NOT ASSESSED	*					
	Waste Cinders		NOT ASSESSED	*					
Sulfuric Acid	Recover Pellets & Metals	② N	⑥ N	② N	⑥ N	N	N	N	N
	Waste Cinders	① N	⑤ N	① N	⑤ N	N	N	N	N
Phosphoric Acid	Recover Pellets & Metals		NOT ASSESSED	**					
	Waste Cinders		NOT ASSESSED	**					
Via Pyrite to Sulfur Dioxide	Recover Pellets & Metals	⑨ 11.5	⑩ 25.2	③ 23.8	⑦ 30.5	9.6	22.8	23.2	N 28.5
	Waste Cinders	10.2	20.5	24.4	26.5	8.0	17.7	23.7	24.3

○ Process No. on p. 1-6 of Summary Report
N = Negative.

* Eliminated in Preliminary Screening because of small market.
** Eliminated in Preliminary Screening because of captive market.

than 30% will result in optimistic estimates for ROI. Table 7.2 summarizes the GIR values for the most attractive alternatives when the processing center is located at Crandon. These values are slightly optimistic because they do not take into account a marginal increase in the cost of hauling phosphoric rock and ammonia to Crandon instead of Green Bay. Multiplying the GIR values in Table 7.2 by 0.17 yields optimistic ROI values. It is clear that none of the alternatives has a ROI above 6%, which is well below bank interest levels.

RECOMMENDATIONS

The alternatives to process Exxon's mill tailings fail to achieve sufficient economic attractiveness. Furthermore, the environmental impact of the most favorable alternatives is far more complex than that of impounding the mill's tailings. Although more work is needed to strengthen McKee's reports I do not believe that the such work would substantially modify the reports' final conclusions.

TABLE 7.2

ESTIMATED GAIN/INVESTMENT RATIO WHEN PROCESSING
CENTER IS LOCATED AT CRANDON

(%)

Alternative	No H ₂ SO ₄ from Zn Refinery		320,000 T/A of H ₂ SO ₄ from Zn Refinery	
	Only Slimes	All Tailings	Only Slimes	All Tailings
Sulfur	N	8.8	N	8.8
Sulfuric Acid				
(sell price \$15/T)	N	4.6	N	4.6
(sell price \$30/T)	3.2*	14.8*	3.2	14.8
DAP	13.8	28.5	25.9	33.7

* Revenue increment for these cases estimated in Table 4.2.

Source: Own estimates. Pyrite freight cost savings vs. Green Bay are estimated at \$3 million (267,000 T @ 11.44 \$/T) for the slimes and \$13 million (1,094,000 T @ 11.44 \$/T) for all the tailings. The actual savings will be lower since freight of phosphoric rock and ammonia higher than to Green Bay.

8. SALT CAKE DISPOSAL

8.1 Background

Exxon's milling operation in Crandon will reuse most of its process water. The proposed water treatment unit frees the water from carbonates precipitating them with lime to form calcium carbonate. The remaining liquid is further treated in vapor compression evaporators/reverse osmosis units. As a result, a sludge containing essentially sodium sulfate and thiosulfate is obtained. As the sludge cools down, some of the sodium sulfate absorbs water to form Glauber's salt ($\text{Na}_2\text{SO}_4 \cdot 10 \text{ H}_2\text{O}$). Exxon, in several communications (MWDF feasibility study) has indicated the intention to sell a purified sodium sulfate cake to kraft paper manufacturers in the area or, if no clients are found, to dispose of the cake in an environmentally safe manner. In this section the (a) availability of markets for salt cake, (b) suitability of Exxon's salt cake for kraft pulping, and (c) environmental effects of salt cake disposal are reviewed.

8.2 Sodium Sulfate Markets

8.2.1 Demand Factors.

Sodium sulfate production in the U.S. has declined from about 1.1 million T in 1978 ([21] p 252) to 0.8 million T in 1984 [34, 36]. Table 8.1 presents the supply/demand situation for sodium sulfate from 1981 to 1984. Market reports up to 1979 showed that two thirds of the sodium sulfate was used in the Kraft pulping process, while some 26% went to detergents

Table 8.1

U.S. Supply/Demand for Sodium Sulfate
(1000T)

	1981	1982	1983	1984 ^(b)
Production				
Natural	553	373	364	355
Synthetic	<u>457</u>	<u>413</u>	<u>414</u>	<u>455</u>
TOTAL PROD.	1010	786	778	810
Imports	265	356	312 ^(c)	273 ^(c)
Exports	113	101	82	77
Consumption				
Pulp	543	515	453	450
Detergents	441	419	395	445
Other	148	139	116	117
TOTAL CONS. (a)	1132	1073	964	1012

(a) Apparent Consumption = Production + Imports - Exports + Inventory Change.

(b) Estimated using annualized data up to July.

(c) Canada accounted for 247 in 1983 and is expected to ship 220 in 1984 [37].

Source: [36]

[21] p 254). For a consumption level of 1.16 million T reported in [21], this means some 780,000 T going to pulp and 300,000 T going to detergents. The current figures indicate that the pulp uses have dropped to 450,000 T, or 44% of the consumption and detergent uses have increased to 445,000 T, also 44% of the consumption. The major factor affecting the kraft pulping use of sodium sulfate is the adoption of stricter environmental regulations. These have forced all industries with sodium sulfate emissions to recover the salt cake. Thus, the wood pulp companies using the kraft process have reduced their net (make-up) requirements of sodium sulfate [37, 40, 32]. Consumption is down to 25 kg/T of pulp for some processes [33]. Cheaper chemical replacements sporadically affect the consumption of salt cake in the pulp industry but are not considered a long range threat to sodium sulfate. Sodium and sulfur values are present in the effluent from chlorine dioxide and could permanently replace purchased salt cake, reducing the need for this chemical in the future [37,40]. All these indicators point to a diminishing market for sodium sulfate in the pulping industry. How fast will this market shrink will depend on the demand for pulp and on the technical ability (and economic attractiveness) to recover sulfur and sodium values from pulping effluent streams. At the present time the demand for pulp is experiencing a strong recovery [38,39]. The US pulp demand grew 6.5% per annum over the last two years, from 44.8

million T in 1982 [39] to 50.8 million T in 1984 [35]. This growth was not enough to offset a drop in sodium sulfate pulping use from 515,000 T in 1982 to 453,000 T in 1983 (see Table 7.1). The fall seems to have subsided and the estimated use for 1984 is around 450,000 T. The environmental and economic attractiveness of recovering more sulfur and sodium values from pulping effluents seems to have achieved equilibrium. The use of sodium sulfate for kraft pulping is expected thus to diminish at a slow rate.

The use of sodium sulfate as a component of household laundry detergents, on the other hand, has grown moderately in the last four years (see Table 8.1). Anhydrous sodium sulfate is a preferred inert ingredient because of its whiteness and particle size. As much as 75 wt% of household laundry detergents can be sodium sulfate. Detergent use is expected to increase in the future [21 p254, 36].

8.2.2 Potential Market for Exxon's Salt Cake.

There are 195 wood pulp mills in the US [39]. From these, 120 use the sulfate (kraft) process, accounting for some 70% of the pulping capacity of 51 million T. Exxon identified three kraft pulp mills in Wisconsin with a total requirement of some 9,600 T/A of sodium sulfate (Thilmany 7,300 T/A, Nekoosa 1,300 T/A and Mosinee 1,000 T/A). Exxon's maximum production of 4,620 T/A could then be absorbed by these three mills if they would agree to purchase its product. To gain their acceptance Exxon will

have to offer competitive price and adequate purity. The current suppliers include Saskatchewan Minerals, from Canada and Green Bay Packaging Co. from Green Bay. Saskatchewan's salt cake is very pure (98.93% according with their specifications), mined from Glauber's salt deposits. Thanks to the strong US dollar, they are able to offer their sodium sulfate substantially cheaper than the US price. For the northern US, the current listed price for sodium sulfate is US \$90/T, while Canada's export sulfate is listed at Can \$75/T [36]. At an exchange rate of 1.3176 Can\$/US\$ (Barron's, Nov 26 1984, p138) their export price is equivalent to US \$60/T. Green Bay Packaging, on the other hand, offers a byproduct consisting of a mixture of 80% sodium sulfate and 20% sodium carbonate. Since sodium carbonate is more expensive than the sulfate this mixture should command a higher price than the sodium sulfate alone. Green Bay Packaging, however, needs to get rid of this byproduct and is willing to sell at substantial discounts.

In conclusion, according to the market information reviewed in section 8.2.1, and the prices and local markets for sodium sulfate reviewed in this section, Exxon could sell its salt cake if willing to offer substantial discounts. It is likely that some amounts will have to be allocated to detergent manufacturers.

8.3 Suitability of Exxon's Salt Cake for Kraft Pulping.

Exxon's claim that the actual specifications of the salt cake are secondary to price for the kraft pulp manufacturers seems to be supported by technical writings on the subject [21 p254&399, 41,42]. The processing requirements call for make up sources of sodium and sulfur. The technical specifications are measured in terms of the sulfidity, with an acceptable range for this variable of 15-35% in the cooking chemical [42 pl37]. This can be fulfilled by many combinations of inorganic chemicals containing the required sulfur and sodium elements.

The only problem that has been mentioned by consulted experts is the ability of the pulping industry to accept potential chlorine contamination in Exxon's salt cake. This chlorine originates in sodium chloride obtained with the sodium sulfate. Although no chemical analysis of the salt cake is provided, an estimated composition is 95% sodium sulfate and 5% sodium chloride and sodium thiosulfate (MWDF Feasibility). If the resulting cake is unacceptable to the kraft pulp manufacturers Exxon will be forced to seek the detergent market, or to impound the salt cake.

8.4 Environmental Effects of Salt Cake Disposal.

Sodium sulfate is not considered a particularly noxious chemical [21 p254]. Its main environmental threat is its high solubility, which results in sulfate seepage to the groundwater. A high

concentration of sulfates in the drinking water has laxative effects. To help establish the magnitude of the problem I include several rough calculations.

Exxon's water treatment unit is expected to generate a maximum of 4,620 T/A of salt cake consisting mainly of sodium sulfate. Over 30 years of mining this represents 138,600 T of salt cake, requiring $69,300 \text{ m}^3$ of impoundment facilities (Exxon's estimate is $68,040 \text{ m}^3$, MWDF Feasibility Study). According to sodium sulfate solubility charts [30,31] water can dissolve up to 30-33% of this salt at temperatures above 33°C (90°F). The ground temperature at Crandon is not expected to exceed 16°C (55°F), in which case part of the rain water will be permanently trapped in the sodium sulfate to form Glauber's salt ($\text{Na}_2\text{SO}_4 \cdot 10 \text{ H}_2\text{O}$). The remaining solution can contain up to 11-12% of sodium sulfate. Glauber's salt retains about 1.3 T of water per T of sodium sulfate, thus one year's production of salt cake could trap as much as 5860 T of water to form the stable Glauber's salt. Table 8.2 shows that sodium sulfate impounded in a 5 acre pond with an average depth of 11.4 ft would disappear completely in 75 years. A 4 acre pond would extend the life of the sulfate to 95 years. Reducing the surface area of the pond reduces the seepage losses.

The conclusion that emerges from this rough, oversimplified calculation is that sodium sulfate will seep through to the ground water sooner or later, unless it can be kept from rain water.

Table 8.2

Sodium Sulfate Dissolution Estimates

Surface Area (acres)	Avg. Depth (ft) (a)	Water Collected per Year (b) (T/A)	Salt Cake ^(c) Annual Seepage(T)		Years to wash-off All the Salt Cake (d) (years)
			<30	>30	
2	28.6	6050	31	825	197
4	14.3	12100	1023	1650	95
5	11.4	15125	1520	2063	75

- (a) Total volume is 69,300 m³ (57.2 acre-ft).
 (b) For annual precipitation of 30".
 (c) Total cake = 138,600 T. A different disappearance rate is applied to the first 30 years of operation (<30) and the non operative years after the mine is closed (>30).
 (d) 5860 T/A of water trapped to form Glauber's salt. The remaining solution contains 12% sodium sulfate.

Exxon's salt cake will be recovered in solid form [106]. As the effluent sludge solidifies it will acquire the shape of the container. There is no evidence of any sodium sulfate disposal facility in the US in the literature. A comprehensive search using computer data bases was conducted and fourteen references mention the generation of salt cake but not the manner of disposal [80-93]. Interviews with experts corroborated the absence of industrial experience with this disposal problem, although no unsurmountable technical problems are foreseen to solve it [23,24, 106]. An appropriate design would provide an impermeable liner to protect the sulfate from water.

- [11] Aplin, C.L. and Argall, G.O., Tailing Disposal Today, Miller Freeman Publications, 1973
- [12] Argall, G.O., Tailing Disposal Today, Miller Freeman Publications, 1979.
- [13] Down, C.G., Environmental Impact of Mining, (with J. Stocks), Halstead Press (Subsidiary of Wiley), 1977.
- [14] Roe, L.A., Iron Ore Beneficiation, Minerals Publishing Co., 1957.
- [15] Riegel's Handbook of Industrial Chemistry-8th. Edition Kent, J.A., Ed., Van Nostrand Reinhold, 1983.
- [16] Denver Flowsheets, Denver, CO.
- [17] Thomas, R.W. and Farago, P.J., Industrial Chemistry, Heinemann Educational Books, 1973
- [18] Sulfur Removal and Recovery, Pfeiffer, J.B., Ed., Advances in Chemistry Series No. 139, American Chemical Society, 1975.
- [19] Same as [5].
- [10] Shreve, R.N. and Brink, J.A., Chemical Process Industries, McGraw-Hill, 1977.
- [11] Sulfur and Sulfur Dioxide Developments, Chemical Engineering Progress Technical Manual, Published by the American Institute of Chemical Engineers, 1971.
- [12] Sulfuric Acid/Phosphoric Acid Plant Operation, Chemical Engineering Progress Technical Manual, published by the American Institute of Chemical Engineers, 1981 Annual Meeting.
- [13] Slack, and Hollinden, Sulfur Dioxide Removal from Waste Gases, Noyes Data Corp., 1975
- [14] Sulfur Dioxide Control in Pyrometallurgy, Chatwin, T.D. and Kikumoto, N., Eds., Proceedings of the 110th AIME Annual Meeting, Chicago, IL, Feb 1981, Published by the Metallurgical Society of the AIME.
- [15] The Costs and Benefits of SO_x Control, OECD, 1981.
- [16] The Control of Sulphur and Other Gaseous Emissions, 3rd. International Symposium, Institution of Chemical Engineers and University of Salford, Salford, England, Apr 1979.
- [17] Nriagu, J.O., Sulfur in the Environment, Part I, Wiley-Interscience, 1978.
- [18] Sulfur Recovery and Utilization, ACS Preprints of the Meeting in Atlanta, GA, March 29, 1981, Vol 26, No. 1, February 1981.
- [19] Eckenfelder, W.W., Principles of Water Quality Management, CBI Publishing Co., 1980.
- [20] Geotechnical practice for Disposal of Solid Waste Materials, Proceedings ASCE, Ann Arbor, MI., June 1977.
- [21] Kirk-Othmer Encyclopedia of Chemical Technology, 3rd. Ed., Wiley Interscience, 1984
- [22] Smith, A.C.S., and Middleton, B.J., "Environmental Control of Calcine Disposal," copy provided in Appendix A.

- [23] Berthouex, M. , Professor Civil Engineering, UW-Madison, Personal Communication.
- [24] Kerrigan, J. , AMAX, Golden, CO., Personal Communication.
- [25] Caldwell, J., Smith, A., McPhail, G., "The Use of Geomembranes for Phosphogypsum Impoundments in South Africa," in Proceedings of the International Conf. on Geomembranes, Denver, CO., June 20-24, 1984, pg. 221-226.
- [26] Ross, R.C., "Uranium Recovery From Phosphoric Acid Nears Reality as a commercial Uranium Source," in E/JM Operating Handbook of Mineral Processing.
- [27] Smith, A., Hutchison, I. and Caldwell, J., "Aspects of Phosphogypsum Waste Disposal," copy attached.
- [28] U.S. Dept. of the Interior, Bureau of Mines, Mineral Industry Surveys: Sulfur, Monthly, May 10, 1984.
- [29] U.S. Dept. of the Interior, Bureau of Mines, Mineral Industry Surveys: Sodium Compounds, Monthly, May 10, 1984.
- [30] Hougen, O.A., Watson, K.M., Ragatz, R.A., Chemical Process Principles, Part 1: Material and Energy Balances, 2nd. ed., Wiley International, NY, 1966, Pg. 141.
- [31] Castellan, G.W., Physical Chemistry, Addison-Wesley, 1964, pg. 304.
- [32] Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed., Wiley-Interscience, Vol 21, 1984, pg. 245.
- [33] Hurley, P.J., "Energy Balances for Alternate Recovery Systems," Chem., Eng., Progress, Feb. 1980, pg. 43.
- [34] Webber, D., "Top 50 Chemical Products ," Chem. & Eng. News, May 7, 1984, pg. 8.
- [35] Pulp and Paper, Nov. 1984, pg. 9
- [36] Shockett, B., "Sodium Sulfate Markets Recovering Slightly in 1984," Pulp and Paper, Aug. 1984, pg. 187.
- [37] _____, " Pulp/Paper Chemical Use, Prices Continue to Strengthen in 1984-85, " Pulp and Paper, Nov. 1984, pg. 77.
- [38] Pulp and Paper, Oct. 1984, pg. 33.
- [39] Sutton, P., O'Donoghue, D., Kalish, J., "World Pulp and Paper Industry: Strong Recovery Sets New Records," Pulp and Paper, Aug. 1984, pg. 53.
- [40] Gray, J., Axegard, P., "Chlorine Dioxide Systems Can be a Key to Reducing Bleaching Costs," Pulp and Paper, Nov. 1984, pg. 64.
- [41] MacDonald, R.G., Ed., PULP AND PAPER MANUFACTURE 2nd Ed., Vol I, THE PULPING OF WOOD, McGraw-Hill, 1969, pg. 349.
- [42] Britt, K.W., Ed., Handbook of Pulp and Paper Technology, 2nd Ed., VanNostrand Reinhold, NY, 1970, pg. 135.
- [43] Kudelka, H., Dobbener, R., Piret, N.L., "Copper Electrowinning at Duisburger Kupferhuetten," Can. Min. Metall Bull, Aug. 77, 70, (784), 186-197.
- [44] Nogueira, E.D., Regife, J.M., Arcocha, A.M., "Winning Zn through Solvent Extraction and Electrowinning," Eng. Min. J., 180, (10), 92-94, Oct. 79.
- [45] Arrigada, F.J., Osseo-Asare, K., "Gold Extraction from Refractory Ores: Roasting Behavior of Pyrite and Arsenopyrite," Precious Metals: Mining, Extraction and Processing, Los Angeles, CA., 27-29, Feb. '84, Metallurgical Society/AIME,

- [46] 420 Commonwealth Dr., Warrendale, PA 15086 (See also [47,57])
Ryazanora, T.A., "Pressure Leaching of Roasted Pyrite Concentrates," (Translation), Sov. Non-Ferrous Metals Res., 10, (4), 301-305, 1982, ISSN 0307-7349.
- [47] Arriagada, F.J., Osseo-Asare, K., "Roasting of Auriferous Pyrite Concentrates," Process Mineralogy II: Applications to Metallurgy, Ceramics and Geology, Dallas, TX, 14-18, Feb. '82. Metall. Soc./AIMRE (See also [45,57]).
- [48] Filmer, A.O., "The Dissolution of Gold from Roasted Pyrite Concentrates," J.S. Afr. Inst. Min. Metall., 82, (3), 90-94, March '82.
- [49] Strauss, G.K., Gray, K.G., "Complex Pyritic ores of the Iberian Peninsula and their Beneficiation, with Special Reference to Tharsis Co. Mines, Spain", in Complex Sulphide Ores, Rome, Italy, 5-8 Oct., 1980, Publ. Inst. of Mining & Metallurgy, 44 Portland Place, London, WI England, 1980.
- [50] Lesoille, M., Evrard, L., Lierde, A., "Treatment of Auriferous Pyrite and Arsenopyrite by Roasting and Cyanidation," Ind. Miner. Mineral (Supplement), 59, (3), 19, June '77.
- [51] Hanf, N.W., Schmidt, C.G., "The Roasting and Leaching of Witwaters and Pyrite Concentrates," J.S., Afr. Inst. Min. Metall., 79, (13), 365-371, August '79.
- [52] Toguri, J.M., Metallurgical Society of CIM Annual Volume Featuring Molybdenum. 1977, Can. Inst. of Min. and Metall., 1130 Sherbrooke St., West, Montreal, Quebec, Canada, H3A 2M8, 1978.
- [53] Moussoulos, L., Potamianos, N., Kontopoulos, A., "Recovery of Gold & Silver from Arseniferous Pyrite Cinders by Thiourea Leaching," Precious Metals Min. Extr. Process. Proc. Int. Symp. Pg. 323-35, 1984. Pub. by Metall. Soc./AIME, Feb. 1984, Los Angeles, CA.
- [54] Goksel, M., Schott, T.A., "Metalized Pellets and Hot Metal Production from Pyrite Cinder by the MTU (Pelletech) Process," Proc. Inst. Briquet. Agglom. Bienn. Conf., 17, Pg. 159-71, 1982.
- [55] Lodha, T.R., Sinha, N.K., Srivastava, A.C., "Utilization of Pyrite Cinder Obtained as a By-Product from Pyrite-Based Sulfuric Acid Plant," Fert., Technol., 17 pg. 96-100, 1980.
- [56] Quecedo, I., "Use of Pyrites and Profitable use of the Cinders," Proc. Symp. New Uses Sulphur pyrites, 1st, Pg. 92-6, 1976, Union Explos. Rio Tinto S.A., Madrid, Spain.
- [57] Arriagada, F.J., Osseo-Asare, K., "Roasting of Auriferous Pyrite Concentrates," Process Mineral. Proc. Symp. 2nd. Pg. 173-86, 1982, Dept. of Water. Sci. Eng. Penn State Univ., Univ. Park, PA 16802.
- [58] Mian, S., Jha, C., Varma, P.C., Sinha, S.B., Guptars "Process Gas Dedusting in a Pyrite-Based Sulfuric Acid Plant," Fert. Technol. 18, pg. 66-70, 1981.
- [59] Martin-Morales, A., "Roasting of metal Sulfides (Pyrite, Blende, Galena, Chalcopyrite, or Complex Sulfides) with Recovery of Heat, Aplicaciones de la Energia, S.A., Spain.
- [60] Roy, B.B., "Manufacture of Sulfuric Acid Based on Indigenous Pyrite and Smelter Gases," Recent Adv. Inorg. Acides., Ind. Proc. Lect. Ser. Pg. 24-44, 1980.
- [61] Banerjee, A.C., Rangaswamy, P., "Air Oxidation of Iron Pyrites in Fixed Bed," Indian J. Technol., 15, pg. 265-6, 1977.

- [62] U.S. Envir., Protection Agency, "Standards of Performance for New Stationary Sources: Phosphate Fertilizer Industry; Wet Process Phosphoric Acid Plants; Superphosphoric Acid Plants; DAP plants, TSP plants, "Fed. Regist. 48, pg. 7128-9, 1983.
- [63] Shah, M.V., "Improving Productivity of DAP plant," Fert. New, 27. pg. 90-3, 1982.
- [64] Salladay, D.G. Achorn, F.P, Greenhill, J.L., "Recent Developments in Producing Monoammonium & Diammonium Phosphates using the TVA Pipe-Cross Reactor," Proc. Annu. Meet. - Fert. Ind. Round Table 31st, pg. 72-87, 1981.
- [65] Boyda, R.B., "Flue Gas Desulfurization and Fertilizer Manufacturing: Pircon-Peck process, " by Arthur G. McKee & Co., 1979 (See McKee's Appendix Report, pg. 158)
- [66] McCullough, J.F., Sheridan, R.C., "Purified DAP, "TVA, 161280, 1980.
- [67] _____, " Purification and Conversion of Phosphoric Acid to Ammonium Phosphates," TVA 021280, 1980.
- [68] Koenig, H.J., "Technical and Economic Advantages of Fisons Hemihydrate Processes," Fert. News 27. pg. 71-5, 1982.
- [69] Parker, M.L., McDonald, C.R., "Recent Experiences in Phosphoric Acid Production by Hemihydrate Routes," Proc., Fert. Soc. 209, pg. 20, 1982.
- [70] Parkinson, G., "Phosphoric Acid process Proven for Large Capacity Plants, "Chem Eng. 89, pg. 66-7, Sept. 1982.
- [71] Landgrat, E., "Energy Conservation by Hemihydrate Process, "Sulfuric/Phosphoric Acid Plant Oper. Symp., Pg. 134-46, 1982.
- [72] Caesar, M.B., Smith, H.C., Mercado, L.E., "The Oxy Hemihydrate Phosphoric Acid Process," Chem Age India, 31. Ptech-4, 8 pp., 1980.
- [73] Ishaque, M., Ahmed, I., "Production of Phosphoric Acid from Lagarbam Rock Phosphate by Hemihydrate Process," Fert. News, 26, Pg. 18-21, 1981.
- [74] Mercado, L.E., "Occidental's Florida Hemihydrate Operating Experience," Proc. Annu. Meet. Fert. Ind. Round Table, 30th pg. 50-60, 1980.
- [75] Ore F., "Development of the Occidental Hemihydrate Phosphoric Acid Process," Fert. Acids, Proc. Br. Sulphur Corp. Int. Conf. Fert. 3rd, 1, paper No. 12, 14 pp., 1979.
- [76] Goers, W.E., "New Technique/Old Technology Nissan 'C' Hemihydrate Process," Proc. Annu Meet. Fert. Ind. Round Table, 28th, pg. 99-107, 1978.

- [77] Kunkel, L.V., "A Review of Improvements of the Claus Sulfur Recovery Process," Proc. AnnU. Conv. - Gas Process. Assoc. 57, pg. 147-51, 1978.
- [78] Nobles, J.E., Palm, J.W., Knudtson, D.K., "Design and Operation of the First Amoco CBA Unit, "Proc. Gas Cond. Conf. 27, PL/1 - L/11, 1977.
- [79] Wright, R.D., Strange, J.W., "Innovative Process for Claus Sulfur Recovery," Proc. Gas Cond. Conf. 27, PS/1-S/8, 1977.
- [80] Parr, J.L., "Escanaba's Environmental Systems: The First Five Years," Paper Ind. Management Assoc. Magazine, Vol. 60, No. 9, Pg. 14-15, Sept. '78.
- [81] Okada, T., Hosomi, N., Kawamvia, S., "Waste Disposal System for Chemical Plants," Hitachi Review, 27, 1, pg. 27-32, Jan. '78.
- [82] EPA, "Mineral Mining and Processing Point Source Category Interim Final Rulemaking," Fed. Regist. 40, 201, pg. 48652-64, Oct. 16 '75.
- [83] Evans, J.C.W., "Unique Process for Sulfite Spent Liquor Keeps Older Mill Viable," Pulp and Paper, 49, 10, pg. 63-65, Sept. '75.
- [84] Gardner, W.C., "Present and Future Requirements of the Chlor-Alkali Industry for Effective Pollution Control," in Electrochemical Contributions to Environmental Protection, T.R. Beck Ed., The Electrochem. Soc. Inc. N.J., '72 pg. 16-28.
- [85] Fowler, D.E., Carpenter, W.L., Berger, H.F., "Study of the Relation Between Residual Soda & Water-Extractable Components of Vacuum Drum Washed Kraft Pulp and of Repulped Corrugated Container Effluent Characteristics," National Council of the Paper Ind. for Air and Stream Improvement (NCASI) Tech. Bulletin, No. 277, October '74.
- [86] Chem Week, 114, 18, pg. 33-34, May 1, 1974 "Recycling Helps Paper Mills Clean Up Their Image,".
- [87] Rapson, W.H., "The Effluent-Free Bleached Kraft Pulp Mill. Part V. The R4 Process for Chlorine Dioxide Manufacture to Decrease Production of Sodium Sulphate," Reprints 1973, Intl. Pulp Bleaching Conf., June 3-7, Vancouver, B.C., 1973.
- [88] _____, Reeve, D.W., "Effluent-Free Bleached Kraft Pulp Mill: Present State of Development," TAPPI, 56, 9, Pg. 112-115, September '73.

- [89] Hill, B.V., Brown, J.L., Smith, A.L., Alspaugh, T.A., Pangle, J.C., "What Mills are Doing to Control Water Pollution," Textile Chemist & Colorist 1, 6, pg. 146/25-156/35, March 12, '69.
- [90] Dermurari, C.V., Chandorikar, M.V., "Reverse Osmosis Plant Design for Recovery of Sodium Sulfate from Rayon Mill Spent Liquor: An Illustration," Desalination, 48, 3, pg. 331-7, 1983.
- [91] Millano, E.F., "Sodium Thiosulfate Wastewater Treatment in Activated Sludge Systems," Univ. Microfilms Order No. DA8319650, 1983.
- [92] Smirnova, N.M., Laskorin, B.N., Mishukova, Y.S., Bonsov, A.V., "The Application of Electrodialysis with Ion-Exchange Membranes for Treatment of Sodium Sulfate Solutions," Desalination, 46, pg. 197-201, 1983.
- [93] Lobley, D., Pinder, K.L., "Recovery of Sulfuric Acid and Salt Cake from Smooth Rock Falls Chlorine Dioxide Generator Effluent," Waste Treat. Util. Proc. Int. Symp., 2nd. Editor Moo-Young, Murray, 1982, pg. 63-70.
- [94] Becker, J.J., Goesele, W., Neth, N., Adlkofer, J., "Sulfuric Acid Production --- State of the Art," Chem. Eng. Tech. 51, 8, August '79, pg. 789-795.
- [95] "Tailing Reclamation: New Profits for Ergo and Others," Eng. Min. J. 183, 11, November 1982, Pg. 132-133, 135.
- [96] Anon, "New Uses for Sulfur & Pyrites: Proceedings of the Symposium, 1976," Int. Symp. on New Uses for Sulphur & Pyrites, 1st, Proc. Madrid, Spain May 17-19, 1976., Pub. by Sulphur Inst., London.
- [97] Morizot, G., Winter, J.M., Barbary, G., "Volatilization Chloridation with Calcium Chloride of Complex Sulfide Minerals and Concentrates," Complex Sulphide Ores, Paper Conf. pg. 151-8, 1980.
- [98] Friedman, L.J., "Production of Liquid Sulfur Dioxide, Sulfur and Sulfuric Acid from High Strength Sulfur Dioxide Gases," Sulfur Dioxide Control Pyrometal, Proc. Symp. pg. 205-20, 1981.
- [99] Ransom, J.M., Torstrick, R.L., Tomlinson, S.V., "Feasibility of Producing and Marketing By Product Gypsum from Sulfur Dioxide Emission Control at Fossil-Fuel-Fired Power Plants," TVA, Gov. Rep. Announce. Index 1979, 79(9), 143.
- [100] Christian, D.W., "Power Plant Flue Gas Desulfurization by the Wellman-Lord Sulfur Dioxide Process," Proc. Air Pollut. Ind. Hyg. Conf. Air Quality Management Electro. Power Ind., 12th, pg. 458-94, 1976.
- [101] Brown, G.N., Reed, C.M., Repik, A.J., Stallings, R.L., Torrence, S.L., "Development of the Westvaco Activated Carbon Process for Sulfur Oxides Recovery as Elemental Sulfur," Vol. II, Appendix, Gov. Rep. Announce. Index 1977, 77(9), 115.
- [102] Brown, G.N., Reed, C.M., Repik, A.J., Stallings, R.L., Torrence, S.L., "Development of the Westvaco Activated Carbon Process for Sulfur Oxides Recovery as Elemental Sulfur," Vol. I, Gov. Rep. Announce., Index 1977, 77(1), 91.

- [103] Hellmer, L., "The Removal of Sulfur Dioxide by the Wellman-Lord Process and its Processing to Elemental Sulfur," Control Gaseous Sulphur Nitrogen Compd. Emiss. Paper Int. Conf., 2nd., 1, PI, 13 pp., 1976.
- [104] Layman, P.L., "Brisk Detergent Activity Changes Picture for Chemical Suppliers," Chem. Eng. News, Jan 23, 1984, p 17.
- [105] Greek, B.F., "U.S. Farming Pickup Helps Natural Gas-Based Petrochemicals," Chem. Eng. News, Jan 30, 1984, p 11.
- [106] Rittorf, T., HPD Inc., Personal communication.
- [107] Strasma, J., Bilkey, W., Clum, J., Weidemann, W., "Alternative Solutions for Pyrite Mine Waste Problems: Sulphur Markets, SO₂ Control in Pyrite Processing, and the Use of Fly Ash in Treating and Isolating Mine Waste," Technical Report No. 1, Mining Research Program, Univ. of Wisconsin, 427 N. Lorch St., Room 224, Madison, WI 53706, Jan 1981.

10. APPENDICES

- A. Selected Papers
- B. Computer Search Output
- C. Emission Calculations

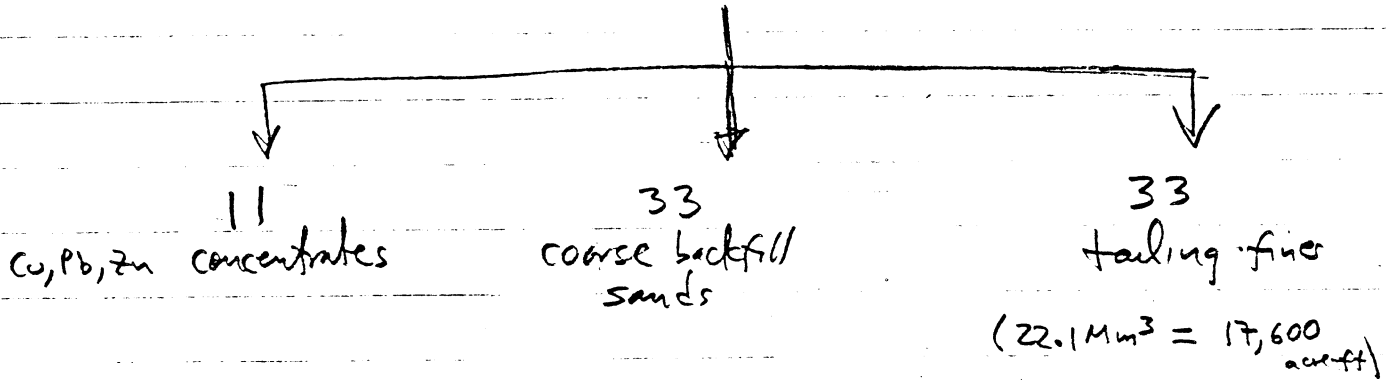
APPENDIX C

Emission Calculations

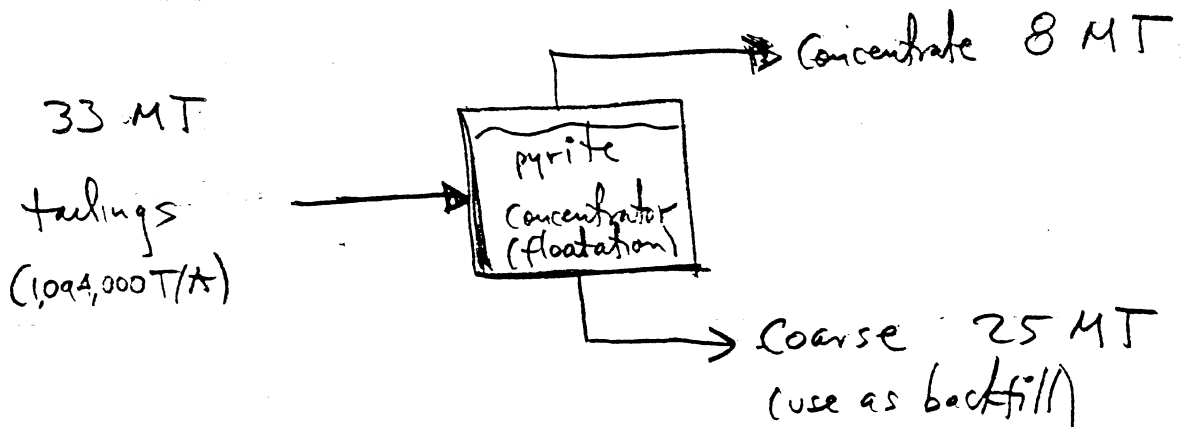
12/12/84

C-1

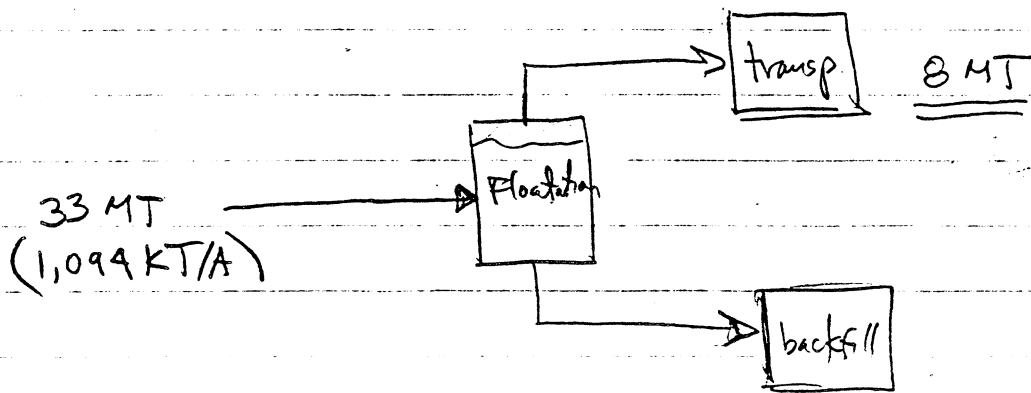
Crandon Ore body $\approx$ 66 MT
 + 17% contingency = 11 MT
 Total 77 MT



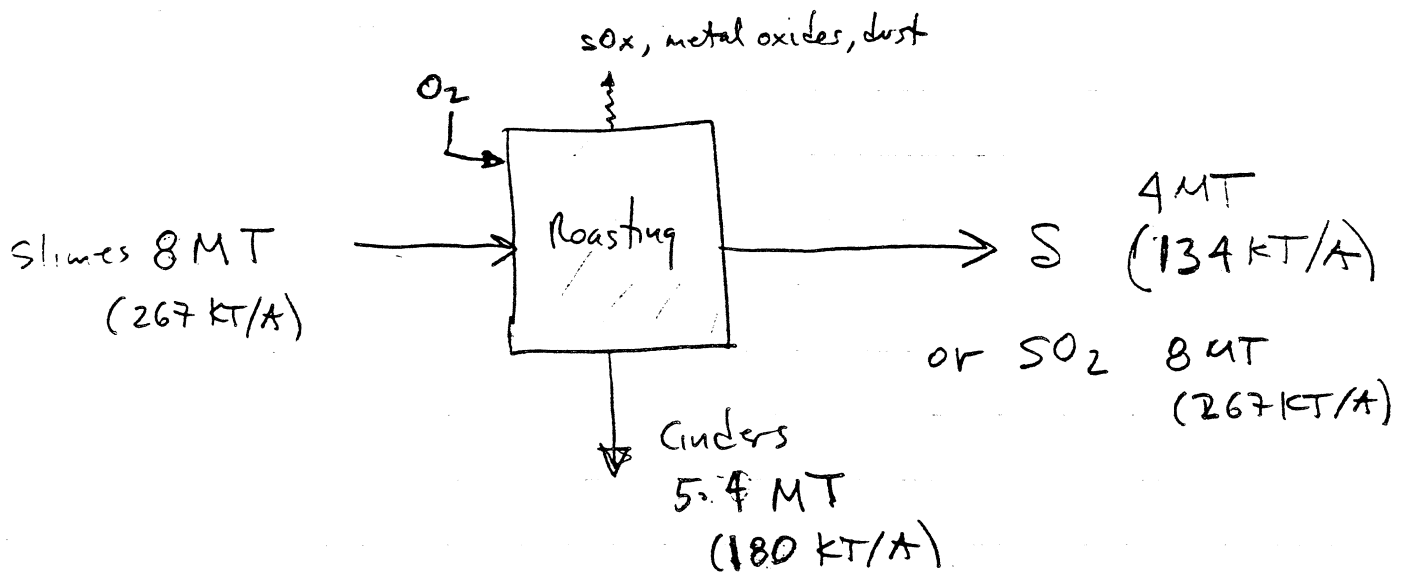
	Mm³	Acre ft	
Impoundment	22.1	17,600	tailings water treatment
	1.0	800	
	<u>23.1</u>	<u>18,400</u>	



Handling (includes flotation)



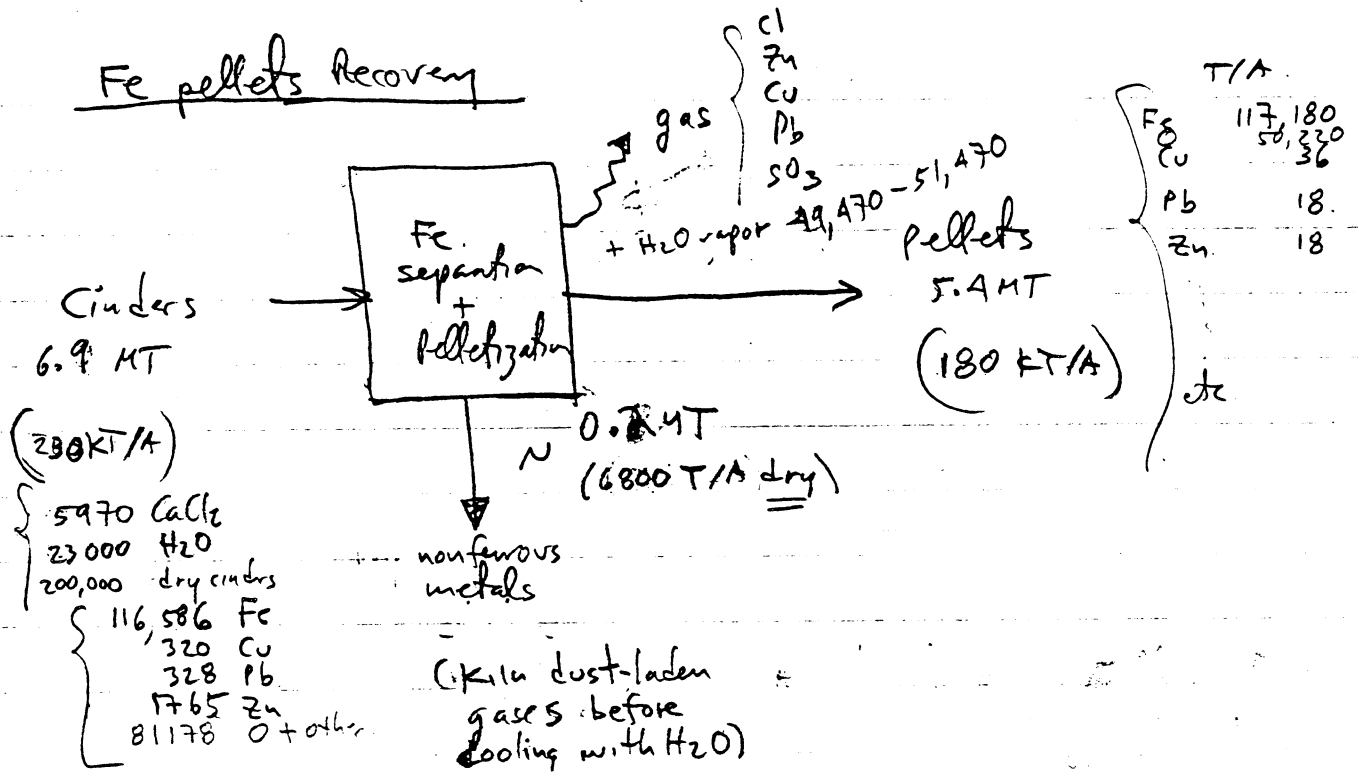
Roasting to S or SO₂



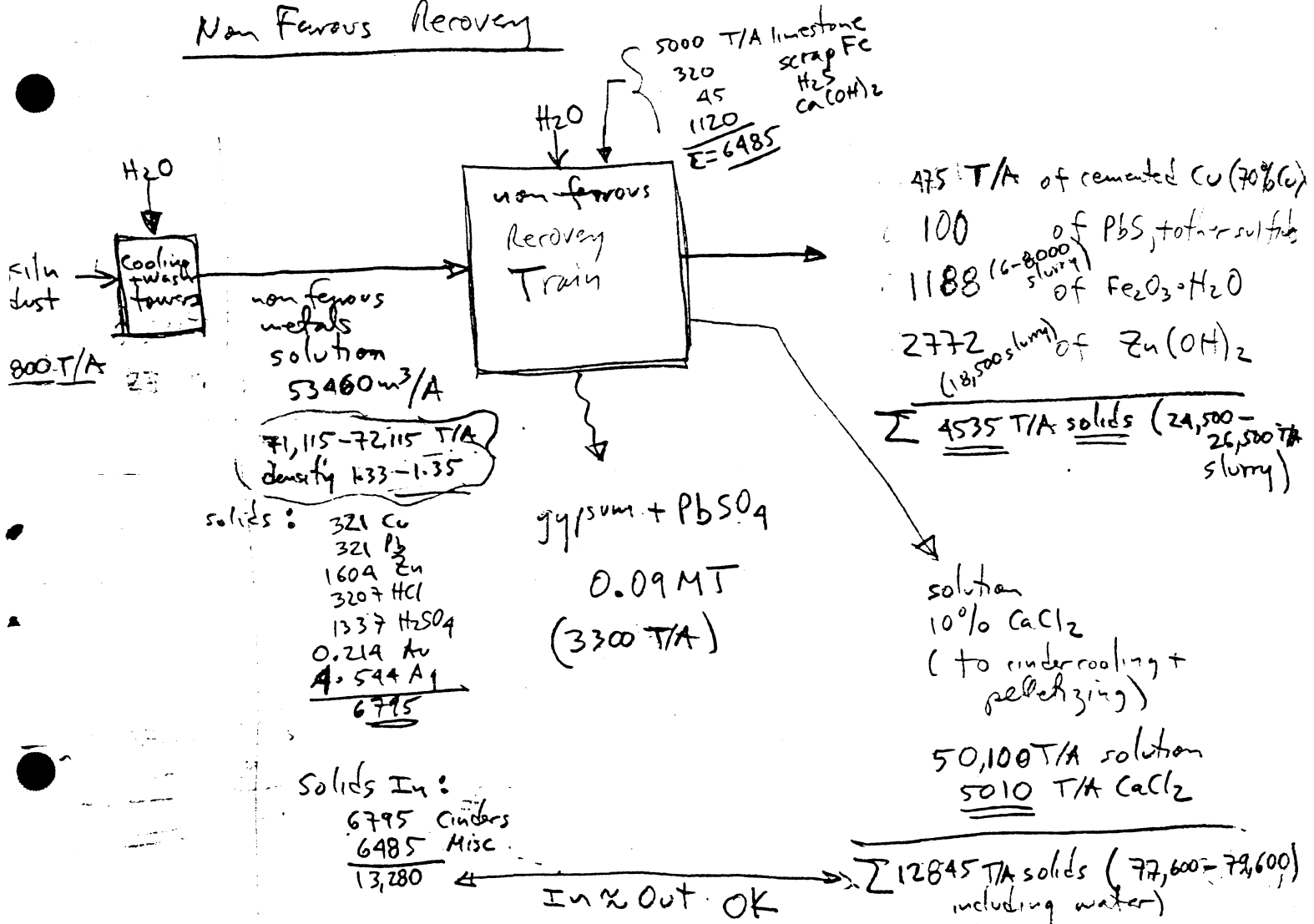
Required electricity 400 kWh / T of slimes
or 106,800 MWh/A.

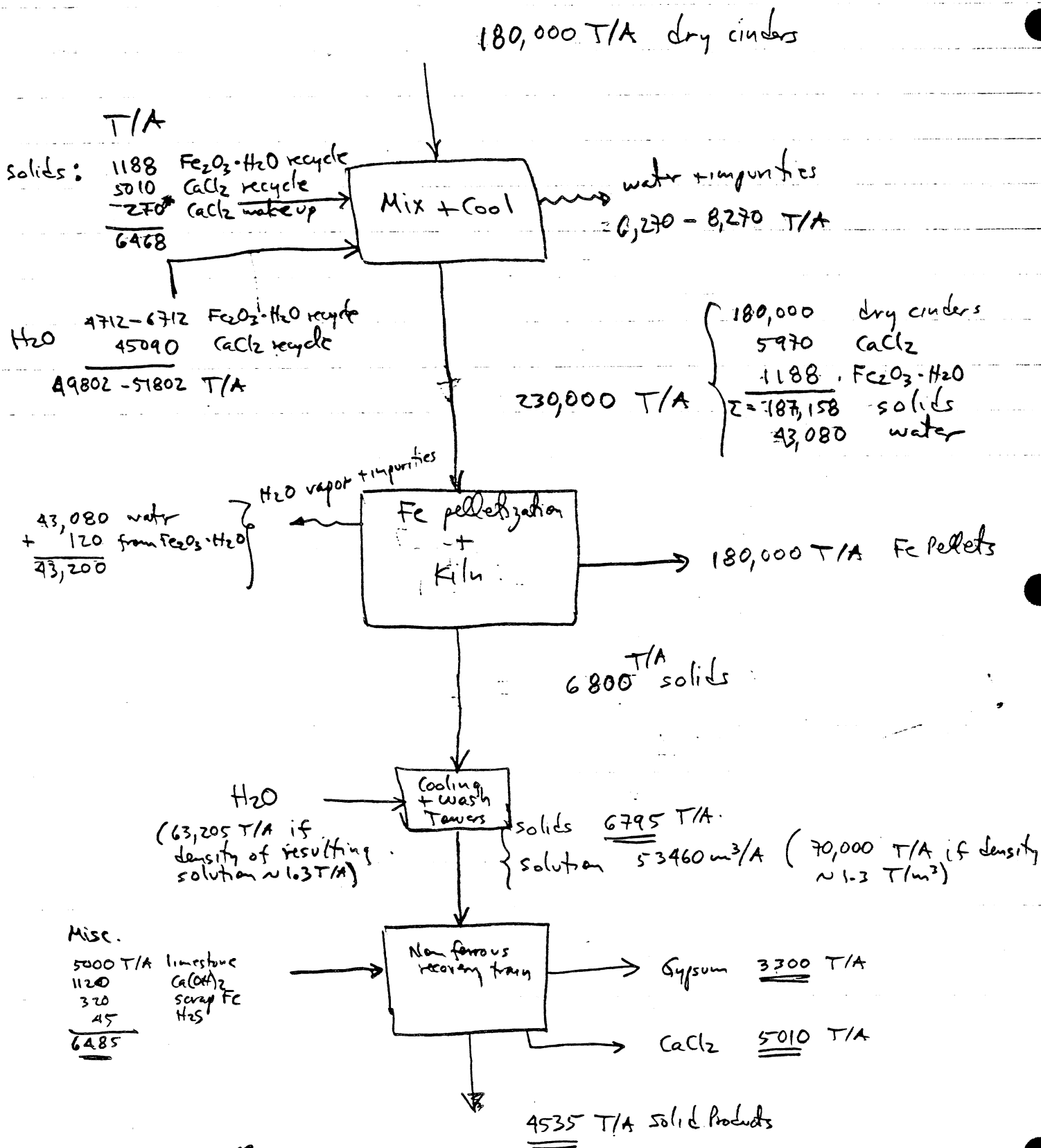
(Phase I p 4-8)

Fe pellets Recovery

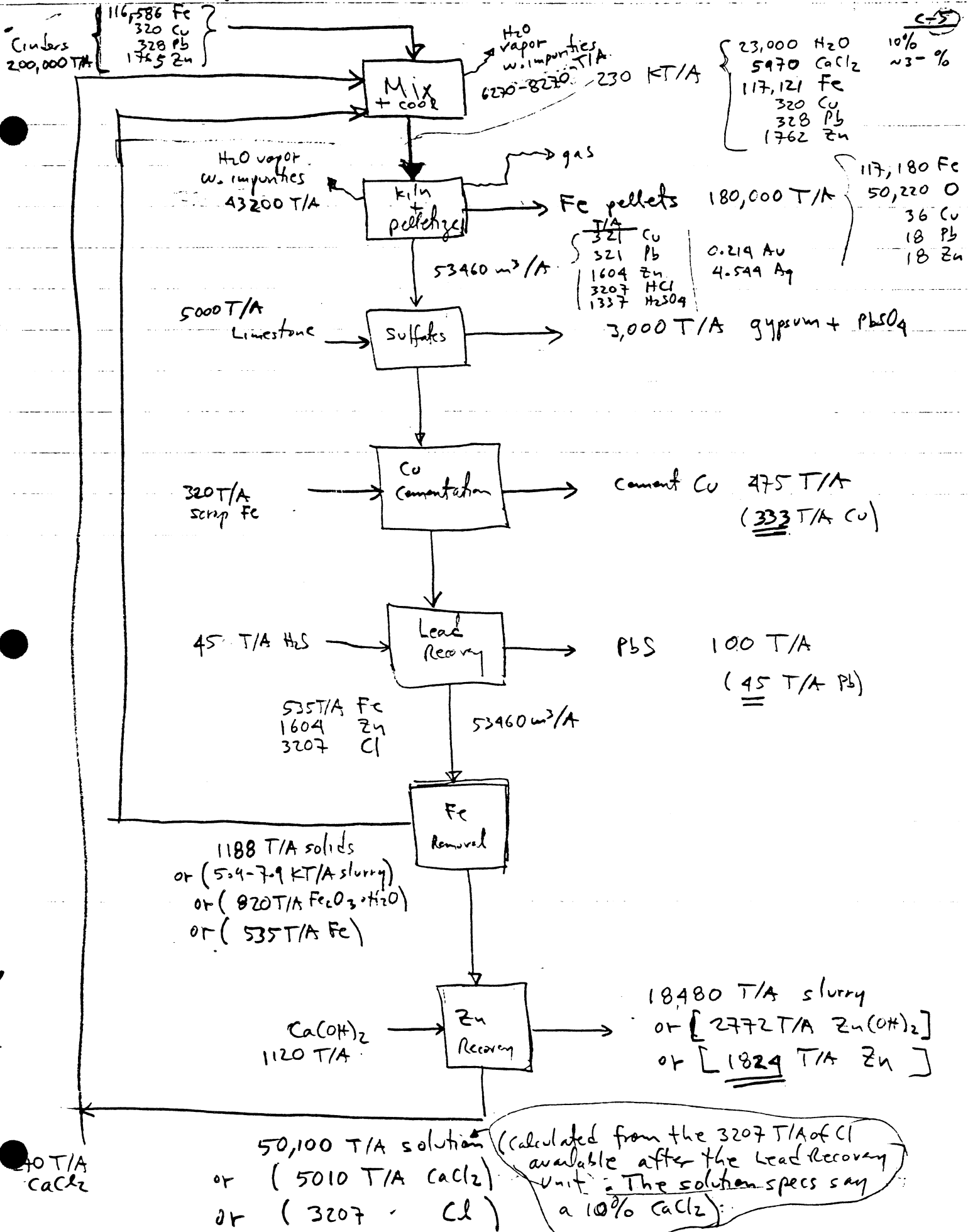


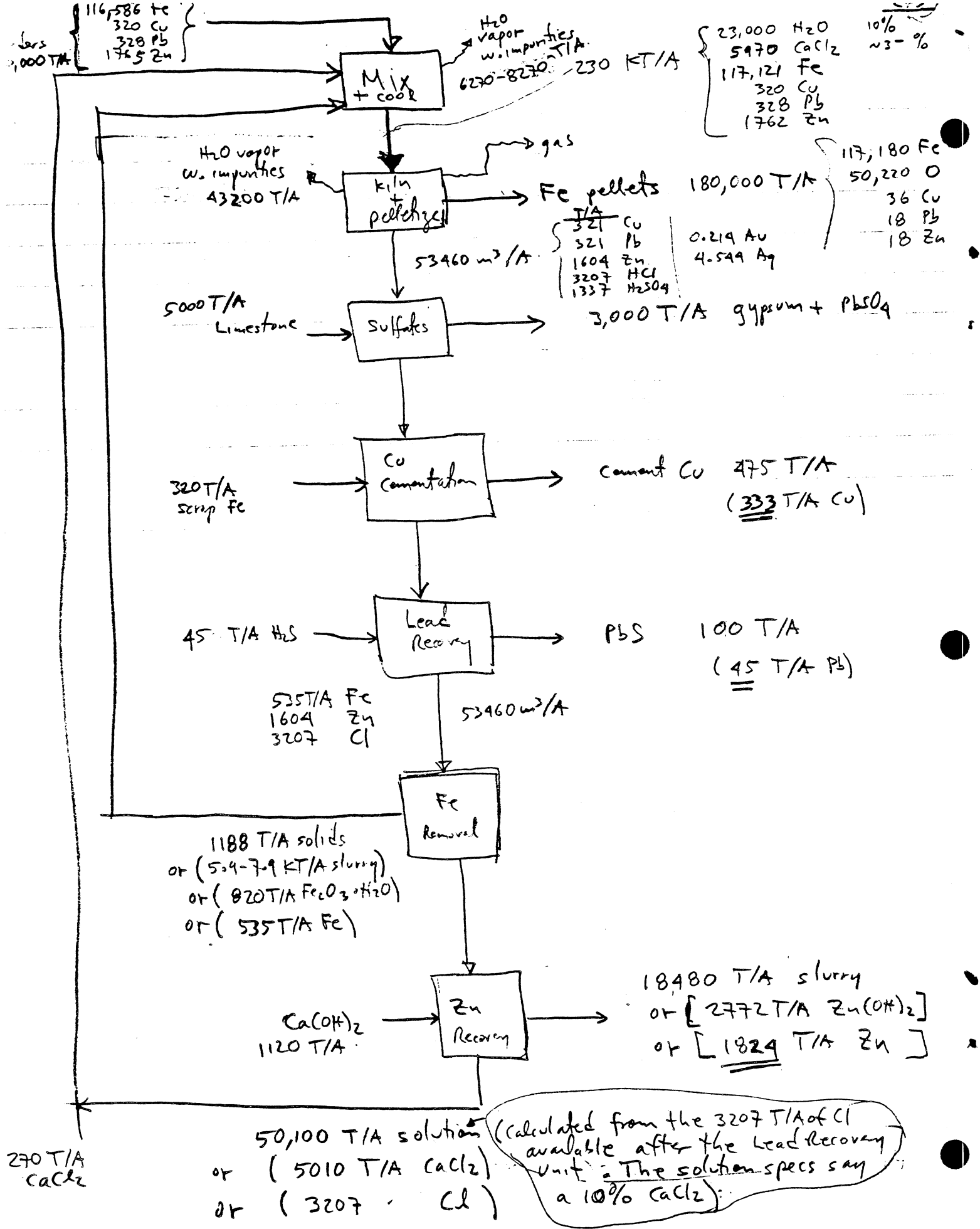
Non Ferrous Recovery





* 960 T/A are really needed to close the material balance. The calculation is part of my estimates in all likelihood.





CORRESPONDENCE / MEMORANDUM

STATE OF WISCONSIN

DATE: December 14, 1984
TO: Waste Reuse Review Report Users
FROM: Robert Grefe *R. Grefe* Engineer (Contract Manager)
SUBJECT: Appendices A and B

FILE REF: 4400

The attached report is entitled "Review of the Crandon Project Reports Submitted by Exxon Minerals Company Assessing Possible Uses for Pyrite Tailings", prepared by Dr. Andres A. Trevino, and dated December 14, 1984. The report was prepared under contract between the Wisconsin Department of Natural Resources and Dr. Trevino. The report is supplied in whole along with the bibliography and Appendix C. Appendices A and B are separate volumes and are reproductions of selected references listed in the Bibliography and of computerized literature search outputs. Together these appendices total 664 pages. Due to their bulk, they were reproduced for a limited distribution. Copies are available for public inspection and reproduction at the following Department of Natural Resources repositories:

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RG:san
4323V
Attach.