COST ESTIMATING A
NICKEL REFINERY BY
COMPUTER

by
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ABSTRACT

A computer program, written in FORTRAN, is described which calculates capital and operating cost statements and performs a process economic analysis for a "grass roots" nickel refinery that processes lateritic ores and uses reductive ore roasting-ammoniacal leaching technology.

The capital and operating cost statements are effected by calculating utility and chemical plant requirements, sizing equipment for the unit operations relative to ore or metal throughputs, and by applying inflation and cost scaling factors to fixed cost data. Capital and operating costs are presented in summary form as well as in a more detailed format.

Economic evaluation includes net present value (NPV), discounted cash flow rate of return (DCFROR), sensitivity, and risk analyses. A coefficient of variation in the profitability of the project is also presented.
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ACKNOWLEDGEMENTS

The author is indebted to the Mineral Sciences Division of UOP, Incorporated for supplying computer time and access to cost files, and to Steven E. Werle for his formula translation services. The author also expresses his appreciation to the many persons, including Professor Charles E. Lienert, who have supplied constructive criticism and helpful suggestions.
INTRODUCTION

Engineers at the Mineral Sciences Division of UOP Inc. Tucson, Arizona, completed a metallurgical study in 1978, under a contract for the United Nations, which provided test work and engineering design of a commercial plant based on the most suitable process for treating a nickel-bearing laterite ore from the Musongati region of Burundi, Africa. The conceptual design provided for a processing plant which would utilize reductive ore roasting, roasting additive, and ammoniacal leaching technology. This design was based on a fully integrated, grass roots, battery limits metallurgical facility which would contain equipment for ore preparation and handling, reductive roasting, leaching and washing, and recovery of product by solvent extraction and electrowinning. The study provided a capital cost estimate and an annual operating cost statement.

The Mineral Sciences Division of UOP Inc. offers a variety of technical and economic services to the minerals industry, as well as the development and licensing of new and improved extractive metallurgical technology. Because of an expanding industrial interest in developing nickel laterite ore bodies and of numerous requests by industry for economic information, the Division needed a computer-
ized approach to performing capital and operating cost estimates as well as project economic analyses of proposed projects involving nickel laterite ore-processing plants.

For this purpose, a computer program—UOPEC (UOP's Plant Evaluation Calculator)—has been developed which utilizes a conceptual design similar to that used for the Burundi study but with slight modification. UOPEC is currently being used for cost estimating, analyzing, and evaluating potential projects for UOP clients. Based upon input data, such as ore tonnage and composition, expected metal recoveries, ore feed oversize fraction and moistures, the plant mass throughputs and energy requirements are calculated prior to plant process equipment sizing, utility and process chemical requirement calculations, and capital cost statement composition. An operating cost statement is then calculated, based on input data which includes relative labor rates, relative productivity factors, the Chemical Engineering cost index, a U.S. wage rate, electric power and fuel costs, and process chemicals costs.

An extensive economic analysis is then performed involving net present value (NPV), discounted cash flow rate of return (DCFROR), sensitivity, and risk analyses. Program input data include the minimum acceptable rate of return, the income tax rate, metal selling prices,
project life, and ore mining costs. Sensitivities are computed for such variables as capital and operating costs, metal selling prices, metal ore grades and recoveries, fuel oil costs, productivity, and the discount rate. After a large number of profitabilities are calculated, the mean profitability and the standard deviation are calculated to determine the coefficient of variation in the profitability of the project.

A computer output from UOPEC is included in Appendix I. The input and cost data used for this output are intended to reflect a "real world" project. Actual data from UOP, Inc. studies were not used because of the confidential nature of such data.

A complete listing of the computer program is included in Appendix II. UOPEC is not a process simulator for computing steady-state mass and energy balances such as Monsanto's FLOWTRAN or Amax Metal's APEX. It is, however, a model to provide quick cost and economic analysis for a specialized metallurgical extraction plant. Other commercially available programs, including SSI/100 of Simulation Sciences and GPS-II of McDonnell Douglas, are not easily adapted to metallurgical processes.
THE PROCESS

The conceptual plant design utilized in UOPEC is based on the reductive roast-ammoniacal leach processing of nickel laterite ores utilizing certain proprietary additives to enhance the extractability of nickel, cobalt, and copper (Figure 1). This process was selected over acid processes because of its ability to treat the lower saprolite zones of the laterite ore body as well as the upper limonite zones.

Near the surface of laterite deposits, iron-rich mineralization occurs in the limonite zones where nickel oxide is finely disseminated among a mixture of several different hydrated iron oxides. In this zone, the nickel content might range from 0.8 to 1.5 percent while the iron content might range from 20 to 50 percent. Near the bottom of the deposits, minerals rich in magnesium and silicates occur in the saprolite zone where they can increase in concentration to as much as 30 percent for magnesium and 40 percent for silicates. In the saprolite zone, nickel can range from one to two percent and may reach five percent or more\(^1\). In between these two zones is an ore zone in which the iron content is decreasing but the silica-magnesium
FIGURE 1 - REDUCTIVE ROAST-AMMONIACAL LEACH TECHNOLOGY
content is increasing. These same laterite deposits may also contain commercial quantities of cobalt and copper. Acid processes are limited in application because of the high acid consumption in the extraction process as the magnesium oxides increase above five percent.

The reductive roast-ammonia leaching process has been applied on a large commercial scale in three plants located at Nicaro, Cuba\(^{(2)}\), Yabulu, Australia\(^{(3)}\), and Nonoc Island, Republic of the Philippines\(^{(4)}\). The UOP conceptual plant design, however, introduces solvent extraction and electro-winning for nickel, copper and cobalt metal recoveries. In this process, cathode nickel, copper, and cobalt are produced. The plant is designed to operate 24 hours per day but the number of operating days per year (on-time factor) is a program input variable.

**Ore Preparation and Handling**

Run-of-mine ore is conveyed to a crushing plant located at the mine site where a double-roll crusher reduces the material to minus four inches. The crushed ore is conveyed to an open stockpile at the processing plant. The minus four inch ore is reclaimed by a bucket wheel reclaimer and is transported to rotary drying kilns where the ore is then dried from about 40 percent to three percent free moisture.
A stand-by kiln provides additional capacity if the moisture content of the ore should approach 60 percent. The kilns are fired with either peat, coal, or fuel oil. Dust loading in the dryer off-gas stream is collected by cyclone and baghouse and is, therefore, delivered to fine ore storage silos.

The dried ore, crushed in a hammermill to minus \( \frac{1}{2} \) inch, is gravity fed to a ball mill where it is then ground to 95 percent minus 65 mesh (Tyler). Dust from the grinding circuit is collected by a baghouse and transported to storage silos.

**Roasting and Off-Gas Treatment**

Bucket elevators transport the fine ore from storage to surge bins feeding multiple-hearth roasters where some of the metal oxides in the ore are reduced to their respective metals by a gaseous reductant. The roaster calcine is cooled, without air, to prevent re-oxidation of the metals, and is then slurried before being pumped to the leaching section. The cooling of each roaster discharge occurs inside horizontal cylindrical drums which rotate while partly submerged in cooling water baths. Roaster reducing gas is generated either from coal or peat gasification or from the incomplete combustion of fuel oil.
Equipment for supplying roaster additives to the ore feed is included along with the dust collection, scrubbing, and absorption equipment. The recovered dust and additives are thereby recycled to the roasting section.

**Leaching and Washing**

Quenched calcine from roasting is pumped to cyclone classifiers where the underflow is charged to a ball mill and comminuted to 95 percent minus 200 mesh. The cyclone overflow stream proceeds to the first of several counter-current leach tanks where the selective leaching of nickel, cobalt and copper metals occurs at ambient temperatures and pressures. This leaching is caused by the solubility of the metals in ammoniacal ammonium carbonate solution. Soluble amine carbonates of nickel, cobalt, and copper are formed, and the pregnant liquor, after separation from the pulp, is shipped to the solvent extraction area for metals extraction. After leaching, the ore is washed in a counter-current-decantation (CCD) washing circuit for additional metal recovery. The final wash thickener underflow ore tailings are thus pumped to a gas-recovery plant for ammonia and CO₂ recovery.

**Solvent Extraction**

Pregnant liquor from the leaching section is delivered to a storage tank in the nickel-copper solvent extraction
General Mills LIX-64N, diluted in an inert organic carrier such as kerosene, is the organic extractant used. The organic stream flows counter currently to the pregnant liquor where the extraction of nickel and copper occurs in covered, mixer-settler tanks. Mixing and pumping are provided by turbine agitators.

The nickel and copper barren liquor is then passed from the last extraction stage to a surge tank for feed to the cobalt-extraction circuit. Coalescers are utilized for the removal of the entrained organic which is subsequently returned to the organic feed stream. The loaded organic, as it leaves the first extraction stage, flows to a surge tank before going to the first stage nickel-stripping mixer.

Spent nickel electrolyte from the electrowinning plant is used to strip nickel from the loaded organic in counter-current equipment similar to that used for extraction. Again, coalescers are used for organic removal and recovery. Pregnant electrolyte, upon leaving the first nickel stripping stage, is pumped to a surge tank in the electrowinning plant, and the nickel-stripped organic is delivered from the last nickel stripping stage settler to a surge tank in the copper-stripping circuit.

The copper-stripping circuit is almost identical to that used for nickel stripping, however, a different number
of stages is employed to strip the copper metal from the organic, which uses spent copper electrolyte from the electrowinning plant. The stripped organic is finally pumped back to the nickel-copper extraction circuit.

The nickel and copper-barren liquor from the Ni-Cu extraction circuit is pumped from the surge tank to a tower containing shredded cobalt cathodes and scrap where soluble cobalt in the stream is reduced by the metal. Retention time is carefully controlled so that all cobaltic ions are reduced with a minimum dissolution of cobalt metal. Nitrogen is fed to the tower to provide an inert atmosphere.

After reduction, cobalt is extracted in a circuit which is similar to that used for nickel-copper extraction and designed on the same basis; however, the organic extractant used is a solution of General Mills XI-51 in an isodecanol and kerosene diluent. The metal-free raffinate stream from the last cobalt extractor is delivered to a reslurrry tank in the roasting plant and then the cobalt-loaded organic is pumped to the cobalt-stripping circuit.

This cobalt-stripping circuit is similar to that used for copper stripping. Pregnant electrolyte is delivered to the cobalt-electrowinning plant and the stripped organic is pumped back to the cobalt-extraction circuit.
Electrowinning

Heat exchange and preheat heat trains for heating pregnant electrolytes are provided in the electrowinning facilities. Nickel and cobalt are electrowon in separate cells containing calcium-lead anodes and starter-sheet cathodes. Separate cells, used for starter-sheet cathode preparation, are identical to those in the product modules and accommodate the stainless steel starter blanks being used as the starter-sheet cathodes.

Conventional cells are utilized for copper electrowinning and starter-sheet cathode cells. These starter-sheet cathodes are deposited on titanium blanks and the pregnant copper electrolyte is pumped through the heat-exchange train and back to the copper-stripping circuit.

Product cathodes are pulled, at a weight of approximately 160 pounds, by an overhead crane, then washed with steam and condensate, and prepared for shipment. Starter sheets are separated from the blanks and placed in product cells. The starter blanks are subsequently returned to the starter cells to produce starter cathodes.

Auxiliary Plants and Miscellaneous Support Facilities

Facilities are provided for peat or coal pulverizing if the appropriate fuel choice is indicated in the program.
input statement. In addition, a steam plant is provided and equipped with steam turbine generators that continuously feed electric power into the plant's electrical system, however, they cannot supply the full requirement.

A gas-recovery plant processes the leach plant tailings by steam stripping in a sieve-tray column. The product vapors, consisting of ammonia, carbon dioxide, and water, are sent to the reagent recovery section for absorption in a series of condenser-absorbers and scrubber towers. The resulting solution is recycled to leaching. The steam-stripped tailings are then pumped from a common sump to the tailings pond. All ponds are earthen and lined with impervious clays assumed to be available on-site. Tailings pond overflow is reclaimed and utilized for process water make up.
UOPEC is a computer program written in FORTRAN. The programming includes statements to read and interpret input data files, to define computational sequence, to effect the sizing and costing of equipment, labor, and process chemicals, to perform economic analyses, and to print the results. Certain process design criteria, such as process stream temperatures, leaching and washing stages, wash ratios and efficiencies, solvent extraction organic-to-aqueous ratios, maximum metal loading in organic solutions, and electrical densities and efficiencies for the electro-winning cells, are included in the print-out statements for the specific benefit of the client, although these criteria are not directly calculated in the program.

The input-data logsheet is presented in Table 1 and includes the project identification. Annual plant throughput, ore feed oversize fraction, and ore composition and recoveries, are inputs to the program so that different size-processing plants and their economics of scale can be examined. The ore-feed moisture is an important input for the calculation of the total energy requirement. Relative labor rates and relative productivity factors are included.
so that the program will facilitate international usage. The Chemical Engineering cost index is utilized to bring pre-programmed equipment costs up to date. Similarly, the U.S. Wage rate is used to update labor costs for field installation of equipment, maintenance labor, and plant operating labor. Operating cost variables that are included in the input statement are those for electric power, process chemical, and fuel. The program is designed to calculate plant-operating costs if either peat fuel, fuel oil, or coal is selected as the fuel source.

Input data for economic analyses include the minimum acceptable rate of return that reflects the return expected from alternate uses of the capital, the income tax rate, nickel, cobalt, and copper-selling prices, project life, and ore-mining costs. The calculation of capital and operating costs for mining the laterite ore is beyond the scope of the program; however, these costs are expected to be included in the ore mining cost input variable. The number of days per year that the plant is expected to operate provides a measure of uptime and is an important factor in examining productivity.
### TABLE 1—INPUT DATA LOGSHEET

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<tr>
<td>1.</td>
<td>Project Identification</td>
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<td>Case A</td>
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<td>2.</td>
<td>Annual Plant Throughput, tons</td>
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<td>2500000</td>
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<td>3.</td>
<td>Ore Composition and Recoveries, percent</td>
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<tr>
<td>Nickel</td>
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<td>Cobalt</td>
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<tr>
<td>Copper Recovery</td>
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<td>Calcium Oxide</td>
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<td>Oversize Fraction, percent</td>
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<td>Ore Feed Moisture, percent</td>
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<td>Relative Labor Rate</td>
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<td>(Foreign Rate/U.S. Rate, $30,000)</td>
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<tr>
<td></td>
<td>Relative Productivity Factor</td>
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<td>(Foreign People/U.S. People)</td>
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<td>C.E. Cost Index</td>
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<td>Wage Rate, U.S. Dollars</td>
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<td>Electric Power, $/kwh</td>
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<td>Peat Net Heating Value, Btu/lb</td>
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<td>11.</td>
<td>Additive Cost, $/on</td>
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<td>Peat Cost, $/ton</td>
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<td>13.</td>
<td>Fuel Oil Cost, $/barrel</td>
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<td>14.</td>
<td>Coal Cost, $/ton</td>
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<td>Coal Heating Value, Btu/lb</td>
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<td>Select One: (1)-Peat Fuel (2)-Fuel Oil</td>
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<td></td>
<td>(3)-Coal</td>
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<td>Cost of Ore, $/ton</td>
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<td>18.</td>
<td>Selling Price of Nickel, $/lb</td>
</tr>
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<td>3.00</td>
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<td>19.</td>
<td>Selling Price of Cobalt, $/lb</td>
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<tr>
<td>20.</td>
<td>Selling Price of Copper, $/lb</td>
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<td>21.</td>
<td>Minimum Acceptable Rate of Return, percent</td>
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<td>0.18</td>
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<td>22.</td>
<td>Project Life, years</td>
</tr>
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<td>20.00</td>
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<tr>
<td>23.</td>
<td>Income tax, percent</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
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<tr>
<td>24.</td>
<td>Operating Days Per Year</td>
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<td>330.00</td>
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CAPITAL AND OPERATING COST ESTIMATES

Plant Sizing

To effect the formulation and calculation of the capital and operating cost statements for a grass-roots nickel refinery, the metallurgical extraction plant, as well as those plants required for utility and process chemical production, must first be properly sized according to plant-feed rates based on the program input variables of annual plant ore throughput, ore composition, expected metal recoveries, feed moisture, and the run-of-mine ore feed oversize fraction.

Ore Throughput

Annual plant ore throughput, measured in short tons, is used as the basis for computing the hourly plant ore throughput (THRPUT) in both short tons per hour (STPH) and metric tons per hour (MTPH). The plant, it is assumed, will operate 24 hours per day and less than 365 days per year. Although the refinery is not scheduled for a shutdown at any period throughout the year, the ore throughput is based on the assumed operating uptime factor.
**Ore Preparation and Drying**

The input variables of annual plant throughput and run-of-mine ore oversize fraction (OSFRAC) are used to determine the total dry ore feed (ROMFED) sent to the ore preparation plant. Run-of-mine ore moisture content (ROMMST), another input variable, is used to convert the ore feed rate from dry to wet tons per hour (ROMFEW).

Because the ore oversize fraction is removed from the process flow by a grizzly screen immediately after the ore is brought into the plant, the wet ore feed rate for the crushing and drying operation is based on the annual plant throughput and the ore feed moisture content.

Dryer train sizing is effected by assuming that the maximum ore dryer train feed rate is 173 wet tons per hour. The quotient, received from the division of the ore drying plant feed rate (DYFED) by the dryer train feed rate, is rounded upward to an integer to arrive at the total number of drying trains required. Additionally, a standby drying train is required to arrive at the total number of dryers (ANUM). After the total wet-ore-tonnage-to-drying and the number of operating drying trains (less the standby) have been determined, the actual dryer train feed rate (DYFEDR) is calculated. If the dryer
train feed rate drops below the maximum fixed value (173 wet tons per hour), the size of the dryer train equipment is reduced accordingly. The equipment, associated with each ore dryer train, includes ore feed hoppers, pan feeders, combustion air blowers, ore discharge conveyors, dust cyclones, fans, and baghouse dust collectors. The size and numbers of this equipment changes in a direct relationship to the changes in the size and numbers of the ore dryers. Additional items of ore-preparation equipment included are ore crushers, hammermills, ball mills and dust collection equipment associated with crushing and grinding. This equipment also becomes larger or smaller relative to the changes in plant throughput.

Some of the process design criteria are fixed within the program and are not variable input data; therefore, as an aid to the program user, certain algorithms and program line numbers which show fixed design criteria locations are presented in the text. Expression 1, presented below, calculates the total number of ore dryers on program line number 1420. Line 1420 displays the maximum ore dryer train feed rate (173 wet tons per hour) as well as the number of standby ore drying trains (one).

\[ ANUM = \frac{DYFED}{173} + 1 \] (1)
Roasting and Off-Gas Treatment

It is assumed, and therefore fixed into the programming calculations, that ore losses do not occur through the drying operation after the initial oversize fraction has been removed. The feed to the reductive ore-roasting operation (RSTIN) is then equal to the plant throughput or equal to the dry ore feed rate to the ore-drying plant.

Equipment for the multiple-hearth ore reductive roasting trains is sized in a manner identical to that of the ore-dryer trains, however, the maximum feed rate to an ore-roaster train (RSTFER) is 38.9 dry tons per hour with the standby capacity being eliminated. Program line number 1890 contains the equation for sizing the multiple-hearth roasters. Equipment in each roaster train includes air blowers, dust cyclones, dust baghouse, calcine coolers, quench tanks, agitators, slurry pumps, and coal or peat gasification apparatus, if these items have been selected on the program input statement.

Leaching and Washing

The leaching and washing plant-sizing expression (line 901) assumes an 83-percent recovery of the dry ore after the reductive roasting step. The weight loss is due to the reduction of the metal oxides and the waters of
hydration that are driven off.

Equipment in the leach/wash plant includes leaching and surge tanks, agitators, slurry pumps, a ball mill, slurry coolers, thickeners and reslurry tanks, a cyclone, and a pregnant liquor polish filter. For capital cost estimating, this equipment becomes either larger or smaller relative to the roaster-calcine production rate.

Solvent Extraction

The solvent extraction and electrowinning plants are sized relative to the calculated metal production (recovery) which is a function of annual plant feed, ore composition, and expected metal recoveries—all input variables. The program is written to tally individually the output tonnage of nickel, copper, and cobalt.

Capacities for mixer-settlers, makeup liquids and surge tanks, organic coalescers, pumps, and ammonia scrubbers, vary directly with the individual metal products, therefore, the solvent extraction plant is broken into four circuits for proper equipment sizing. Equipment capacities for the nickel-copper extraction circuit are a function of the total combined nickel and copper production. Sizing of the nickel-stripping circuit is a function of the total nickel metal produced; similarly, the copper-stripping
circuit sizing is a function of the total copper metal produced. The cobalt extraction and stripping equipment is sized directly with the cobalt metal production.

The solvent extraction plant had to be divided into the four circuits because the three metals not only differed in their ratios among the different ore bodies, but in some cases, did not appear at all. Consequently, when copper is not present in the plant feed, the nickel-copper extraction will become smaller, and the copper-stripping circuit will be completely eliminated.

Electrowinning

In the electrowinning plant, the electrowinning cells for nickel, copper, and cobalt metal production are assumed to have a fixed optimum size. As the individual metal production outputs vary, the number of cells will either increase or decrease in number, according to the direction of the production change.

Each nickel electrowinning cell has a fixed production rate of 38 pounds of nickel-cathode metal per hour. Production rates for copper and cobalt electrowinning cells are 41 and 27 pounds per hour, respectively.

During actual plant operation, electrowinning cells are used for preparing starter sheets by plating the metals
on titanium (copper) or stainless steel (nickel and cobalt) blanks in addition to the electrowinning production cells. Actual cell production rates are higher than those assumed in the program (44.3 lb/hr versus 38 lb/hr for nickel), however, the lower capacity listed above will allow for the calculation of extra electrowinning cells—cells that are assumed to be used for starter sheet preparation.

Equations for calculating the number of electrowinning cells are found adjacent to the following line numbers in the program listing.

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Line No.</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel</td>
<td>3860</td>
<td>ACLNI = ANIPRD * 83.33/DOO/38 (2)</td>
</tr>
<tr>
<td>Copper</td>
<td>3910</td>
<td>ACLCU = CUPRD * 83.33/DOO/41 (3)</td>
</tr>
<tr>
<td>Cobalt</td>
<td>3960</td>
<td>ACLCO = COPRD * 83.33/DOO/27 (4)</td>
</tr>
</tbody>
</table>

The required number of nickel electrowinning cells (ACLNI) is determined by converting the annual nickel-metal production (ANIPRD) to a pound-per-hour basis using the constant 83.33 and the number of plant operating days per year (DOO), and then by dividing the pounds of nickel produced per hour by 38 pounds-per-hour production capacity of one nickel electrowinning cell. The number of copper and cobalt cells required are calculated in an identical fashion except that the copper and cobalt cells produce 41 and 27 pounds per hour of metal, respectively.
In addition to calculating the total number of electro-winning cells, additional equipment for the storing, heating, and pumping of electrolytes and for the washing, handling, and packaging of cathode products is sized proportionally to the total metal produced.

**Fuel**

The metallurgical plant fuel source is an input variable that can either be peat fuel, fuel oil, or coal. To ultimately calculate capital and operating cost statements for the fuel storage and preparation plant, the total fuel requirement is thus calculated on the total plant heat requirements (discussed below). The total fuel requirements therefore, represent an effective size for the fuel storage and preparation plant.

**Utility Plants and Requirements**

Utilities, including steam, process water, cooling water, fuel, and electric power, are all required for the process. Respective utility plants are sized according to the individual utility demands of the metallurgical processing plant.

**Steam Requirement**

Steam is required to heat electrolytes, to wash metal cathodes, to strip leach tailings, and to manufacture
ammonia for the leaching operation. Before the total steam requirement can be calculated for steam plant sizing, however, the ammonia requirement for leaching and the expected ammonia recovery from leach tailings in the gas-recovery plant must be determined.

The total ammonia usage is actually the makeup ammonia required for the leaching operation after the recovered ammonia (from the gas-recovery plant) has been returned to the leaching plant. This usage rate is about 327 lb of ammonia per ton of metal produced (line 980). The basis of total metal produced or recovered is used rather than the total available metal in the leach ore feed because the total metal available in the ore will not completely form ammoniacal complexes because of the incomplete reduction of the metal oxides in the roasting step.

The total steam demand is calculated from the following fixed data(5).

1. Steam for the ammonia plant is 2.04 tons per ton of ammonia produced (line 990).

2. Steam required for the gas-recovery plant is 262 pounds per ton of roaster calcine available (line 1000).

3. Steam required for the electrowinning plant is:
   (a.) 509 pounds per ton of cathode metal washed.
   (b.) 3961 pounds per ton of cathode metal produced (required for electrolyte heating).
Cooling Water Requirements

Cooling water (CWUSE) is required in the roasting plant for calcine cooling (CWRST), in the leaching plant for removal of exothermic heat of reaction (CWLEC), in the ammonia production plant (CWNH4), and in the oxygen plant (CWO2). Oxygen is used to enrich the air in peat or coal gasification, therefore, if fuel oil is selected as the energy source, the oxygen plant requirements are omitted from the estimate.

To demonstrate the basis for the cooling water requirement, the following calculation is presented. The rotary-calcine coolers (designed to reduce the calcine temperature from 1450° F to 199° F with an average heat capacity of 0.23 Btu/lb-°F) utilize cooling water supplied at 84° F which leaves the drum cooler at 106° F.

Heat loss from ore (1450° to 199° F):

\[ 1 \text{ pound calcine} \times \frac{0.23 \text{ Btu}}{1 \text{ lb-°F}} \times (1450° - 199°) = 288 \text{ Btu} \]

Heat gained by water (84° to 106° F):

- at 84°F, enthalpy content of 1 lb water = 52.01 Btu
- at 106°F, enthalpy content of 1 lb water = 73.95 Btu

enthalpy change is 22 Btu per pound of water

THEREFORE:

\[ \frac{288 \text{ Btu loss}}{\text{pound calcine}} \times \frac{1 \text{ lb water}}{22 \text{ Btu gain}} \times \frac{\text{gallon water}}{8.35 \text{ lb}} \times \frac{2000 \text{ lb}}{\text{ton}} = 3136 \text{ gallon per ton} \]
Usage equals: 3136 gallons cooling water per ton of calcine.

UOPEC is programmed to calculate the usage of 3136 gallons of cooling water per ton of calcine cooled (line 1090), 3013 gallons of cooling water per ton of calcine leached (line 1110), 169,640 gallons of cooling water per ton of ammonia produced (line 1160), and 9257 gallons of cooling water per ton of oxygen produced (line 1240). Before the total oxygen requirement can be calculated, however, the roaster and gasifier heat requirements and subsequent peat or coal demand must be determined since the oxygen consumption is a function of that demand.

**Process Water Requirement**

Process water is required for the leaching and roasting plants, for cooling water makeup, and for steam generation. When peat or coal fuel is used in the roasting plant, process water (PWRST) is also required for slag disposal. Slag from the burner gasifiers is slurried with process water to about 33 percent solids; this is equivalent to using 15.3 gallons of water per ton of peat or coal burned.

Process water required in the leaching plant as makeup water (PWLEC) is added to the leaching thickener wash circuit at a rate of 44.9 gallons per ton of calcine feed to leaching. Makeup water for the steam plant (PWSTM)
and the cooling water plant (PWCW) is calculated at 186 gallons per ton of steam, and at 0.022 gallon per gallon of water cooled.

**Fuel Requirement**

The program is designed to calculate the total energy requirements and the annual operating costs if either coal, fuel oil or peat fuel is selected as the fuel source, and thus, allow a direct comparison of plant economics to alternate fuel sources.

The total fuel demand is the summation of energy required for ore drying (BTUD), ore roasting (BTUR), ammonia production (BTU4), and steam generation (BTUSTM). The dryer heat requirement equation considers the run-of-mine moisture content (ROMMST-a program input) and calculates the Btu's required to heat and evaporate the free moisture, thereby leaving a three-percent moisture content in the dryer discharge product. Sensible heat is added and a dryer efficiency of 75 percent is assumed (line 1530). The total Btu requirement for ammonia production is based on using $39.851 \times 10^6$ Btu per ton of ammonia produced. The energy requirement for the steam plant is based on 2321 Btu per pound of steam produced.

The energy requirement for the roasting plant (BTUR)
is calculated to be $1.3 \times 10^6$ Btu per ton of roaster ore feed from the following data:

- **Calcination temperature:** $1450^\circ F$
- **Heat of dehydration** $^{(6)}$ 100,000 Btu/ton iron oxide ($Fe_2O_3$) in ore feed
- **Sensible heat to ore in raising temperature from 151°C to 1450°F** 598,000 Btu/ton ore
- **Heat of reduction** $^{(6)}$ (exothermic) 45,000 Btu/ton ore
- **Sensible heat to free water** 86,000 Btu/ton ore
- **Sensible heat to combined water** 364,000 Btu/ton ore
- **Shell losses** 160,000 Btu/ton ore

Additional heat required for gasifier operation if coal or peat fuel is selected, (including heat for shell and slag losses and for air, oxygen, and additive heating) is $1.3 \times 10^6$ Btu per ton of roaster ore feed. The total heat required for the roasting plant then becomes $2.6 \times 10^6$ Btu per ton of roaster ore feed.

The oxygen demand is computed by calculating either the coal or peat tonnage and then multiplying that figure by 0.305 ton oxygen (line 1200) per ton of coal or peat required. The coal and peat tonnage is calculated by dividing the total roaster heat requirement (BTUR) by the
input net heating value of coal or peat (COLBTU and PETBTU, respectively) in Btu's per unit.

**Peat:** If coal is selected on the input statement, the coal preparation plant size is determined by dividing the total Btu requirement (for the processing plant) by the coal heating value, a program input.

**Fuel Oil:** The equations for fuel oil usage are similar to those for coal or peat usage except that the total Btu requirement in the roasting plant is reduced because of the elimination of the gasifiers, a heat consumer. Fuel oil burners replace the gasifiers and experience a substantially reduced shell heat loss over the gasifiers. It is assumed that each burner will experience a heat loss of about 50,000 Btu per hour and that each gallon of fuel oil will release about 150,000 Btu.

**Electric Power:** The Burundi Metallurgical Study electric power requirements were compiled based upon equipment lists for each individual production facility. Because the program allows the size of equipment to vary, and in some cases to be added or subtracted, the electric power requirements used in the program are factored according to individual plant-feed requirements. A listing of the base electric power requirement follows:
<table>
<thead>
<tr>
<th>PLANT</th>
<th>POWER REQUIREMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ore Preparation and Handling</td>
<td>1019 kwh per dryer train with capacity of 173 tons per hour plus 2931 kwh for ore handling equipment with 520 tons per hour capacity.</td>
</tr>
<tr>
<td>2. Reduction Roasting and Off-Gas</td>
<td>373 kwh per roaster train with capacity of 311 tons per hour.</td>
</tr>
<tr>
<td>(a) With Coal or Peat Fuel</td>
<td>373 kwh per roaster train with capacity of 311 tons per hour.</td>
</tr>
<tr>
<td>(b) With Fuel Oil</td>
<td>223 kwh per roaster train.</td>
</tr>
<tr>
<td>3. Leaching/Washing</td>
<td>17 kwh per ton calcine feed.</td>
</tr>
<tr>
<td>5. Electrowinning</td>
<td>60.7 kwh per Ni cell</td>
</tr>
<tr>
<td>6. Oxygen</td>
<td>60.4 kwh per Cu cell</td>
</tr>
<tr>
<td>7. Ammonia</td>
<td>67.7 kwh per Co cell</td>
</tr>
<tr>
<td></td>
<td>323 kwh for overhead cranes</td>
</tr>
<tr>
<td>8. General Offices</td>
<td>0.0319 kwh per ton O₂ produced.</td>
</tr>
<tr>
<td>9. Steam</td>
<td>0.1319 kwh per ton NH₄ produced.</td>
</tr>
<tr>
<td>10. Cooling Water</td>
<td>24 kwh</td>
</tr>
<tr>
<td></td>
<td>0.205 kwh per 1000 ton steam</td>
</tr>
<tr>
<td>11. Process Water</td>
<td>0.029 kwh per million gallons</td>
</tr>
<tr>
<td></td>
<td>0.305 kwh per mill gallons</td>
</tr>
<tr>
<td>12. Peat or Coal Fuel Processing</td>
<td>1.472 kwh per 1000 fuel processed.</td>
</tr>
<tr>
<td></td>
<td>664 kwh based on plant throughput of 311.4 tons per hour.</td>
</tr>
</tbody>
</table>
Process Chemical Plant Requirements

The ammonia gas-recovery plant, as well as the oxygen and ammonia manufacturing plants, are sized according to individual plant output demands.

Oxygen Plant Requirement

Oxygen is required for fuel gasification when peat fuel or coal is combusted. After calculating the Btu requirement of the ore roasting plant, either the coal or peat usage is determined. This figure is then used to calculate the oxygen requirement based on using 0.3051 ton of oxygen per ton of coal or peat gasified.

Ammonia Plant Requirement

The ammonia requirements are based on the usage of 327 pounds of ammonia as makeup per ton of product metal.

Gas-Recovery Plant

The gas-recovery plant size is similarly based on the total tons of metal product and the subsequent ammonia usage.
Cost Estimation

The capital and operating cost estimates determined by the program can be assumed to be order-of-magnitude estimates as defined by the American Association of Cost Engineers (7). This estimate has a probable accuracy of ± 50 percent and is based on knowledge of major items of equipment and of rough utility and process chemical requirements.

Equipment costs for the program were obtained either from UOP, Inc. in-house files, from published data, or from appropriate equipment vendor quotations. To obtain the preliminary cost estimate for the metal refining plant, equipment lists were formulated and FOB prices were tallied for all pieces of equipment including the buildings. These costs were subsequently built into the program.

According to Lang (8), the delivered cost of all equipment could be summed and multiplied by a factor of 4.9 to obtain all the costs involved in the design and construction of a solid-fluid plant, however, this method of cost estimating is not extremely accurate because the Lang factors are based on the premise that equipment costs are a certain fraction of the total cost of the plant. Equipment costs, however, are very dependent on the materials used
to make them, and the cost of building, site preparation, wiring, piping, instrumentation, insulation, etc. are independent of the materials of construction.

To make the cost estimate more accurate, the plant was divided into modules according to Guthrie\(^9\). The module concept groups similar equipment items, such as roasting, solvent extraction, electrolytic cells, etc., and applies multiplication factors, to arrive at a total direct installed cost which includes labor and materials. This concept differs from the Lang factor in that it does not include contractor's fees or other indirect costs. If the process module is made of metals other than carbon steel, or is operated at high pressures, the difference in cost is then added to the cost of the standard module.

The Guthrie method of capital cost estimating is illustrated in Table 2. The direct capital cost of a typical "norm" chemical process module can be calculated using FOB equipment costs as a basis.

The total cost of materials can be expressed as a material factor equal to 1.62 times the FOB cost of equipment. Similarly, the labor factor and the direct cost factor are 0.58x and 2.20x, respectively. The labor to materials (L/M) ratio is equal to 0.36.
TABLE 2—DIRECT CAPITAL COST ESTIMATING

<table>
<thead>
<tr>
<th>Direct Material, M</th>
<th>Direct Labor, L</th>
<th>Direct M &amp; L cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment, FOB</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Piping</td>
<td>32.0</td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td>8.9</td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Instruments</td>
<td>7.3</td>
<td></td>
</tr>
<tr>
<td>Electrical</td>
<td>8.3</td>
<td></td>
</tr>
<tr>
<td>Insulation</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>Paint</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Total Materials</td>
<td>162.2 + 58.0 = 220.2</td>
<td></td>
</tr>
</tbody>
</table>

The power law and sizing model is used frequently throughout the program for adjusting equipment costs from fixed program cost information. The model is given as (10):

\[ C = Cr \left( \frac{Q_c}{Q_r} \right)^m \]

- \( C \) = total value sought for design size \( Q_c \)
- \( Cr \) = known cost for reference size \( Q_r \)
- \( m \) = correlating exponent, \( 0 < m < 1 \)

The Chemical Engineering cost index is utilized to reflect changes in price information caused by the effects of time on costs. The model is given as (11):

\[ \text{Cost in year A} = \frac{(\text{Index in year A})}{(\text{Index in year B})} \times \text{Cost in year B} \]
Labor cost, including fringe benefits, are calculated from the U.S. wage rate input variable. These costs can be adjusted for international usage by the relative productivity factor and the relative labor rate factor, both input variables. According to Bauman (7), a correlation exists between the wages paid to miners and chemical workers in the United States and the wages paid to equivalent workers abroad. The relative labor rate factor therefore adjusts the foreign labor costs by essentially comparing the foreign labor rate to the labor rate of the United States.

Workers abroad not only work longer hours per week than their American counterparts, but in most cases, they require considerably longer time to perform a task. The relative productivity factor is used to either increase or decrease the total labor force required and uses the U.S. worker as a base.

**Auxiliary Chemical and Utility Plants**

Capital and operating costs for four utility, and three process chemical plants, are calculated individually. Utility plants include facilities for process water, cooling water, steam generation, and fuel preparation and/or storage. Process chemical plants include facilities for manufacturing oxygen and ammonia, as well as for recovering ammonia in a gas-recovery plant.
**Process Water Plant**

The capital cost for a process water facility (CCPW) varies with the total process water requirement. The power law and sizing model, using an exponent of 0.7, is utilized to adjust capital cost from a base of $163,000 for a facility capable of processing about 659 million gallons of water per year. The time basis used is 1979 as indicated by the C.E. Plant Cost Index of 238.

The sizing model (also known as the "six-tenths-factor rule") indicates that as a rule of thumb, a log-log plot of equipment capacity versus the cost for a specified type of equipment should be a straight line with a 0.6 slope, although the actual values can vary from less than 0.2 to greater than 1.0\(^{12}\). For the purpose of scaling the costs for the utility and process chemical plants, a 0.7 factor was used to allow for tying together a number of pieces of dissimilar equipment.

Expression Number 5 illustrates the calculation of the capital cost for the process water plant (CCPW).

\[
1600 \text{ CCPW} = \frac{\text{PWUSE}}{6.59\times10^8} \times 0.7 \times (116.8 + (46.2 \times \text{ALABFAC})) \times \left(\frac{\text{CEINDX}}{238}\right)
\]

The known cost for a certain capacity process water plant was broken down into the cost of purchased equipment (FOB) and the cost of materials and labor for field installation.
of the equipment. Direct cost factors used, according to Guthrie, include 1.7x, 0.67x, and 2.34x for total materials, field labor, and total direct cost, respectively. The L/M ratio is 0.40.

The total material (M) and field labor (L) costs are fixed into the program language. The field labor cost of $46,200 (line 1600) is first multiplied by the relative labor rate and the relative productivity factors, and then is added to the total material cost of $116,800, to arrive at the total direct cost of $163,000 for the process water plant. The cost of the new capacity plant is determined by scaling the total direct cost of the given capacity plant by a factor of 0.7. Finally, the new plant direct cost is escalated to the appropriate time by the C.E. Plant Cost Index.

The operating costs for the process water plant (OCPW) include salaries and labor (ALSPW), electric power (EPPWCST), and maintenance and miscellaneous costs (AMMPW). Four operators (U.S.) are assumed necessary to operate the plant.

After the total operating cost for process water has been determined, the cost of water per 1000 gallons is computed, thus allowing the operating costs for process water to be redistributed to those plants requiring process water.
Cooling-Water Plant

The cooling-water plant capital cost (CCCW) is based on a plant cooling 22 billion gallons of water per year and costing $1,269,000. The scaling exponent used is 0.6 (Guthrie), and the C.E. Plant Cost Index base is 238. The direct capital cost for the cooling-water plant is calculated similarly to that for the process water plant, except that the total direct cost factor used was 1.16x(Guthrie).

\[
1680 \quad \text{CCCW} = \left(\frac{\text{CWUSE}}{2.2 \times 10^10}\right)^{0.6} \times (1094 + (175 + \text{ALABFAC}) \times \text{CEINDX}/238)
\]  

The operating cost statement is comprised of salaries and labor (ALSCW), electric power (EPCWCST), makeup water (PWCWCST), and maintenance and miscellaneous (AMMCW) costs. Again, it is assumed that 4 operators (U.S.) are required for plant operation. Cooling water costs are calculated per 1000 gallons and distributed to those plants requiring cooling water.

Steam Plant

The capital estimate for the steam plant (CCSTM) is based on a 389,500 ton per year plant costing $10,150,000 in 1978. The total installed cost is broken down into $8,750,000 for equipment and materials, and $1,400,000 for field labor. This represents a field installation factor (M & L) of 1.44 (Guthrie). The size exponent is 0.8.
Operating costs for the steam generation plant are comprised of electric power costs (EPSTCST), maintenance and miscellaneous costs (AMMST), salaries and labor (ALSSTM), and fuel cost (FUELST), less credit for a small amount of electrical power generated by a steam turbine (EPCRE). The steam generation plant, it is assumed, would require eight operators (U.S.) and four supervisors. If a foreign location is selected the four supervisors are expatriots and their salaries would not, subsequently, be adjusted downward.

The total cost of salaries and labor for the steam plant, including payroll, is calculated on line 2280 of the program. After computing the wages of the operators and salaries of the supervisors, the two values are summed and multiplied by a factor of 1.37. This factor, therefore, represents the cost of fringe benefits and taxes which burden the payroll.

\[
2280 \quad ALSSTM = \left(\frac{8 \times WAGE \times ALABFAC}{1000}\right) + \left(\frac{4 \times WAGE}{1000}\right) \times 1.37
\]

The credit for electric power generation is based on a turbine producing one megawatt (MW) of electrical power per 43,000 tons of steam-generating capacity.
Fuel for the steam plant can either be peat, fuel oil, or coal. The total heat requirement for the steam plant is divided by the net heating value of the fuel and multiplied by the fuel cost. The heating value for fuel oil is fixed at 150,000 Btu per gallon (line 2230), however, the net heating values for peat fuel and coal are program variable inputs. The costs for peat and coal used for the steam plant are not the input values, but the values that include costs for cleaning and/or processing of the solid fuel at the metallurgical plant facility.

Fuel Plant

The fuel plant capital cost statement is estimated from one of three, mutually exclusive expressions that are dependent upon fuel selection.

1960 \( \text{CCPET} = \left( \frac{\text{PETUSE}}{1069000} \right)^{0.85} \times (1626 + (424 \times \text{ALABFAC})) \times \left( \frac{\text{CEINDX}}{238} \right) \) \hspace{1cm} (9)

2080 \( \text{CCOIL} = \left( \frac{\text{TOIL}}{2205} \right)^{0.63} \times (1034 = (216 \times \text{ALABFAC})) \times \left( \frac{\text{CEINDX}}{236} \right) \) \hspace{1cm} (10)

2120 \( \text{CCCOAL} = \left( \frac{\text{TCOAL}}{629011} \right)^{0.85} \times (6020 + (1570 \times \text{ALABFAC})) \times \left( \frac{\text{CEINDX}}{238} \right) \) \hspace{1cm} (11)

Equation nine calculates the direct capital cost of the peat processing plant (CCPET) using the method previously described. Crushed peat from the peat site is pulverized to 70 percent minus 65 mesh with roller mills in the peat
fuel preparation plant. In 1976, a plant, capable of processing 1,069,000 tons of peat containing 30 percent moisture, cost $2,050,000. Most types of crushing equipment can be scaled by using a 0.85 factor, and the direct capital cost can be determined by multiplying the purchased equipment prices (FOB) by a factor of 1.57\(^{9}\).

The operation cost estimate assumed that five operators would be required to operate the plant. Additional operating costs included expenses for electric power, maintenance and miscellaneous expenses, harvesting costs, and a cost of about $0.35 per ton to reclaim peat from stockpiling. The cost to harvest peat is a variable program input.

The direct capital cost of the fuel oil plant (CCOIL) is determined by equation ten. This facility includes equipment for the storage and distribution of fuel oil and is sized to hold a 30-day supply of oil. The program assumes a capital cost of $1,250,000 for a facility built in 1975. Operating costs for the fuel oil distribution plant are assumed to be the labor charges for two operators.

The coal preparation plant is similar to the peat plant in that coal is cleaned and sized for combustion and gasification. The capital cost (expression 11) is based on a plant processing 629,000 tons of coal at a cost of $7,590,000 in 1978. Of that cost, $6,020,000 was for equipment and
field materials, and $1,570,000 was for erection labor. Again, salaries and labor, electric power, maintenance and miscellaneous expenses, and raw coal costs comprise the basis for the operating cost estimate. Twelve men are required to operate the plant, however, this number fluctuates with plant size by a power of 0.25\(^{(13)}\). Maintenance and miscellaneous expenses are calculated as 44 percent of the coal plant capital cost for maintenance materials and 44 percent of capital for labor costs. The labor costs, however, are adjusted by the relative labor rate factor. As with peat, the purchase price of the coal and the other costs of operating the coal preparation plant are redistributed to those utilities requiring fuel.

**Oxygen Plant**

Oxygen is required for peat or coal gasification in the ore reductive roasting plant. The Burundi study, which formed the base for this program, contained an oxygen plant with an annual production capacity of about 145,000 tons of oxygen per year. The capital cost base was $4,250,000 for equipment and material costs and $1,109,000 for installation labor cost. (Total cost = $5,359,000). Although oxygen requirements for peat gasification were known, the requirements for coal gasification were not, therefore, it was assumed that the coal requirement was the same as that for peat.
Operating costs for the oxygen plant (OC02) include electric power costs (EPO2CST) for 32 watts of power per ton of oxygen produced, cooling water costs (CWO2CST) for 9,000 gallons of cooling water per ton of oxygen, wages (ALSO2) for four plant operators, and maintenance and miscellaneous costs (AMMO2) equal to 1.5 percent of the installed equipment costs. The entire cost of the oxygen plant operation is redistributed to the roasting plant operating cost statement. The cost of oxygen in the base case is about $13.00 per ton.

**Ammonia Plant**

Ammonia is required for the selective leaching of metals under oxidizing conditions in the leaching plant where soluble amine carbonates of nickel, copper and cobalt are formed. The base case for the computer model is a plant with a production capacity of 7300 tons of ammonia per year. The estimated capital cost (CCNH4) for this plant in 1978 was $4,385,000 including $3,478,000 for equipment and materials, and $907,000 for installation labor. A power factor of 0.7 is used to adjust the installed cost of this plant relative to production capacity changes (line 2330).

Operating costs (OCNH4) include salaries for four supervisors and wages for eight operators (ALSNH4),
electric power costs (EP4CST) for 132 watts of power per ton of ammonia produced, steam costs (STM4CST) for two tons of steam per ton of product, cooling water costs (CW4CST) for 170,000 gallons of water per ton of product, fuel costs (FUEL4) for 40 million Btu per ton of product, and maintenance and miscellaneous expenses (AMM4) equal to 2.6 percent of installed equipment costs. The total cost of operating the ammonia plant (about $200 per ton in the base case) is redistributed entirely to the leaching plant operating cost statement.

**Gas-Recovery Plant**

The gas-recovery plant provides partial recovery of ammonia gases by steam stripping of the leach plant tailings in vertical sieve tray columns. A capital cost (CCGAS) of $1,827,000 in 1976 U.S. dollars is fixed into the model (line 2500). The size of the gas-recovery plant, however, is tied directly to the total annual ammonia production rate.

Four salaried supervisors and eight plant operators are included in the labor costs (ALSGAS). Other operating costs are for steam (STMGCST), at a rate of 37.8 tons per ton of ammonia produced, and maintenance and miscellaneous costs (AMMGAS).
Ore Preparation and Handling

The 1978 Burundi metallurgical study provided an engineering design for an ore preparation and handling plant that would process 311.5 dry tons of ore per hour. The design criteria set forth in the study provided for grinding and drying of the ore from 40 to three percent moisture, at 350°F, in a rotary kiln. The maximum drying kiln ore feed rate was established at 173 wet tons per hour with dryer dust carry-over set at ten percent (wt). The dryer discharge product is crushed in a hammermill at a design feed rate of 280.4 dry tons per hour, and then finely ground to minus 65 mesh (Tyler) in a closed circuit dry ball mill having a work index of 6.1 kilowatt-hours per ton.

An equipment list was formulated for the ore preparation section and all subsequent processing sections, and costs were assigned to each item. This equipment list for the ore preparation section is included in Appendix III. The total installed cost for the ore preparation and drying equipment is $25,837,000 in 1978 dollars. The equipment list indirectly assumes that the energy source will be fuel oil. If coal or peat fuel is utilized, a fuel surge bin and fuel screw feeder will be required for each drying train, thus raising the cost to $25,969,000.
The program (after having determined the ore throughput, number of drying trains required, and size of each train), calculates the cost of equipment, materials, and installation labor for one drying train (DYCST). This drying train consists of a drying kiln, feed hopper, dryer pan feeder, combustion air blower, dryer discharge conveyor, cyclone, baghouse, and an off-gas fan. Equipment and material costs for each dryer train are $1,549,000 with solid fuel handling equipment. Total installed costs, including labor, are $1,847,000 with, and $1,880,000 without the solid fuel handling capability. These calculations can be found on lines 2610 and 2630 of the program. The size exponent required for cost adjustment with ore throughput variation is 0.68\(^9\).

The total installed equipment cost for the ore preparation and handling section (CCOREP, line 2640) includes, in addition to the cost of the ore dryer trains, the cost of equipment common to the dryers such as crushers, grinding mills, conveyors, baghouses, bucket elevators, front-end loaders, ore reclaimers, and ore-storage silos. This equipment adds $14,835,000 plus $3,614,000 for field labor to the cost of the dryer trains (line 2630) when deriving the total direct capital cost for the ore preparation and drying section.
The electric power requirement equation (EPWRO, line 2660) assumes a straight-line relationship between the kilowatts required and the ore throughput. Each dryer train will utilize 6.92 kw per ton of dryer output.

Fuel costs for ore preparation and drying (FUELO) are affected by dividing the total heat requirement for ore drying (BTUD) by the net heating value of the selected fuel source. Fuel costs are input variables, however, costs for coal or peat fuel preparation are added to the purchase costs and distributed to those plants requiring fuel.

The basis for ore preparation and drying plant labor costs are estimated from an analysis of the number of personnel required for a three-shift, continuing operation of the plant. This analysis, conducted by Singmaster and Breyer (6) in a feasibility study and cost evaluation of a similar commercial-size plant, includes operating labor and plant supervision. In the analysis, job positions were identified and total manning requirements for continuous operations were computed as 1.6 times the 40-hours-per week-shift manpower requirement.

Singmaster and Breyer calculate that 25 jobs (or 40 people, U.S.) would be required to operate an ore-drying plant sized to process 208.3 dry tons of ore per hour.
This then becomes the basis for the labor cost calculation in the drying plant. Because manning requirements do not vary linearly with plant size, the assumption is made that they do vary according to a power factor of 0.25\(^{(13)}\).

The line statement number for manpower requirements for the ore preparation and drying plant (APEP) is 2780.

Statements are included to round the calculated real number upward to an integer. The total number of people determined is then multiplied by the variable wage rate and the relative productivity, and the relative labor factors, to compute the cost of labor for ore preparation. Five people are added to the statement in addition to allow for technical control and administration. This then becomes the total cost for ore preparation and drying labor and supervision (ALABRO) (LINE 2840).

Materials for maintenance and miscellaneous (AMMO) are calculated at 4.7 percent of installed equipment costs as are maintenance labor costs, however, the labor costs are adjusted by the relative labor rate and relative productivity factors.

Consumables (CONCO) are calculated according to the following schedule:

<table>
<thead>
<tr>
<th>Consumable</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grinding Balls</td>
<td>0.09 lb/ton feed</td>
</tr>
<tr>
<td>Ball Mill Liners</td>
<td>0.009 lb/ton feed</td>
</tr>
</tbody>
</table>
Crusher Liners 0.018 lb/ton feed
Conveyor Replacement $0.018/ton feed

Using this schedule amounts to about $0.117/ton of ore throughput on a 1978 cost basis.

Ore Roasting and Off-Gas Treatment

The Burundi report contains a list of equipment and purchase costs for a reductive roasting plant having throughput capacity of 311.4 tons of dried ore per hour. It is assumed that the largest individual multiple-hearth roaster has a capacity of 38.9 dry tons of ore per hour.

Costs for a hearth roaster, a solid-fuel gasifier, ore and fuel handling equipment, as well as for off-gas treatment equipment are assembled for a single-roaster equipment train. The total equipment required for the ore-roasting and off-gas treatment plant is simply a multiple of that required for a single-hearth roaster train, plus chemical reagent storage facilities. Although a power factor of 0.6 is commonly used as a rule of thumb for adjusting equipment costs relative to size variations, a factor of 0.85 was selected from Guthrie\(^{(9)}\) for process furnaces.

After determining the total FOB equipment prices for the ore-roasting section, a Guthrie factor of 1.62 was applied to arrive at the total direct installed cost, less
the freight and insurance. The expenses required for the installation of process furnace equipment are broken down into equipment plus material costs, and erection labor costs. The ratio of labor to materials is 0.21. Guthrie field installation factors for material and labor, for process furnaces, are presented in Table 3.

<table>
<thead>
<tr>
<th>TABLE 3-INSTALLATION FACTORS FOR PROCESS FURNACES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furnace equipment cost, E</td>
</tr>
<tr>
<td>Piping</td>
</tr>
<tr>
<td>Concrete</td>
</tr>
<tr>
<td>Steel</td>
</tr>
<tr>
<td>Instruments</td>
</tr>
<tr>
<td>Electrical work</td>
</tr>
<tr>
<td>Paint</td>
</tr>
<tr>
<td>Field materials, m</td>
</tr>
<tr>
<td>Direct materials, E+m = M</td>
</tr>
<tr>
<td>Material erection (labor), L</td>
</tr>
<tr>
<td>Direct M and L cost</td>
</tr>
<tr>
<td>L/M ratio</td>
</tr>
<tr>
<td>Size exponent</td>
</tr>
</tbody>
</table>
Chemical reagent storage facilities, consisting of horizontal pressure storage vessels, require a factor of 1.20 for total installed costs. The ratio of labor to materials, including equipment, is 0.36\(^{(9)}\).

The equipment list for the multiple-hearth roasting and off-gas treatment plant is presented in Appendix III. Equipment in the list costs $34,061,000 to purchase and install, and uses peat fuel (or coal). If fuel oil were used, the solid fuel handling and gasification equipment would be eliminated, thus lowering installed cost to $24,245,000.

The sizing and costing of the roasting plant is performed in a manner similar to that for ore drying. The total installed cost for the roasting plant (CCRST) is simply a multiple of the individual-hearth roaster train cost (RSTCST), plus $964,000 (1979 dollars) for compressors and additive storage facilities.

Operating costs for the roasting and off-gas treatment plant contain amounts for electric power (EPRCST), fuel (FUELR), labor and supervision (ALABRR), process chemicals (CHEMR), maintenance labor and materials (AMAINR), and consumables (CONSR). The power requirement is 9.59 kw per ton of dry ore feed when using solid fuel handling and gasification, or 5.73 kw per ton when using liquid fuel,
plus six kw for chemical-additive pumping. The operating power requirement is calculated as 80 percent of the connected power obtained from the equipment list.

Fuel costs (FUELR) are determined as a function of the total roasting plant Btu requirement, the fuel source selected, the net heating value of the fuel, and the expenses involved with purchasing and preparing the fuel for combustion or gasification.

Labor and supervision requirements are modeled from Singmaster and Breyer\(^{(6)}\) with the assumption that 40 people would be required to operate a roasting plant having a production capacity of 175 dry tons per hour, however, an additional 18 people would be needed if fuel gasification is required for operation.

**Leaching and Washing Plant**

The equipment list for the leaching and washing plant is contained in Appendix III. The method used to derive the total installed cost for the leaching and washing plant was again that of Guthrie\(^{(9)}\). The FOB prices of the equipment listed above totaled $9,349,100 (1978) and were obtained from UOP, Inc. in-house cost files. After using a power factor of 0.65 to adjust equipment prices relative to equipment sizes, the purchase price was factored
by \(2.20^{(9)}\) to arrive at the total installed cost of $20,568,000. The installed direct cost includes materials and labor for piping, concrete work, instrumentation, electrical work, insulation, painting, material erection, and equipment setting. The labor to material ratio from Guthrie was 0.35. The model, according to Guthrie, is presented in Table 4.

<table>
<thead>
<tr>
<th>Equipment FOB cost, E</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piping</td>
<td>39.70</td>
</tr>
<tr>
<td>Concrete</td>
<td>6.00</td>
</tr>
<tr>
<td>Steel</td>
<td>-----</td>
</tr>
<tr>
<td>Instruments</td>
<td>6.00</td>
</tr>
<tr>
<td>Electrical work</td>
<td>5.00</td>
</tr>
<tr>
<td>Insulation</td>
<td>5.00</td>
</tr>
<tr>
<td>Paint</td>
<td>0.50</td>
</tr>
<tr>
<td>Field materials, m</td>
<td>62.20</td>
</tr>
<tr>
<td>Direct materials, E + m + M</td>
<td>162.20</td>
</tr>
<tr>
<td>Material erection</td>
<td>50.40</td>
</tr>
<tr>
<td>Equipment setting</td>
<td>7.70</td>
</tr>
<tr>
<td>Direct Field Labor, L</td>
<td>58.10</td>
</tr>
<tr>
<td>Direct M &amp; L cost</td>
<td>220.30</td>
</tr>
<tr>
<td>L/M ratio</td>
<td>0.35</td>
</tr>
</tbody>
</table>
Guthrie also includes factors for freight, insurance and taxes, which together with the direct field labor cost, comprise Guthrie's bare-module cost. In this program, however, indirect costs are tallied after all of the installed direct costs of the plant are calculated and summed.

The electric power requirement for the operating cost statement is calculated to be 17 kw per ton of calcine feed to leaching. Manning requirements, from Singmaster and Breyer, are for 37 people to operate a 265-ton-per-hour leaching plant. Costs for maintenance and miscellaneous expenses are eight percent of the total installed costs. One-half of those costs are adjusted for labor by the relative labor rate and the relative productivity factors. Consumable materials include grinding balls (1.08 lb/ton feed) and ball mill liners (0.1 lb/ton feed) at a cost of $0.59 per ton of roaster calcine feed. This 1978 cost is adjusted for time by the C.E. Index.

Cooling and process water requirements and costs, calculated earlier, are added as well as ammonia and ammonia gas recovery costs, to finally arrive at the total operating cost for the leach/wash plant.

**Solvent-Extraction Plant**

The solvent-extraction plant was divided earlier into
four integrated circuits for (1) nickel-copper extraction, (2) nickel stripping, (3) copper stripping, and (4) cobalt extraction and stripping. The total installed, direct equipment cost for each section is determined by multiplying the equipment price (less delivery) by a factor of 2.5. This factor assumes a labor to materials ratio of 0.41; the size exponent used for scaling is 0.67\(^9\).

**TABLE 5—DIRECT COSTS FOR SOLVENT-EXTRACTION PLANT**

<table>
<thead>
<tr>
<th></th>
<th>Nickel-Copper Extraction</th>
<th>Nickel Stripping</th>
<th>Copper Stripping</th>
<th>Cobalt Extraction &amp; Stripping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchased Equipment</td>
<td>541</td>
<td>1253</td>
<td>978</td>
<td>547</td>
</tr>
<tr>
<td>Field Materials</td>
<td>418</td>
<td>968</td>
<td>756</td>
<td>970</td>
</tr>
<tr>
<td>Installation Labor</td>
<td>393</td>
<td>911</td>
<td>711</td>
<td>398</td>
</tr>
<tr>
<td>Total Direct Cost</td>
<td>1353</td>
<td>3132</td>
<td>2444</td>
<td>1367</td>
</tr>
<tr>
<td>Program Line Number</td>
<td>3520</td>
<td>3530</td>
<td>3540</td>
<td>3550</td>
</tr>
</tbody>
</table>

Table 5 lists the costs for purchased equipment, field materials, installation labor, and the total direct cost for each of the four solvent-extraction circuits. Program
line numbers are also included to provide the user with easy access to the programming.

Operating expenses for labor, supervision, and power are calculated for each of the four circuits. Manning requirements for the solvent-extraction plant are based on: twelve people for a 43,061-ton-per-year nickel and copper extraction circuit (PENCX, line 3660); eight people for a 33,973-ton-per-year nickel stripping circuit (PEPNS, line 3670); eight people for a 9989-ton-per-year copper stripping circuit (PECUS, line 3680); and twelve people for a 1480-ton-per-year cobalt extraction and stripping circuit (PECOS, line 3690). A power factor of 0.25 is used to adjust the manning requirements relative to plant size variations.

Maintenance materials and maintenance labor are estimated at three percent of the total installed equipment cost. The labor cost is subject to adjustment by the relative labor rate and relative productivity factors (ALABFAC).

Miscellaneous expenses are .05 percent of the total installed-equipment cost. Finally, expenses for solvent losses (CHEMX) are calculated at $8.94 per ton of product metal and escalated for inflation by the C.E. Index.

Total operating costs for the solvent-extraction
plant then include those for electric power, manpower, maintenance materials and labor, miscellaneous expenses, and solvent losses.

**Electrowinning**

Nickel, copper, and cobalt are electrowon from pregnant electrolytes, (supplied by the solvent-extraction circuit) in a tank house of conventional design. The pregnant electrolytes are free of any additives or buffering agents and they contain 75.0 grams-per-liter nickel, 45.0 grams-per-liter copper, and 47.0 grams-per-liter cobalt in their respective solutions. Metal cathode starting sheets are either pure nickel, plated in-house on stainless steel blanks; pure copper, plated on titanium blanks; or pure cobalt, plated on stainless steel blanks.

The design basis assumes there are 188 nickel, 53 copper, and 12 cobalt product electrolytic cells in addition to 32 nickel, 9 copper, and 2 cobalt starter cells. Electrolyte holding tanks, pumps, electrolyte heaters, and cathode handling equipment complete the equipment list for the electrowinning plant.

Nickel starter and product cells measure 3.2 feet wide by 24.1 feet long by 3.4 feet high, and have a volume of about 1961 gallons. There are 42 cathodes, 43 calcium-
lead anodes, and 42 diaphragms in each nickel electrowinning cell. All cells have a voltage of 3.4, with a current density of 20 amps per square foot, and a current efficiency of 95 percent (except for copper which has only 93 percent).

Copper starter and product cells, measuring 3.2 feet wide by 15.8 feet long by 3.9 feet high, have a total volume of 1475 gallons; 42 cathodes and 43 calcium-lead anodes are present in each copper cell.

Cobalt cells, measuring 3.2 feet high by 27.6 feet long by 3.9 feet wide, have a total volume of 2577 gallons, and contain 47 calcium-lead anodes in each cell.

Presented in Appendix III is the equipment list required for the electrowinning plant upon which the program equipment costs are based. Electrowinning cell costs are based on a 2000-gallon cell price at $10,000 in 1977. The installation factor utilized is 2.5; the labor to materials ratio is 0.40 because of the abnormally high amount of field work involved in setting cells, placing electrodes, connecting bus bars and piping. The nickel, copper, and cobalt, cell direct cost is $25,000, $20,500, and $30,275, respectively. The higher cost of the cobalt cells is due to their larger volume. Total cell cost is derived by tallying the number of electrowinning cells by product type, multiplying this number by the respective installed
cost, and then adding.

In addition to cell cost, $10,777,000 is included for common equipment, such as pumps, tanks, heat exchangers and retifiers. A power factor of 0.7 is used to adjust costs relative to plant metal output fluctuations.

Equations used to effect the capital cost of the electrowinning plant are located on lines 4010 through 4020 of the program listing, found in Appendix II.

Total annual operating costs for the electrowinning plant include: labor and supervision, based on the requirement of 30 people for a 19,440 TPY metal output; maintenance material costs of 4.4 percent of the electrowinning plant total installed equipment charges, another 4.4 percent for maintenance labor; and miscellaneous expenses equal to 0.5 percent of the installed equipment costs. Steam and electric power (EPWEW) costs are also included. Electric power costs are based on the use of 60.7, 60.4, and 67.7 kw per cell for each nickel, copper, and cobalt cell, respectively, plus the use of 323 kw for cathode handling equipment.

The total operating power required is assumed to be 90 percent of the total connected kilowatts that appear on the equipment list.
General Office

Capital and operating cost statements for utility, process chemical, and metallurgical extraction plants were calculated by the program. The capital costs compiled thus far are simply total installed equipment costs (including buildings) less freight and insurance charges. Plant managerial costs are included in the general office costs which have been tabulated and added to the annual operating cost and capital cost statements.

The assumption is made that one plant superintendent, one assistant plant superintendent, and four shift superintendents, as well as six secretaries and typists, will be required regardless of plant size, therefore, the annual salary costs of $279,000 and the miscellaneous costs of $44,000 per year vary only with respect to the change in the C.E.Index. Miscellaneous expenses include costs of vehicles, communications, expense accounts, maintenance, and gifts, donations, etc. The electrical power requirement for the general office is 24 kw, (line 4260 on the program listing).

Capital costs for the general office grounds (including buildings, access road, civil, and fences) total $4,465,000. In the program, this value is adjusted by the C.E. Index only.
Miscellaneous Auxiliary Plants

Miscellaneous auxiliary plant facilities for sewage treatment, tailings disposal, compressed air, fuel and reagent storage, fire protection, and technical services have been included. The sewage treatment facilities will provide for aeration, sludge settling, clarification, and effluent chlorination.

The conceptual metallurgical process plant produces 2,095,000 dry short tons per year of leached, washed, and steam-stripped tailings (in a 50-percent water slurry) which are pumped from a common sump to the tailings pond. The pond is earthen and lined only with clays which are assumed available on the site.

The air compressor facility will provide for plant and instrument air at a capacity of 1295 cubic feet per minute at a pressure of 115 pounds per square inch.

The technical services department includes plant engineers, chemists, draftpersons, technicians and other support personnel, as well as buildings, laboratories and analytical equipment.

Capital and annual operating costs for the miscellaneous auxiliary plants are effected by grouping the plants together and then determining total costs.

Program capital fixed data considers a cost of
$21,500,000 (line 4390) to build these auxiliary facili-
ties for a plant designed for an ore throughput of 311
dry tons per hour. The power factor used to adjust the
dollar value, because of ore throughput changes in the
program input statement, is 0.7

The annual operating costs for the miscellaneous
auxiliary plants are comprised of labor, supervision,
power, and maintenance costs. The total number of people
required is held constant at 17, regardless of plant size,
however, the total labor cost is adjusted for inflation
by the C.E. Index.

Electric power requirements of 664 kw for a 311-ton-
per-hour plant are adjusted linearly with the plant through-
put.

Maintenance and miscellaneous expenses were estimated
to be $134,000 per year (in line 4360) and are adjusted
in the program by the C.E. Index.

**Estimation of Total Capital Investment**

The total capital investment is calculated and printed
on page two of the computer print out (Appendix I). Direct
costs of process equipment, installation materials and labor,
buildings, and yard improvements are tallied from each of
the ore processing, utility, process chemical, and
miscellaneous auxiliary plants. Costs which are not directly involved with equipment installation, materials, or labor are factored from the direct costs according to the schedule presented in Table 6. Transportation charges and construction expenses are extremely high because of the remote locations of most of the world's nickel laterite deposits.

After direct and indirect costs are tabulated, the fixed capital investment can be stated, from which a contingency fee of 20 percent is calculated. The contingency fee is included, not to cover careless engineering cost estimating, but to compensate for unpredictable events and unforeseen expenses which are likely to occur since a factored estimate cannot allow for 100 percent of the total fixed capital investment.

<table>
<thead>
<tr>
<th>Indirect Cost</th>
<th>Percent of Direct Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spare Parts</td>
<td>3.2</td>
</tr>
<tr>
<td>Transportation (Overseas)</td>
<td>24.0</td>
</tr>
<tr>
<td>Engineering and Supervision</td>
<td>18.7</td>
</tr>
<tr>
<td>Construction Expenses</td>
<td>24.5</td>
</tr>
</tbody>
</table>

Contractor's fees are calculated at three percent of
the fixed capital investment, plus contingency. The working capital requirement is, therefore, finally computed as 17.5 percent of the direct cost, and added to the above fees and costs to arrive at the total capital investment.

Direct operating costs and total annual power requirements are tallied and are also presented on page 2 of the output, (Appendix I).

**Accuracy of the Estimate**

The capital and operating costs for the original Burundi Plant were calculated by UOPEC and the estimated capital investment required for the plant was 5.8 percent higher when calculated by the program. The estimated annual operating cost was 13.1 percent higher, however, it was believed that more reliable labor figures were known and built into UOPEC than were available for the original study. Additionally, UOPEC was compared to an earlier study performed by the R. M. Parson's Company on a similar project. The estimated capital costs agreed within ten percent.

Figure 3 illustrates a log-log plot of plant equipment capacity versus total capital cost as calculated by UOPEC. Capital costs were calculated for the base case (x) and for six plant sizes ranging from 0.1x to 3x. The slope of the line is approximately 0.72
FIGURE 2—PLANT SIZING EXPONENT

ANNUAL PLANT FEED
(MILLIONS OF TONS)

CAPITAL COSTS (MILLIONS OF DOLLARS)
ECONOMIC EVALUATION OF THE INVESTMENT OPPORTUNITY

Introduction

Some measure of project profitability must be objectively examined so that management can compare the investment opportunity either with alternative projects or with other profit-yielding fields of activity. The concept of opportunity cost, according to Rudawsky (14) follows:

"...the advantage forgone due to alternative use of investment funds - must be considered as an integral part of the economic evaluations."

For this purpose, an economic evaluation is undertaken which measures annual cash flows subsequent to net present value (NPV) and discounted cash flow rate of return (DCFROR) analyses.

"...Net value analysis is based on formally looking at the difference between revenues and costs on an equivalent basis...with time value of money calculations made at the minimum rate of return..." Stermole, page 86 (15)

DCFROR analysis calculates the rate of return that makes the present value of the cash flows equal to the present worth of the investments. The DCFROR and NPV calculations are based on after-tax costs, however, before-tax analyses are possible by eliminating the income tax rate in the program input statement. However, in order to
have valid economic analyses, income tax considerations (that can vary widely among investment alternatives) must be included because they are project costs as are labor and materials costs. Therefore, DCFROR and NPV calculations based on a before-tax method must be analysed with caution.

Grade and tonnage calculations for ore bodies are based upon the analyses of a small fraction of the entire ore body. These calculations are generally quite different from the true average grade. The difference depends on the variability of the deposit and the sampling procedure. This difference constitutes one aspect of uncertainty in the investment analyses. Other uncertainties are those of future events. It is important to incorporate the uncertainty dimension into the expected profitability analyses of the investment; sensitivity analysis is the method used by the program. Although sensitivity analysis cannot measure the uncertainty of the investment, since there is no estimate of the probability that a change will really occur, it is used to identify the critical variables that can considerably change the profitability of the project. Probability analyses are beyond the scope of the program, however.

An analyses of the risk is attempted by assuming that at some cost of capital, the profitability of the project is considered a random variable (P), with a mean profit-
ability and a standard deviation. The standard deviation of profitability is often referred to as a measure of risk, however, a combination of the mean and the standard deviation provides a better measure of risk. A combination commonly used is the ratio of the standard deviation to the mean profitability of the project, referred to as the coefficient of variation in profitability (16).

Net Present Value and Discounted Cash Flow Rate of Return Analyses

Net present value (NPV) analysis has been included, not only for comparative analyses of investment alternatives, but also for the sensitivity analysis, as the effect of a change in a cost variable is measured by the change in the net present value of the project. The program has been used for foreign client studies and the NPV analysis has been the preferred method.

To formulate the cash flows, the total annual revenue ($KREV$) is calculated as a function of the input variables of metal content, the recoveries, and the metal selling prices. Net annual revenues ($NREV$) are derived by deducting the previously tabulated annual operating costs plus the cost of mined ore, an input variable. Depreciation is taken, as the total capital investment less working capital, on a straight-line basis, for fifteen years. Depletion is
not considered, as this allowance will be reflected in the cost of ore to the metallurgical facility. Income taxes are input variables and can be effectively deleted (for foreign consideration).

In an effort to model a real world situation, four annual cash flows are developed with the assumption that 50 percent of the total capacity for revenue will be realized after one year of plant operation, 80 percent realized after two years, and 100 percent from the end of the third year until the end of the project life. During the first three years, however, the full cost of plant operation will be borne because all manpower and most utilities will be required. Productivity at this point is low because experience or learning factors are developing. The annual cash flow is presented in Table 7.

Investment tax credits do not appear in the applicable years, nor are losses carried forward, because of the international usage the program receives.

The calculation of the NPV and the DCFROR requires that some assumptions be made concerning the time at which capital expenditures are made. It is assumed, therefore, that 60 percent of the capital expenditures are made two years prior to plant start-up, or time zero.
TABLE 7-ANNUAL CASH FLOW MODEL

<table>
<thead>
<tr>
<th></th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3-15</th>
<th>Year 16+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales Revenue</td>
<td>500</td>
<td>800</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>(Operating Cost)</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>(Cost of Ore)</td>
<td>50</td>
<td>80</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Gross Profit</td>
<td>(50)</td>
<td>220</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>(Depreciation)</td>
<td>80</td>
<td>80</td>
<td>100</td>
<td>00</td>
</tr>
<tr>
<td>Taxable Income</td>
<td>00</td>
<td>140</td>
<td>320</td>
<td>400</td>
</tr>
<tr>
<td>Tax</td>
<td>00</td>
<td>70</td>
<td>160</td>
<td>200</td>
</tr>
<tr>
<td>Net Profit</td>
<td>(50)</td>
<td>70</td>
<td>160</td>
<td>200</td>
</tr>
<tr>
<td>+Depreciation</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>00</td>
</tr>
<tr>
<td>Annual Cash Flow</td>
<td>30</td>
<td>150</td>
<td>240</td>
<td>200</td>
</tr>
</tbody>
</table>

The time diagram, according to Stermole (15), is presented in Figure 3.

FIGURE 3-TIME DIAGRAM

![Time Diagram](image)

where C = capital expenditures

CF = cash flow

L = salvage value

WC = working capital

n = last year of project life
The net present value is calculated from the following equation. (The project life equals 20 years).

\[
\text{NPV} = -0.6C - 0.3C(P/F_{i,1}) - 0.1C(P/F_{i,2}) + CF1(P/F_{i,3}) + \\
CF2(P/F_{i,4}) + CF3(P/A_{i,12})(P/F_{i,5}) + CF4(P/A_{i,4}) \\
(P/F_{i,18}) + WC(P/F_{i,22})
\]

where: \( WC \) = working capital

\( i \) = minimum acceptable rate of return

\( P/F \) = Single Payment Present-Worth Factor

\[
\text{Present Value} = \text{(Future Value)} \left(\frac{1}{(1+i)^n}\right)
\]

\( P/A \) = Uniform Series Present-Worth Factor

\[
\text{Present Value} = \text{(Annual Value)} \left(\frac{(1+i)^n - 1}{i(1+i)^n}\right)
\]

The DCFROR is calculated by trial and error from a present-worth equation. The interest rate that makes the present worth of capital expenditures equal to the present worth of the cash flows, plus returned working capital, becomes the discounted cash flow rate of return.

**Sensitivity Analysis**

UOPEC's economic evaluation program uses the sensitivity analysis to determine what the impact variations in the input data elements will have on the project profitability. Although the sensitivity analysis cannot estimate the probability of variations in the profitability, it can
estimate a variety of outcomes under pre-established conditions which allow for the identification of the strategic elements in the economic model.

The sensitivity analysis program output statement (Appendix I) shows the change in project profitability as the input variables are changed independently of one another, thus displaying the strategic variables. Once identified, these variables can be subjected to better definition thereby eliminating the waste of time and money in attempting to more closely define the variables that have little impact on project profitability. In this manner, sensitivity analyses can provide a mechanism for reducing the risk of the metallurgical project by focusing attention on the strategic variables.

**Metal Selling Price Sensitivity Analysis**

The market selling prices of nickel, copper, and cobalt metals are beyond the control of the project manager, therefore, obtaining a better definition of the input variable is somewhat difficult. A sensitivity analysis of market prices can, however, prove valuable, particularly when the market is somewhat volatile and unpredictable.

Four metal price sensitivity analyses are performed in UOPEC. The first analysis considers the impact of fluctuations in all metal prices by increasing or decreasing
the total revenues by +10, +20, and +30 percent. Prices for nickel, copper, and cobalt metals do not necessarily exhibit either a positive or negative correlation, therefore, the analysis is performed for each metal in a manner identical to that for the total revenues.

**Operating Cost Sensitivity Analysis**

Operating cost sensitivity analysis can be very useful in determining if perhaps a more extensive materials and/or energy balance is justified. The program for operating cost sensitivity analysis adjusts the annual operating and mining costs by +10, +20, and +30 percent.

**Capital Cost Sensitivity Analysis**

UOPEC also performs sensitivity analysis on the cost of the capital investment by adjusting the total capital investment value by +20 and +40 percent.

**Metal Recovery Sensitivity Analysis**

Nickel and cobalt metal recoveries are adjusted from +2 to +10 percent in increments of two percent. Operation of the reductive ore roasting and ammoniacal leaching equipment can have a noticeable effect on the recovery of nickel and cobalt metals. Sensitivity analysis can help to determine if expenditures for roaster-additive equipment and chemicals (which are known to enhance the extraction of nickel and cobalt metals) is warranted.
Nickel and Cobalt Grade Sensitivity Analysis

Nickel and cobalt ore grade estimates may be better defined by additional expenditures on drilling, sampling, and ore reserve calculations. A sensitivity analysis of these variables by $\pm 10$ and $\pm 20$ percent can indicate whether or not additional geological work is required.

Fuel Oil Cost Sensitivity Analysis

Increases in the price of fuel oils have been dramatic in recent years; therefore, the sensitivity analysis considers cost increases of 20, 40, 60, and 80 percent of the input fuel oil price. Because of the program's ability to evaluate alternate fuel sources of coal or peat fuel, a direct comparison of fuels and their effects on the expected project profitability can be made.

Productivity Sensitivity Analysis

Mechanical, metallurgical, and/or labor problems can, and most probably will, alter the extraction plant's productivity. To observe the effects of such problems, the sensitivity analysis determines expected profitability if the productivity drops by 10, 20, and 30 percent of the design metal output.

Discount Rate Sensitivity Analysis

The discount rate may be altered because of changes in the cost of capital and in the risk premium (an important
variable when borrowing money). To observe this effect, the sensitivity analysis alters the discount rate by ± 3 and ± 6 percent of the minimum acceptable rate of return (an input variable). After performing and evaluating the sensitivity analysis, the redefined data (once available), can be re-evaluated by repeating the sensitivity analysis process. This use of the sensitivity analysis provides an important mechanism for reducing the risk inherent in any mining or metallurgical project.

Project Profitability

The changes in the expected project profitability, determined by the sensitivity analysis, are used to measure risk. Each new profitability value is summed, and a mean and a standard deviation calculated which reflect the probability that the project profitability may be something other than that expected. The standard deviation alone cannot successfully measure risk because, for example, project A with a higher standard deviation than project B may be less risky if the mean value is substantially higher than that for project B. Therefore, the ratio of the standard deviation to the mean (the coefficient of variation) is calculated as a better measure of the risk.
**Inflation**

The economic evaluation performed by UOPEC assumes that the inflation of costs is exactly offset by the inflation of revenues. World economic conditions in the late 1970's has shown that this washout does not occur for most projects. Therefore, investment analysis using today's dollar values is not permissible. The effects of inflation on costs and revenues must be considered by using current dollar analysis.
LITERATURE CITED

(1) Richardson, J. M., Stevens, L. G., Kuhn, M. C., "The Recovery of Metal Values from Nickel-Bearing Laterite Ores by Reductive Roast/Ammonia Leach Technology": presented at the American Chemical Society, Los Angeles, California, September, 1977.


(4) O'Kane, P. T., "Development of the Surigao Nickel Project": Philippine Mining Record, September, 1972.


APPENDIX I

COMPUTER OUTPUT REPORT
### CASE A METALLURGICAL PROJECT

**PLANT CAPACITY**

<table>
<thead>
<tr>
<th></th>
<th>STHP</th>
<th>MTPH</th>
<th>STPY</th>
<th>MTPY</th>
</tr>
</thead>
<tbody>
<tr>
<td>36675 TONS PER YEAR OF CATHODE NICKEL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PLANT THROUGHPUT (DRY)**

|         | 315.7 | 286.3 | 2500000 | 2268000 |

**ORE COMPOSITION, %**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NICKEL</td>
<td>1.63</td>
</tr>
<tr>
<td>COBALT</td>
<td>0.18</td>
</tr>
<tr>
<td>COPPER</td>
<td>0.51</td>
</tr>
<tr>
<td>IRON</td>
<td>44.90</td>
</tr>
<tr>
<td>SiO2</td>
<td>7.90</td>
</tr>
<tr>
<td>Al2O3</td>
<td>3.52</td>
</tr>
<tr>
<td>MgO</td>
<td>0.56</td>
</tr>
<tr>
<td>CaO</td>
<td>0.03</td>
</tr>
</tbody>
</table>

**MOISTURE CONTENT**

|       | 39. % |

<table>
<thead>
<tr>
<th></th>
<th>36675</th>
<th>33264</th>
</tr>
</thead>
<tbody>
<tr>
<td>NICKEL PRODUCED AT 90. % RECOVERY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COBALT PRODUCED AT 60. % RECOVERY</td>
<td>2700</td>
<td>2448</td>
</tr>
<tr>
<td>COPPER PRODUCED AT 90. % RECOVERY</td>
<td>11475</td>
<td>10407</td>
</tr>
</tbody>
</table>
### SUMMARY OF CAPITAL COSTS

<table>
<thead>
<tr>
<th>Category</th>
<th>US $(000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore Preparation and Handling</td>
<td>27086</td>
</tr>
<tr>
<td>Roasting and Off-Gas</td>
<td>26212</td>
</tr>
<tr>
<td>Leaching and Washing</td>
<td>20299</td>
</tr>
<tr>
<td>Solvent Extraction</td>
<td>9103</td>
</tr>
<tr>
<td>Electrowinning</td>
<td>19980</td>
</tr>
<tr>
<td>Auxiliaries, Ancillaries and Support Facilities</td>
<td>47860</td>
</tr>
<tr>
<td><strong>Total Direct Costs</strong></td>
<td><strong>150540</strong></td>
</tr>
<tr>
<td>Spare Parts</td>
<td>4817</td>
</tr>
<tr>
<td>Transportation</td>
<td>36129</td>
</tr>
<tr>
<td>Engineering and Design</td>
<td>28150</td>
</tr>
<tr>
<td>Construction Expenses</td>
<td>36882</td>
</tr>
<tr>
<td><strong>Total Direct and Indirect Costs</strong></td>
<td><strong>256518</strong></td>
</tr>
<tr>
<td>Contingency (at 20% of direct and indirect)</td>
<td>51304</td>
</tr>
<tr>
<td>Contractors Fee (at 3% of project cost)</td>
<td>9234</td>
</tr>
<tr>
<td>Working Capital</td>
<td>26344</td>
</tr>
<tr>
<td><strong>Total Capital Investment</strong></td>
<td><strong>343400</strong></td>
</tr>
</tbody>
</table>

### SUMMARY OF DIRECT OPERATING COSTS

<table>
<thead>
<tr>
<th>Category</th>
<th>US $(000) PER YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore Preparation and Handling</td>
<td>33482</td>
</tr>
<tr>
<td>Roasting and Off-Gas</td>
<td>31859</td>
</tr>
<tr>
<td>Leaching and Washing</td>
<td>13173</td>
</tr>
<tr>
<td>Solvent Extraction</td>
<td>1737</td>
</tr>
<tr>
<td>Electrowinning</td>
<td>11441</td>
</tr>
<tr>
<td>Auxiliaries, Ancillaries and Support Facilities</td>
<td>1203</td>
</tr>
<tr>
<td><strong>Total Annual Operating Cost</strong></td>
<td><strong>92975</strong></td>
</tr>
<tr>
<td><strong>Total Power Requirement, KWH</strong></td>
<td><strong>36488</strong></td>
</tr>
</tbody>
</table>
### Area 20 Ore Preparation and Handling

#### Throughput

<table>
<thead>
<tr>
<th>Description</th>
<th>Dry</th>
<th>Wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput</td>
<td>316.0 STPH</td>
<td>286.6 MTPH</td>
</tr>
<tr>
<td></td>
<td>518.0 STPH</td>
<td>469.9 MTPH</td>
</tr>
</tbody>
</table>

** Crushed Ore Stockpile:** 248,700 wet tons (225,600 wet tonnes)

#### Drying

<table>
<thead>
<tr>
<th>Type</th>
<th>Rotary Kiln</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Dryers</td>
<td>4</td>
</tr>
<tr>
<td>Dryer Feed Rate</td>
<td>172.5 STPH</td>
</tr>
<tr>
<td>Feed Moisture</td>
<td>39.9 %</td>
</tr>
<tr>
<td>Product Moisture</td>
<td>3 %</td>
</tr>
<tr>
<td>Drying Temperature</td>
<td>350 deg F</td>
</tr>
<tr>
<td>Dryer Dust Carryover</td>
<td>10 %</td>
</tr>
</tbody>
</table>

- **Capital Cost:** $2,708,600
- **Power Requirement:** 7,074 kwh
- **Fuel:** $252,100
- **Labor & Supervision:** $514
- **Maintenance:** $16,060
- **Consumables & Misc:** $293
- **Process Chemicals:** $0

**Total Operating Cost:** $3,348,200
### Roasting

<table>
<thead>
<tr>
<th>Type</th>
<th>Multiple Hearth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Roasters</td>
<td>9</td>
</tr>
<tr>
<td>Roaster Feed Rate</td>
<td>35.1 STPH PER ROASTER (31.8 MTPH)</td>
</tr>
<tr>
<td>Ore Inlet Temperature</td>
<td>150° F (66° C)</td>
</tr>
<tr>
<td>Ore Exit Temperature</td>
<td>1450° F (788° C)</td>
</tr>
<tr>
<td>Off Gas Temperature</td>
<td>600° F (316° C)</td>
</tr>
</tbody>
</table>

### Calcine Cooling

<table>
<thead>
<tr>
<th>Type</th>
<th>Rotary Drum Cooler, Quench Tank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcine Temperature In</td>
<td>1450° F (788° C)</td>
</tr>
<tr>
<td>Calcine Temperature Out</td>
<td>199° F (93° C)</td>
</tr>
<tr>
<td>Quench Liquor Temperature</td>
<td>93° F (34° C)</td>
</tr>
</tbody>
</table>

### Costs

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost $(000)</td>
<td>26212</td>
</tr>
<tr>
<td>Power Requirement KWH</td>
<td>2040</td>
</tr>
<tr>
<td>Power $(000)</td>
<td>727</td>
</tr>
<tr>
<td>Fuel</td>
<td>26984</td>
</tr>
<tr>
<td>Labor &amp; Supervision</td>
<td>461</td>
</tr>
<tr>
<td>Maintenance</td>
<td>832</td>
</tr>
<tr>
<td>Consumables &amp; Misc</td>
<td>107</td>
</tr>
<tr>
<td>Process Chemicals</td>
<td>2747</td>
</tr>
<tr>
<td>Total Operating Cost</td>
<td>31859</td>
</tr>
</tbody>
</table>
## Throughput

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput 263.5 STPH(DRY)</td>
<td>239.0 MTPH(DRY)</td>
</tr>
</tbody>
</table>

## Solids

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Solids</td>
<td>20</td>
</tr>
<tr>
<td>Solids Size Distribution</td>
<td>95% minus 65 mesh</td>
</tr>
</tbody>
</table>

## Ball Mill Feed

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball Mill Feed % Solids</td>
<td>60</td>
</tr>
</tbody>
</table>

## Circulating Load

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circulating Load %</td>
<td>200</td>
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</tbody>
</table>

## Wet Cyclone Feed

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Cyclone Feed % Solids</td>
<td>40</td>
</tr>
</tbody>
</table>

## Cyclone Overflow

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclone Overflow % Solids</td>
<td>20</td>
</tr>
</tbody>
</table>

## Leaching Stages

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaching Stages</td>
<td>2</td>
</tr>
</tbody>
</table>

## Flow

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>Counter-Current</td>
</tr>
</tbody>
</table>

## Temperature

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>100-109 deg F (38-43 deg C)</td>
</tr>
</tbody>
</table>

## Pressure

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>Atmospheric</td>
</tr>
</tbody>
</table>

## Residence Time

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residence Time</td>
<td>60 minutes/stage</td>
</tr>
</tbody>
</table>

## Solids Weight %

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solids Weight %</td>
<td>20</td>
</tr>
</tbody>
</table>

## Thickener Underflow Solids

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickener Underflow Solids</td>
<td>50 wt %</td>
</tr>
</tbody>
</table>

## Pregnant Liquor Analysis

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni</td>
<td>12.0 g/l</td>
</tr>
<tr>
<td>Cu</td>
<td>3.6 g/l</td>
</tr>
<tr>
<td>Co</td>
<td>0.55 g/l</td>
</tr>
<tr>
<td>NH3</td>
<td>75. g/l</td>
</tr>
<tr>
<td>CO2</td>
<td>50. g/l</td>
</tr>
</tbody>
</table>

## Washing Stages

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washing Stages</td>
<td>5</td>
</tr>
</tbody>
</table>

## Flow

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>Counter-Current</td>
</tr>
</tbody>
</table>

## Temperature

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Ambient</td>
</tr>
</tbody>
</table>

## Pressure

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>Atmospheric</td>
</tr>
</tbody>
</table>

## Thickener Underflow Solids

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickener Underflow Solids</td>
<td>50 wt %</td>
</tr>
</tbody>
</table>

## Wash Ratio

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wash Ratio</td>
<td>1.0</td>
</tr>
</tbody>
</table>

## Efficiency

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>97%</td>
</tr>
</tbody>
</table>

## Capital Cost (000)

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost (000)</td>
<td>20299</td>
</tr>
</tbody>
</table>

## Power Requirement, KWH

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Requirement, KWH</td>
<td>4465</td>
</tr>
</tbody>
</table>

## Power, $(000)

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power, $(000)</td>
<td>1591</td>
</tr>
</tbody>
</table>

## Fuel

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>0</td>
</tr>
</tbody>
</table>

## Labor & Supervision

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor &amp; Supervision</td>
<td>298</td>
</tr>
</tbody>
</table>

## Maintenance

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>1030</td>
</tr>
</tbody>
</table>

## Consumables & Misc

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumables &amp; Misc</td>
<td>7060</td>
</tr>
</tbody>
</table>

## Process Chemicals

<table>
<thead>
<tr>
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<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Chemicals</td>
<td>3191</td>
</tr>
</tbody>
</table>

## Total Operating Cost

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Operating Cost</td>
<td>13173</td>
</tr>
</tbody>
</table>
NICKEL COPPER EXTRACTION

EQUIPMENT

COVERED MIXER-SETTLERS
WITH TURBINE TYPE
PUMPING MIXERS

MIXER RESIDENCE TIME 3 MINUTES
NUMBER OF STAGES 3
FLOW COUNTER-CURRENT
O:A RATIO WITHOUT INTERNAL RECYCLE 2.5:1
O:A RATIO WITH INTERNAL RECYCLE 1:1
Ni EXTRACTION 100 %
Cu EXTRACTION 100 %
AQUEOUS ENTRAINMENT BY ORGANIC
NH3 ABSORBED BY DILUENT 0.5 VOL.% OF ORGANIC

AQUEOUS FEED ANALYSIS
Ni 12.0 s/l
Cu 3.6 s/l
Co 0.55 s/l
NH3 75.0 s/l
CO2 50.0 s/l

ORGANIC FEED
THE ORGANIC FEED IS A 25 VOL./VOL.%
SOLUTION OF GENERAL MILLS LIX-65N IN KEROSENE

MAXIMUM Ni LOADING 5.6 s/l
MAXIMUM Cu LOADING 1.9 s/l
DESIGN Ni LOADING 5.0 s/l
DESIGN Cu LOADING 1.5 s/l
Ni CONTENT 0.2 s/l
Cu CONTENT 0.05 s/l

AMMONIA SCRUBBING NICKEL-COPPER CIRCUIT

EQUIPMENT PACKED TOWER
FLOW COUNTER-CURRENT
DISPERSED PHASE AQUEOUS
TEMPERATURE AMBIENT
PRESSURE 50 PSIG (345 kPa)
RESIDENCE TIME 2 MINUTES
O:A RATIO WITHOUT INTERNAL RECYCLE 5:1
O:A RATIO WITH INTERNAL RECYCLE 1:1
NH3 SCRUBBING EFFICIENCY 100 %
AQUEOUS ENTRAINMENT BY ORGANIC
0.5 VOL.% OF ORGANIC
### Nickel Stripping

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Covered Mixer-Settlers with Turbine Type Pumping Mixers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixer Residence Time</td>
<td>4 minutes</td>
</tr>
<tr>
<td>Number of Stages</td>
<td>4</td>
</tr>
<tr>
<td>Flow</td>
<td>Counter-Current</td>
</tr>
<tr>
<td>O:A Ratio without Internal Recycle</td>
<td>3.75:1</td>
</tr>
<tr>
<td>O:A Ratio with Internal Recycle</td>
<td>1:1</td>
</tr>
<tr>
<td>Ni Transfer to Aqueous</td>
<td>18.0 g/l</td>
</tr>
<tr>
<td>Ni Transfer to Organic</td>
<td>4.8 g/l</td>
</tr>
<tr>
<td>Aqueous Entrainment by Organic</td>
<td>0.5 Vol.% of Organic</td>
</tr>
</tbody>
</table>

### Copper Stripping

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Covered Mixer-Settlers with Turbine Type Pumping Mixers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixer Residence Time</td>
<td>4 minutes</td>
</tr>
<tr>
<td>Number of Stages</td>
<td>3</td>
</tr>
<tr>
<td>Flow</td>
<td>Counter-Current</td>
</tr>
<tr>
<td>O:A Ratio without Internal Recycle</td>
<td>5:1</td>
</tr>
<tr>
<td>O:A Ratio with Internal Recycle</td>
<td>1:1</td>
</tr>
<tr>
<td>Cu Transfer to Aqueous</td>
<td>7.3 g/l</td>
</tr>
<tr>
<td>Cu Transfer to Organic</td>
<td>1.45 g/l</td>
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<tr>
<td>Aqueous Entrainment by Organic</td>
<td>0.5 Vol.% of Organic</td>
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### Cobalt Reduction

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Packed Tower</th>
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<tbody>
<tr>
<td>Packing</td>
<td>Shredded Cobalt Cathodes and Scrap</td>
</tr>
<tr>
<td>Type of Flow</td>
<td>Upflow</td>
</tr>
<tr>
<td>Residence Time</td>
<td>1 minute</td>
</tr>
<tr>
<td>Temperature</td>
<td>Ambient</td>
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<tr>
<td>Pressure</td>
<td>Atmospheric</td>
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### Cobalt Extraction

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Covered Mixer-Settlers with Turbine Type Pumping Mixers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixer Residence Time</td>
<td>3 minutes</td>
</tr>
<tr>
<td>Number of Stages</td>
<td>3</td>
</tr>
<tr>
<td>Flow</td>
<td>Counter-Current</td>
</tr>
<tr>
<td>O:A Ratio without Internal Recycle</td>
<td>1:2</td>
</tr>
<tr>
<td>O:A Ratio with Internal Recycle</td>
<td>1:1</td>
</tr>
<tr>
<td>Co Extraction</td>
<td>100%</td>
</tr>
<tr>
<td>Aqueous Entrainment by Organic</td>
<td>0.5 Vol.% of Organic</td>
</tr>
<tr>
<td>NH3 Absorbed by Diluent</td>
<td>0.5 % of Aqueous Content</td>
</tr>
</tbody>
</table>
THE ORGANIC FEED IS A SOLUTION OF 3 VOL.% GENERAL MILLS XI-51 WITH 94 % KEROSENE AND 3 % ISODECONAL
MAXIMUM Co LOADING 2.0 s/l
DESIGN Co LOADING 1.75 s/l
Co CONTENT 0.05 s/l

AMMONIA SCRUBBING COBALT CIRCUIT
EQUIPMENT PACKED TOWER
FLOW COUNTER-CURRENT
DISPERSED PHASE AQUEOUS
TEMPERATURE AMBIENT
PRESSURE 50 PSIG (345 kPa)
RESIDENCE TIME 2 MINUTES
O:A RATIO WITHOUT INTERNAL RECYCLE 2:1
O:A RATIO WITH INTERNAL RECYCLE 1:1
NH3 SCRUBBING EFFICIENCY 100%
AQUEOUS ENTRAINMENT BY ORGANIC 0.5 VOL.% OF ORGANIC

COBALT STRIPPING
EQUIPMENT COVERED MIXER-SETTLERS WITH TURBINE TYPE PUMPING MIXERS
MIXER RESIDENCE TIME 4 MINUTES
NUMBER OF STAGES 3
FLOW COUNTER-CURRENT
O:A RATIO WITHOUT INTERNAL RECYCLE 10:1
O:A RATIO WITH INTERNAL RECYCLE 1:1
Co TRANSFER TO AQUEOUS 17.0 s/l
Co TRANSFER TO ORGANIC 1.70 s/l
AQUEOUS ENTRAINMENT BY ORGANIC 0.5 VOL.% OF ORGANIC

CAPITAL COST, $(000) 9103
POWER REQUIREMENT, KWH 1254
POWER, $(000) 447
FUEL 0
LABOR & SUPERVISION 347
MAINTENANCE 346
CONSUMABLES & MISC 45
PROCESS CHEMICALS 550
TOTAL OPERATING COST 1737
## Nickel Electrowinning

<table>
<thead>
<tr>
<th>CELL TYPE</th>
<th>DIAPHRAGM</th>
</tr>
</thead>
<tbody>
<tr>
<td>CATHODES PER CELL</td>
<td>42</td>
</tr>
<tr>
<td>ANODES PER CELL</td>
<td>43</td>
</tr>
<tr>
<td>ANODE TYPE</td>
<td>CALCIUM-LEAD</td>
</tr>
<tr>
<td>CELL VOLTAGE</td>
<td>3.4 VOLTS</td>
</tr>
<tr>
<td>CURRENT DENSITY</td>
<td>20 A/ft² (215 A/m²)</td>
</tr>
<tr>
<td>CURRENT EFFICIENCY</td>
<td>95%</td>
</tr>
<tr>
<td>CATHODE PULL WEIGHT</td>
<td>151.9 lb (68.9 kg)</td>
</tr>
<tr>
<td>CATHODE DAYS IN CELL</td>
<td>6</td>
</tr>
</tbody>
</table>

### Electrolyte

<table>
<thead>
<tr>
<th>TEMP. DEG F</th>
<th>PREGNANT</th>
<th>SPENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>140.0 (60°C)</td>
<td>1.11</td>
<td>1.11</td>
</tr>
<tr>
<td>149.0 (65°C)</td>
<td>4.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Ni₂⁺/l</td>
<td>75.0</td>
<td>57.0</td>
</tr>
<tr>
<td>H₂SO₄₂⁻/l</td>
<td>0.05</td>
<td>30.15</td>
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</tbody>
</table>

## Nickel Starter Sheet Preparation

<table>
<thead>
<tr>
<th>CELL TYPE</th>
<th>DIAPHRAGM</th>
</tr>
</thead>
<tbody>
<tr>
<td>CATHODES PER CELL</td>
<td>42</td>
</tr>
<tr>
<td>STARTER BLANKS</td>
<td>STAINLESS STEEL</td>
</tr>
<tr>
<td>ANODES PER CELL</td>
<td>43</td>
</tr>
<tr>
<td>ANODE TYPE</td>
<td>CALCIUM-LEAD</td>
</tr>
<tr>
<td>CELL VOLTAGE</td>
<td>3.4 VOLTS</td>
</tr>
<tr>
<td>CURRENT DENSITY</td>
<td>20 A/ft² (215 A/m²)</td>
</tr>
<tr>
<td>CURRENT EFFICIENCY</td>
<td>95%</td>
</tr>
<tr>
<td>STARTER PULL WEIGHT</td>
<td>21.6 lb (9.8 kg)</td>
</tr>
<tr>
<td>STARTER DAYS IN CELL</td>
<td>2</td>
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</table>

## Copper Electrowinning

<table>
<thead>
<tr>
<th>CELL TYPE</th>
<th>CONVENTIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>CATHODES PER CELL</td>
<td>42</td>
</tr>
<tr>
<td>ANODES PER CELL</td>
<td>43</td>
</tr>
<tr>
<td>ANODE TYPE</td>
<td>CALCIUM-LEAD</td>
</tr>
<tr>
<td>CELL VOLTAGE</td>
<td>2.1 VOLTS</td>
</tr>
<tr>
<td>CURRENT DENSITY</td>
<td>20 A/ft² (215 A/m²)</td>
</tr>
<tr>
<td>CURRENT EFFICIENCY</td>
<td>95%</td>
</tr>
<tr>
<td>CATHODE PULL WEIGHT</td>
<td>162.9 lb (73.9 kg)</td>
</tr>
<tr>
<td>CATHODE DAYS IN CELL</td>
<td>6</td>
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</table>

### Electrolyte

<table>
<thead>
<tr>
<th>TEMP. DEG F</th>
<th>PREGNANT</th>
<th>SPENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>122.0 (50°C)</td>
<td>1.15</td>
<td>1.15</td>
</tr>
<tr>
<td>131.0 (55°C)</td>
<td>45.0</td>
<td>37.7</td>
</tr>
<tr>
<td>H₂SO₄₂⁻/l</td>
<td>138.8</td>
<td>150.0</td>
</tr>
</tbody>
</table>
### Copper Sheet Preparation

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathodes Per Cell</td>
<td>42</td>
</tr>
<tr>
<td>Starter Blanks</td>
<td>Titanium</td>
</tr>
<tr>
<td>Anodes Per Cell</td>
<td>43</td>
</tr>
<tr>
<td>Anode Type</td>
<td>Calcium-Lead</td>
</tr>
<tr>
<td>Cell Voltage</td>
<td>2.1 Volts</td>
</tr>
<tr>
<td>Current Density</td>
<td>20 A/f² (215 A/m²)</td>
</tr>
<tr>
<td>Current Efficiency</td>
<td>95 %</td>
</tr>
<tr>
<td>Starter Pull Weight</td>
<td>23.4 lb (10.6 kg)</td>
</tr>
<tr>
<td>Starter Days In Cell</td>
<td>2</td>
</tr>
</tbody>
</table>

### Cobalt Electrowinning

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Diaphragm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathodes Per Cell</td>
<td>47</td>
</tr>
<tr>
<td>Anodes Per Cell</td>
<td>48</td>
</tr>
<tr>
<td>Anode Type</td>
<td>Calcium-Lead</td>
</tr>
<tr>
<td>Cell Voltage</td>
<td>3.4 Volts</td>
</tr>
<tr>
<td>Current Density</td>
<td>20 A/f² (215 A/m²)</td>
</tr>
<tr>
<td>Current Efficiency</td>
<td>95 %</td>
</tr>
<tr>
<td>Cathode Pull Weight</td>
<td>150.8 lb (68.4 kg)</td>
</tr>
<tr>
<td>Cathode Days In Cell</td>
<td>6</td>
</tr>
</tbody>
</table>

### Electrolyte

<table>
<thead>
<tr>
<th></th>
<th>Pregnant</th>
<th>Spent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature, °F</td>
<td>140.0 (60 °C)</td>
<td>149.0 (65 °C)</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.07</td>
<td>1.06</td>
</tr>
<tr>
<td>pH</td>
<td>4.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Co₂⁺/l</td>
<td>47.0</td>
<td>30.0</td>
</tr>
<tr>
<td>H₂SO₄⁺/l</td>
<td>0.05</td>
<td>28.35</td>
</tr>
</tbody>
</table>

### Cobalt Starter Sheet Preparation

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Diaphragm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathodes Per Cell</td>
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</tr>
<tr>
<td>Starter Blanks</td>
<td>Stainless Steel</td>
</tr>
<tr>
<td>Anodes Per Cell</td>
<td>48</td>
</tr>
<tr>
<td>Anode Type</td>
<td>Calcium-Lead</td>
</tr>
<tr>
<td>Cell Voltage</td>
<td>3.4 Volts</td>
</tr>
<tr>
<td>Current Density</td>
<td>20 A/f² (215 A/m²)</td>
</tr>
<tr>
<td>Current Efficiency</td>
<td>95 %</td>
</tr>
<tr>
<td>Cathode Pull Weight</td>
<td>21.6 lb (9.8 kg)</td>
</tr>
<tr>
<td>Cathode Days In Cell</td>
<td>2</td>
</tr>
</tbody>
</table>

### Capital Cost

- Total: $19980

### Power Requirement

- Total: 21182 kWh

### Fuel

- 0

### Labor & Supervision

- Total: 445

### Maintenance

- Total: 1116

### Consumables & Misc

- Total: 2330

### Process Chemicals

- Total: 0

### Total Operating Cost

- Total: 11441
PROCESS ECONOMICS

THE NET PRESENT VALUE (NPV) OF THIS INVESTMENT AT THE MINIMUM ACCEPTABLE RATE OF RETURN OF 18.0 % IS $ 94638.9.

THE ANNUAL CASH FLOW FOR THE PROJECT IS $ 145155. BASED UPON STRAIGHT LINE DEPRECIATION.

THE DISCOUNTED CASH FLOW RATE OF RETURN (DCFROR) FOR THE PROJECT IS 21.9 %.
## Sensitivity Analysis

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>% CHANGE</th>
<th>VALUE</th>
<th>NPV(000)</th>
<th>% CHANGE NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. DISCOUNT RATE</td>
<td>-6</td>
<td>0.12</td>
<td>161942.</td>
<td>71.1</td>
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<tr>
<td>2. ALL METAL PRICE</td>
<td>30</td>
<td>485457.00</td>
<td>159948.</td>
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<tr>
<td>3. ALL METAL PRICE</td>
<td>20</td>
<td>448087.00</td>
<td>138165.</td>
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<td>4. NICKEL PRICE</td>
<td>30</td>
<td>3.90</td>
<td>133125.</td>
<td>40.7</td>
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<tr>
<td>5. CAPITAL COST</td>
<td>-40</td>
<td>206036.00</td>
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<td>6. DISCOUNT RATE</td>
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<td>0.15</td>
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<tr>
<td>7. NICKEL GRADE</td>
<td>20</td>
<td>1.96</td>
<td>120305.</td>
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<td>8. NICKEL PRICE</td>
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<td>3.60</td>
<td>120288.</td>
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<tr>
<td>9. COBALT PRICE</td>
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<td>32.50</td>
<td>110259.</td>
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<tr>
<td>10. ALL METAL PRICE</td>
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<td>410750.00</td>
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<tr>
<td>11. OPERATING COST</td>
<td>-30</td>
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<td>12. COBALT METAL RECOVERY</td>
<td>20</td>
<td>30.00</td>
<td>110384.</td>
<td>16.6</td>
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<td>13. COBALT GRADE</td>
<td>20</td>
<td>0.22</td>
<td>110363.</td>
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<tr>
<td>14. CAPITAL COST</td>
<td>-20</td>
<td>274715.00</td>
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<td>15. NICKEL METAL RECOVERY</td>
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<td>100.00</td>
<td>108905.</td>
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<td>16. COBALT METAL RECOVERY</td>
<td>10</td>
<td>70.00</td>
<td>107769.</td>
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<tr>
<td>17. NICKEL GRADE</td>
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<td>1.79</td>
<td>107478.</td>
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<td>18. NICKEL PRICE</td>
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<td>3.30</td>
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<td>19. OPERATING COST</td>
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<td>20. NICKEL METAL RECOVERY</td>
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<td>22. NICKEL METAL RECOVERY</td>
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<td>96.00</td>
<td>103204.</td>
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<td>10</td>
<td>0.20</td>
<td>102522.</td>
<td>8.3</td>
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<tr>
<td>24. COBALT METAL RECOVERY</td>
<td>6</td>
<td>66.00</td>
<td>102522.</td>
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<td>25. COBALT PRICE</td>
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<td>27.50</td>
<td>102515.</td>
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<td>26. OPERATING COST</td>
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<td>93815.00</td>
<td>100714.</td>
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<tr>
<td>VARIABLE</td>
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<td>NPV(000)</td>
<td>% CHANGE</td>
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<tr>
<td>-----------------------------------</td>
<td>----------</td>
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<tr>
<td>27. NICKEL METAL RECOVERY</td>
<td>4</td>
<td>94.00</td>
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<td>28. COBALT METAL RECOVERY</td>
<td>4</td>
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<td>99899.</td>
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<td>29. COPPER PRICE</td>
<td>30</td>
<td>1.04</td>
<td>97863.</td>
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<tr>
<td>30. NICKEL METAL RECOVERY</td>
<td>2</td>
<td>92.00</td>
<td>97503.</td>
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<tr>
<td>31. COBALT METAL RECOVERY</td>
<td>2</td>
<td>62.00</td>
<td>97276.</td>
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<td>32. COPPER PRICE</td>
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<td>33. COPPER PRICE</td>
<td>10</td>
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<td>95722.</td>
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<td>34. BASE CASE</td>
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<td>35. COPPER PRICE</td>
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<td>93502.</td>
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<td>36. COPPER PRICE</td>
<td>-20</td>
<td>0.64</td>
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<td>37. COBALT METAL RECOVERY</td>
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<td>58.00</td>
<td>92029.</td>
<td>-2.8</td>
</tr>
<tr>
<td>38. NICKEL METAL RECOVERY</td>
<td>-2</td>
<td>88.00</td>
<td>91002.</td>
<td>-3.0</td>
</tr>
<tr>
<td>39. COPPER PRICE</td>
<td>-30</td>
<td>0.56</td>
<td>91442.</td>
<td>-3.4</td>
</tr>
<tr>
<td>40. COBALT METAL RECOVERY</td>
<td>-4</td>
<td>56.00</td>
<td>89406.</td>
<td>-5.5</td>
</tr>
<tr>
<td>41. NICKEL METAL RECOVERY</td>
<td>-4</td>
<td>86.00</td>
<td>88952.</td>
<td>-6.0</td>
</tr>
<tr>
<td>42. OPERATING COST</td>
<td>10</td>
<td>114660.00</td>
<td>88564.</td>
<td>-6.4</td>
</tr>
<tr>
<td>43. COBALT METAL RECOVERY</td>
<td>-6</td>
<td>54.00</td>
<td>86783.</td>
<td>-8.3</td>
</tr>
<tr>
<td>44. COPPER PRICE</td>
<td>-10</td>
<td>22.50</td>
<td>86780.</td>
<td>-8.3</td>
</tr>
<tr>
<td>45. COBALT GRADE</td>
<td>-10</td>
<td>0.16</td>
<td>86753.</td>
<td>-8.3</td>
</tr>
<tr>
<td>46. NICKEL METAL RECOVERY</td>
<td>-6</td>
<td>84.00</td>
<td>86101.</td>
<td>-9.0</td>
</tr>
<tr>
<td>47. COBALT METAL RECOVERY</td>
<td>-8</td>
<td>52.00</td>
<td>84160.</td>
<td>-11.1</td>
</tr>
<tr>
<td>48. NICKEL METAL RECOVERY</td>
<td>-8</td>
<td>82.00</td>
<td>83250.</td>
<td>-12.0</td>
</tr>
<tr>
<td>49. OPERATING COST</td>
<td>20</td>
<td>125082.00</td>
<td>82489.</td>
<td>-12.8</td>
</tr>
<tr>
<td>50. NICKEL GRADE</td>
<td>-10</td>
<td>1.47</td>
<td>81824.</td>
<td>-13.5</td>
</tr>
<tr>
<td>51. NICKEL PRICE</td>
<td>-10</td>
<td>2.70</td>
<td>81815.</td>
<td>-13.6</td>
</tr>
<tr>
<td>52. COBALT METAL RECOVERY</td>
<td>-10</td>
<td>50.00</td>
<td>81537.</td>
<td>-13.8</td>
</tr>
<tr>
<td>53. NICKEL METAL RECOVERY</td>
<td>-10</td>
<td>0.00</td>
<td>80400.</td>
<td>-15.0</td>
</tr>
<tr>
<td>VARIABLE</td>
<td>% CHANGE</td>
<td>VALUE</td>
<td>NPV(000)</td>
<td>% CHANGE NPV</td>
</tr>
<tr>
<td>-----------------------</td>
<td>----------</td>
<td>-------------</td>
<td>----------</td>
<td>--------------</td>
</tr>
<tr>
<td>54. CAPITAL COST</td>
<td>20</td>
<td>412083.00</td>
<td>79723.</td>
<td>-15.8</td>
</tr>
<tr>
<td>55. COBALT GRADE</td>
<td>-20</td>
<td>0.14</td>
<td>78913.</td>
<td>-16.6</td>
</tr>
<tr>
<td>56. COBALT PRICE</td>
<td>-20</td>
<td>20.00</td>
<td>78911.</td>
<td>-16.6</td>
</tr>
<tr>
<td>57. OPERATING COST</td>
<td>30</td>
<td>135513.00</td>
<td>76409.</td>
<td>-19.3</td>
</tr>
<tr>
<td>58. PRODUCTIVITY</td>
<td>-10</td>
<td>2250000.00</td>
<td>72886.</td>
<td>-23.0</td>
</tr>
<tr>
<td>59. ALL METAL PRICE</td>
<td>-10</td>
<td>336081.00</td>
<td>72878.</td>
<td>-23.0</td>
</tr>
<tr>
<td>60. DISCOUNT RATE</td>
<td>3</td>
<td>0.21</td>
<td>72552.</td>
<td>-23.3</td>
</tr>
<tr>
<td>61. COBALT PRICE</td>
<td>-30</td>
<td>17.50</td>
<td>71042.</td>
<td>-24.9</td>
</tr>
<tr>
<td>62. FUEL OIL COST</td>
<td>20</td>
<td>81390.70</td>
<td>71006.</td>
<td>-25.0</td>
</tr>
<tr>
<td>63. NICKEL GRADE</td>
<td>-20</td>
<td>1.30</td>
<td>68997.</td>
<td>-27.1</td>
</tr>
<tr>
<td>64. NICKEL PRICE</td>
<td>-20</td>
<td>2.40</td>
<td>68989.</td>
<td>-27.1</td>
</tr>
<tr>
<td>65. CAPITAL COST</td>
<td>40</td>
<td>480777.00</td>
<td>64804.</td>
<td>-31.5</td>
</tr>
<tr>
<td>66. FUEL OIL COST</td>
<td>40</td>
<td>94955.81</td>
<td>63099.</td>
<td>-33.3</td>
</tr>
<tr>
<td>67. NICKEL PRICE</td>
<td>-30</td>
<td>2.10</td>
<td>56161.</td>
<td>-40.7</td>
</tr>
<tr>
<td>68. DISCOUNT RATE</td>
<td>6</td>
<td>0.24</td>
<td>55228.</td>
<td>-41.6</td>
</tr>
<tr>
<td>69. FUEL OIL COST</td>
<td>60</td>
<td>100520.93</td>
<td>55192.</td>
<td>-41.7</td>
</tr>
<tr>
<td>70. PRODUCTIVITY</td>
<td>-20</td>
<td>2000025.00</td>
<td>51121.</td>
<td>-46.0</td>
</tr>
<tr>
<td>71. ALL METAL PRICE</td>
<td>-20</td>
<td>290742.00</td>
<td>51113.</td>
<td>-46.0</td>
</tr>
<tr>
<td>72. FUEL OIL COST</td>
<td>80</td>
<td>122086.04</td>
<td>47285.</td>
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</tr>
<tr>
<td>73. PRODUCTIVITY</td>
<td>-30</td>
<td>1750021.07</td>
<td>29352.</td>
<td>-69.0</td>
</tr>
<tr>
<td>74. ALL METAL PRICE</td>
<td>-30</td>
<td>261399.00</td>
<td>29346.</td>
<td>-69.0</td>
</tr>
</tbody>
</table>
PROJECT PROFITABILITY

THE MEAN PROFITABILITY VALUE FOR THE PROJECT IS $419803
WITH A STANDARD DEVIATION OF $114542.7

THE COEFFICIENT OF VARIATION IN PROFITABILITY
OF THE PROJECT IS 0.27
APPENDIX II

UOPEC PROGRAM
CAPITAL. 15:23MST 04/28/81

100  DIMENSION NMCCOST(6,14),KANG(76),NAMES(76),VALUE(76),
110  &NPV(76),NEGU(76),NPMEN(76),BINFV(76),PRONM(6),PSNOD(76)
120  ALFA FF/0140400400400/
130  OPEN UNIT=6,FILE=""
140  DATA NMCCOST /"CAPITAL","COST","US","S","US","S","ALL","META","L PR","ICE","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","
150  & "OPER","ATIN","G CD","ST","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","
160  & "ALL","META","L PR","ICE","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","
170  & "NICK","EL P","RICE","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","
180  & "Coba","LT P","RICE","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","
190  & "COP","ER P","RICE","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","
200  & "NICK","EL M","ETAL","REC","OVER","Y","","","","","","","","","","","","","","","","","","","","","","","","","","","","","
210  & "Coba","LT M","ETAL","REC","OVER","Y","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","
220  & "NICK","EL G","RADE","","","","","","","","","","","",","
230  & "Coba","LT G","RADE","","","","","","","","","","","",","
240  & "FUEL","OIL","COS","T","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","
250  & "PROD","UCTI","VITY","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","" 
260  & "DISC","OUNT","RAT","E","","","","","","","","","","","","","","","","","","","","","","","","","","
270  & "BASE","CAS","E","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","","
280  READ("DATA",21)ID1, ID2, ID3
290  21 FORMAT(3I2)
300  READ("DATA",23)PRONM
310  READ("DATA",24)PLTFED
320  READ("DATA",25)ANICMP,ANIREC,COCCMP,COREC,CUCOMP,CUCRE,
330  &FE,SID2,AL203,OMG,CAO
340  READ("DATA",26)DOSFRAC,ROMMST
350  READ("DATA",27)RLAQRT,RPORDF
360  READ("DATA",28)CINDEX
370  READ("DATA",29)WAGE
380  READ("DATA",30)AKWH
390  READ("DATA",29)PETBU
400  READ("DATA",31)CL2CST
410  READ("DATA",32)PETCST
420  READ("DATA",32)OILCST
430  READ("DATA",32)COLCST
440  READ("DATA",29)COLRT
450  READ("DATA",33)NFUEL
460  READ("DATA",34)CRECST
470  READ("DATA",34)ANIPR
480  READ("DATA",35)COPR
490  READ("DATA",34)CUCPR
500  READ("DATA",36)RATE
510  READ("DATA",37)NLS
520  READ("DATA",36)TAX
521  READ("DATA",22)NDOO
522  22 FORMAT(13)
530  23 FORMAT(6A4)
540  24 FORMAT(F8.0)
550  25 FORMAT(F5.4,F3.2,F5.4,F3.2,F5.4,F3.2,F4.3,F3.2)
560  26 FORMAT(F5.4,F3.2)
570  27 FORMAT(F5.3,F4.2)
580  28 FORMAT(F4.0)
590  29 FORMAT(F6.0)
600  30 FORMAT(F4.3)
610  31 FORMAT(F6.2)
620  32 FORMAT(F5.2)
630  33 FORMAT(11)
640  34 FORMAT(F5.2)
650  35 FORMAT(F6.2)
660  36 FORMAT(F5.3)
670  37 FORMAT(13)
PLANT CAPACITY

NPLTCP=PLTFED

NPLTCP=PLTFED*0.907

BROUN=APLTCP/1000+0.5

NBRD=BROUN

NPLTCP=NBRD*1000

D00=N00

THRPUT=PLTFED/D00/24

THRPM=THRPUT*0.907

ANIPRD=PLTFED*ANICMP*ANIREC

NIPRD=ANIPRD

NIPRD=ANIPRD

COPRD=PLTFED*COCOMP*COREC

COPRD=COPRD

COPRD=COPRD

CUPRD=PLTFED*CUCOMP*CUREC

CUPRD=CUPRD

CUPRD=CUPRD

RSTIN=THRPUT

STEAM REQUIREMENT

RSTCAL=THRPUT*0.8347

ALABFAC=ALABRT*ALAPIRM

TMEAL=ANIPRD+CUPRD+COPRD

STMN=ANIPRD*1.662

STMCU=CUPRD*2.895

STMCO=COPRD*2.941

STMCAT=TMEAL*0.255

STMU=STMN+STMCU+STMCO+STMCAT

AUSE=TMETAL*0.1634

STMNH4=AUSE*2.04

STMGR=RSTCAL*3.144*100

STMUSE=STMU+STMNH4+STMGR

STEAM PLANT

CCSTM=((STMUSE/389499)**0.8)*(8750+(1400*ALABFAC))*(CEINHX/238)

EPSTM=STMUSE*2.054E-04

EPSTCST=EPSTM*AKWH*7.92

BTUSTM=STMUSE*4642

COOLING WATER REQUIREMENT

CWRST=RSTCAL*3200*7920

RSTCLM=RSTCAL*0.907

CULEC=RSTCLM*3014*7920

IF (NFUEL.EQ.2) GO TO 38

ITUR=RSTIN*2643642*7.92

GO TO 39

BTUR=RSTIN*(1360000/0.7)*7.92

CWNH4=AUSE*1.6964E05

IF (NFUEL.EQ.2) GO TO 42

IF (NFUEL.EQ.3) GO TO 40

FETUSER=ITUR/FETITU*0.5

O2USE=O2USE*.3051

GO TO 41

COLUSER=ITUR/CO2ITU*0.5

O2USE=O2USE*.3051

CW2=O2USE*9256.5

CUSE=CWRST+CULEC+CWNH4+CW2

GO TO 43

CUSE=CWRST+CULEC+CWNH4

PROCESS WATER REQUIREMENT

PWSTM=STMUSE*186

PWCU=CUSE*0.022

IF (NFUEL.EQ.1) GO TO 44
1330 IF(NFUEL.EQ.3)GO TO 45
1340 PWUSE=PWLEC+PWSTM+PWCU
1350 GO TO 47
1360 44 PWST=PETUSER*15.4
1370 GO TO 46
1380 45 PWUSE=PWLEC+PWSTM+PWCU+PWST
1400C PE=II REQUIREMENT
1410 47 DYPED=THRPUT/(I-ROMMST)
1420 ANNUM=(DYPED/173)+1
1430 NNUM=NANUM
1440 NUMNUM=NANUM
1450 IF(BNUM .LT. ANUM)BNUM=BNUM+1
1460 NUMDYR=BNUM
1470 DYPED=DYPED/(NUMDYR-1)
1480 DYPED=DYPED*0.907
1490 DORE=DYPED/(I-ROMMST)
1500 H2O=DYPED-KROMMST
1510 CH2O=DOR*0.97-DORE
1520 BTUD=((DORE*126960)+(H2O-CH2O)*2297200)+
1530 & (CH2O*553220.)/0.75
1540 PETDRY=BTUD/PETBTU*3.96* (NUMDYR- 1)
1550 BTUD=14ALUSE*39851
1560 PETNH4=BTUD/1PETBTU*0.5
1570 PETSTM=BTUSTM/1PETBTU*0.5
1580 PETUSE=PETDRY+PETUSER+PETNH4+PETSTM
1590C PROCESS WATER
1600 CCFW=((PWUSE/6.5899E08)**0.7)*(116.8+(46.2*ALABFAC))*(CEINDX/238)
1610 ALSPW=2*WAGE*ALABFAC/1000
1620 EFFFW=PWUSE*3.642E-07
1630 EFFFW=CFU*AKW*7.92
1640 AMMPW=PWUSE*1.07E-08
1650 OFPW=ALSPW+EFFFW+AMMPW
1660 PWCT=OFPW*1.0E06/PWUSE
1670C COOLING H2O
1680 CCCW=((CWUSE/2.2029E10)**0.6)*(1094+(175*ALABFAC))*(CEINDX/238)
1690 ALSCW=4*WAGE*ALABFAC/1000
1700 EFFCW=CWUSE*2.905E-08
1710 EFCWST=EFCW*KW*7.92
1720 FWCT=FWCU*KWCT/1.0E06
1730 AMMCW=CWUSE*2.72E-9
1740 OCCW=ALSCW+EFCWCT+FWCT+AMMCW
1750 CWCT=OCCW*1.0E06/CWUSE
1760C OXYGEN PLANT
1770 IF(NFUEL.EQ.2)GO TO 48
1780 CC02=(C02USE/153980)**0.7)*(2500+(1109*ALABFAC))*(CEINDX/238)
1790 EP02=2*2USE*0.0319
1800 EP02ST=EP02*KW*7.92
1810 CW02ST=CW02*KWCT/1.0E06
1820 AMM02=O2USE*0.015
1830 ALSO2=4*WAGE*ALABFAC/1000
1840 OCO2=EP02ST+CW02ST+AMM02+ALSO2
1850 O2CT=OCO2*O2USE/1.0E06
1860C FUEL PLANT
1870 48 TRTU=(BTUD*NUMDYR-1)+(BTUD/7.92)+(BTUD/7.92)+(BTUSTM/7.92)
1880 RSTIN=RSTIN*0.907
1890 ARST=RSTN/30.93
1900 NARST=ARST
1910 BARST=NARST
1920 IF(BARST .LT. ARST)BARST=BARST+1
1930 NUMRST=BARST
1940 IF(NFUEL.EQ.2)GO TO 49
1950 IF(NFUEL.EQ.3)GO TO 50
1960 CCPET=(PETUSE/1069393)**0.85*(1626+(424*ALABFAC))*(CEINDX/238)
1970 ALSPET=5*WAGE*ALABFAC/1000
1980 EFPET=PETUSE*1.4719E-03
1990  EFPET=EPETWEAK*7.92
2000  AMMPET=PETUSE*8.405E-05
2010  PETCRL=PETUSE*3.17E-04
2020  TPETCST=PETUSE*PETCST/1000
2030  OCPT=AMSPET+EFPET+AMMPET+PETCST+PETCRL.
2040  FPETCST=OCPET/PETUSE*1000
2050  GO TO 51
2060  49 TOIL=TBTU*7.92/150000/42
2070  TOILCST=TOIL*TOILST
2080  CCOIL=((TOIL/2205)**0.63)*(1034+(216*ALABFAC))+(CEINDEX/236)
2090  GO TO 51
2100  50 TCOAL=TBTU/TLOTU*3.96
2110  TCOALCST=TCOAL/TCOAL*1000
2120  CCCOAL=((TCOAL/629011)**0.85)*(6020+(1570*ALABFAC))+(CEINDEX/236)
2130  ALSCOAL=((TCOAL/629011)**0.25)*12*WAGE*ALABFAC/1000
2140  EPCOAL=TCOAL*2.89E-04
2150  AAMCOAL=(CCCOAL*0.44)+(CCCOAL*0.44*ALABFAC)
2160  OAMCOAL=TCOALCST+ALSCOAL+(EPCOAL*ALABFAC*7.92)+AAMCOAL
2170  FCOLCST=OAMCOAL/TCOAL*1000
2180  STEAM PLANT COST
2190  51 IF(NFUEL .EQ. 2) GO TO 52
2200  IF(NFUEL .EQ. 3) GO TO 53
2210  FUENST=BTUSTM/PETBTU/2000*PPETCST
2220  GO TO 54
2230  52 FUENST=BTUSTM/150000/42*OILCST
2240  GO TO 54
2250  53 FUENST=BTUSTM/COLBTU/2000*FCOLCST
2260  54 PWSCST=FUENST*FUENST/1.0E06
2270  AMMST=STUSE=0.0011
2280  ALSMST=((8*WAGE*ALABFAC/1000)+(4*WAGE/1000))*1.37
2290  EFCRE=(STUSE/43271)*7920*AKUH
2300  DCOSTM=EPSTCST+FUELST+FUSCST+AMMST+ALSTM-EPRE
2310  STMSEL=DCSTM/STUSE=1000
2320  AMMONIA PLANT
2330  CNH4=(A4USE/7278)**0.7)*(3478+(907*ALABFAC))-(CEINDEX/213)
2340  EPNH4=A4USE*0.1319
2350  EPS4ST=EPNH4*AKUH*7.92
2360  STM4CST=STMH4*STM4CST/1000
2370  IF(NFUEL .EQ. 2) GO TO 55
2380  IF(NFUEL .EQ. 3) GO TO 56
2390  FUEL4=BTU4/150000/42*OILCST
2400  GO TO 57
2410  55 FUEL4=BTU4/150000/42*OILCST
2420  GO TO 57
2430  56 FUEL4=BTU4/COLBTU/2000*FCOLCST
2440  57 CW4CST=CNH4*CW4CST/1.0E8
2450  AMH4=A4USE=0.026
2460  ALSN4=((8*WAGE*ALABFAC/1000)+(4*WAGE/1000))*1.37
2470  OCNH4=EP4CST+STM4CST+FUEL4*CW4CST+AMM4+ALSN4
2480  ANH4CST=OCNH4*AMH4*0.008
2490  GAS RECOVERY PLANT
2500  CCGAS=(A4USE/7278)**0.7)*(1449+(378*ALABFAC))-(CEINDEX/213)
2510  STMG4CST=STMG4CST+STM4CST/1000
2520  AMMGAS=A4USE*0.0197
2530  ALGAS=((8*WAGE*ALABFAC/1000)+(4*WAGE/1000))*1.37
2540  OCGAS=STMG4CST+AMMGAS+ALGAS
2550  ORE PREP AND HANDLING
2560  ROMFED=THRPUT/(1-OSFRAC)
2570  ROMFED=ROMFED*0.907
2580  ROMFED=ROMFED/(1-ROMMST)
2590  ROMFED=ROMFED*0.907
2600  IF(NFUEL .EQ. 2) GO TO 58
2610  DYCST=(DIYFEDR/173)**0.68)*(1549+(331*ALABFAC))-(CEINDEX/213)
2620  GO TO 59
2630  58 DYCST=(DIYFEDR/173)**0.68)*(1521+(326*ALABFAC))-(CEINDEX/213)
2640  59 CCOREP=(DYFEDR/NUMDYR)+(14935+(3614*ALABFAC)*
2650 &((THRPUT/311.4)**0.6)*(CEINDX/213)
2660 EPWR=(NUMDYR-1)*1198*(DYFEDR/173)+(3444*(RSTIN/311.4))
2670 KEF=EPWR
2680 KCCORE=CCOREP
2690 EPOCST=EPWR#AKWH*7.92
2700 IF(NFUEL .EQ. 2) GO TO 60
2710 IF(NFUEL .EQ. 3) GO TO 61
2720 FUELO=PETDRY*PETCST/1000
2730 GO TO 62
2740 60 FUELO=BTUD*1.257E-06*(NUMDYR-1)*0.93
2750 GO TO 62
2760 61 FUELO=BTUD/COLBTU*3.96E-03*(NUMDYR-1)*F*0.93
2770 62 AF'PEP= < (RSTIN/208.3)**0.25) *40
2780 NAPEP=NAPEP
2790 IF(BF'EP .LT. APEP)BPEP=BPEP+1
2800 PEPLO=BF'EP
2810 IFU=EL=FU=EL0
2820 ALABRO=PEPLO#WAGE*ALABFAC/1000+(5#WAGE/1000)
2830 INALABRO=IALABRO
2840 AMMD=(CCOREP#0.0467)+((CCOREP#0.0467#ALABFAC)
2850 IAMMD=IAMMD
2860 CONSO=THRPUT#0.9306
2870 ICONSO=ICONSO
2880 OCOREF=EPOCST+FUELO+ALABRO+AMMD+CONSO
2890 KCORE=OCOREF
2900 COAST=THRPUT*0.9306
2910 RX)NSO=CONSO
2920 OCRST=OCORE+FUELO+ALABRO+AMMD+CONSO
2930 63 RSTCST=(RSTF/38.9)**0.85)*<2404+<506*ALABFAC)*<CEINDX/213
2940 GO TO 64
2950 64 CCRST=(RSTCST#NUMRST)+(710+(255#ALABFAC)*CEINDX/236
2960 LCCRST=CCRST
2970 IF(NFUEL .EQ. 2) GO TO 65
2980 IF(NFUEL .EQ. 3) GO TO 68
2990 FUELR=PETUSER*PETCST/1000
3000 GO TO 69
3010 67 FUELR='BTUR/150000/42*0.1L.CST
3020 68 FUELR=BTUR/COLBTU/2000#F*0.1L.CST
3030 69 IF(NFUEL .EQ. 2) GO TO 70
3040 IF(NFUEL .EQ. 3) GO TO 71
3050 PEPLR=((RSTIN/175)**0.6#40)+18
3060 GO TO 71
3070 70 PEPLR=(RSTIN/175)**0.6)*40
3080 71 ALABRR=PEPLR#WAGE*ALABFAC/1000
3090 IFU=EL=FU=ELR
3100 IALABRR=IALABRR
3110 AMAINR=(CCRST#0.025)+((CCRST#0.025#ALABFAC)
3120 IAMAINR=IAMAINR
3130 CONSR=RSTIN#0.3404
3140 ICONSR=ICONSR
3150 CHEMR=OCO2+(CWRST/1.0E06*CWCST)+(PWRST/1.0E06#F#CST)+(RSTIN#0.034*
3160 &CL2CST)+(RSTIN#3.2
3170 ICHEMR=ICHEMR
3180 OCRST=EPRCST+FUELR+ALABRR+AMAINR+CONSR+CHEMR
3190 LOCST=OCRST
LEACHING AND WASHING

\[ \text{CCLECH} = ((\text{RSTCAL}/264.9)^{0.6}) \times (15426 + (5142 \times \text{ALABFAC})) \times \text{CEINDX/213} \]

\[ \text{LCLECH} = \text{CCLECH} \]

\[ \text{EPWR} = \text{RSTCAL} \times 16.95 \]

\[ \text{FLCLST} = \text{EPWR} \times \text{AKWH} \times 7.92 \]

\[ \text{IEFCLST} = \text{FLCLST} \]

\[ \text{PEPL} = 37 \times (\text{RSTCAL}/264.9) ^ {0.6} \]

\[ \text{ALABR} = \text{PEPL} \times \text{WAGE} \times \text{ALABFAC}/1000 \]

\[ \text{IALABRL} = \text{ALABR} \]

\[ \text{IAMAINL} = (\text{CCLECH} \times 0.04) + (\text{CCLECH} \times 0.04 \times \text{ALABFAC}) \]

\[ \text{CONS} = \text{RSTCAL} \times 4.71 \times \text{CEINDX/213} \]

\[ \text{ICONS} = \text{CONS} \]

\[ \text{CHEML} = \text{DONH} + (\text{CWLEC}/1.0E06 \times \text{CUCST}) + (\text{FWLEC}/1.0E06 \times \text{FUCST}) \]

\[ \text{IEPL} = \text{CHEML} \]

\[ \text{OCLECH} = \text{IEFCLST} + \text{IALABRL} + \text{IAMAINL} + \text{CONS} + \text{CHEML} \]

\[ \text{LOCLC} = \text{OCLECH} \]

SOLVENT EXTRACTION

\[ \text{ANICUEX} = \text{ANIPRD} + \text{CUPRD} \]

\[ \text{CCNCX} = ((\text{ANICUEX}/43061)^{0.67}) \times (\text{CEINDX}/213) \times (960 + (393 \times \text{ALABFAC})) \]

\[ \text{CCNIS} = ((\text{ANIPRD}/33073)^{0.67}) \times (\text{CEINDX}/213) \times (2221 + (311 \times \text{ALABFAC})) \]

\[ \text{CCUS} = ((\text{CUPRD}/9989)^{0.67}) \times (\text{CEINDX}/213) \times (1733 + (711 \times \text{ALABFAC})) \]

\[ \text{CO} = \text{CCNX} + \text{CCNIS} + \text{CCUS} + \text{CCCOES} \]

\[ \text{JCCSX} = \text{CCSX} \]

\[ \text{EFNCX} = (\text{ANICUEX}/43061) \times 365 \]

\[ \text{EPNIS} = (\text{ANIPRD}/33073) \times 278 \]

\[ \text{EPCUS} = (\text{CUPRD}/9989) \times 213 \]

\[ \text{EPCOS} = (\text{CUPRD}/1480) \times 161 \]

\[ \text{EPWEX} = \text{EFNCX} + \text{EPNIS} + \text{EPCUS} + \text{EPCOS} \]

\[ \text{EPWEX} \]

\[ \text{EPXST} = \text{EPWEX} \times \text{AKWH} \times 7.92 \]

\[ \text{IEFPCST} = \text{EPWEX} \]

\[ \text{PENCX} = (\text{ANICUEX}/43061)^{0.25} \times 12 \]

\[ \text{PEPNS} = (\text{ANIPRD}/33073)^{0.25} \times 8 \]

\[ \text{PECOS} = (\text{CUPRD}/9989)^{0.25} \times 8 \]

\[ \text{PECOS} = (\text{CUPRD}/1480)^{0.25} \times 12 \]

\[ \text{APLX} = \text{PENCX} + \text{PEPNS} + \text{PECUS} + \text{PECOS} \]

\[ \text{NAPLX} = \text{APLX} \]

\[ \text{BF1LX} = \text{BFLX} \]

\[ \text{BF1LX} = \text{BFLX} \]

\[ \text{BF} = (\text{BFLX} .LT. \text{AFLX}) \times \text{BFLX} + \text{BFLX} + 1 \]

\[ \text{BF} = \text{BFLX} \]

\[ \text{ALABRX} = \text{PEPL} \times \text{WAGE} \times \text{ALABFAC}/1000 \]

\[ \text{IALABRX} = \text{ALABRX} \]

\[ \text{AMAINX} = (\text{CCSX} \times 0.03) + (\text{CCSX} \times 0.03 \times \text{ALABFAC}) \]

\[ \text{IAMAINX} = \text{AMAINX} \]

\[ \text{AMISCX} = \text{CCSX} \times 0.005 \]

\[ \text{AMISCX} = \text{AMISCX} \]

\[ \text{CHEMX} = (\text{ANICUEX} + \text{COPRD}) \times 8.937E-03 \times (\text{CEINDX}/213) \]

\[ \text{ICHEMX} = \text{CHEMX} \]

\[ \text{DCSX} = \text{EFPCST} + \text{ALABRX} + \text{AMAINX} + \text{AMISCX} + \text{CHEMX} \]

\[ \text{JOCSX} = \text{DCSX} \]

ELECTROWINNING

\[ \text{ACLNI} = \text{ANIPRD} \times 83.33/\text{DOO} \times 38 \]

\[ \text{NAACLNI} = \text{ACLNI} \]

\[ \text{BACLNI} = \text{NAACLNI} \]

\[ \text{IF} = (\text{BACLNI} \ .LT. \text{ACLNI}) \times \text{BACLNI} = \text{BACLNI} + 1 \]

\[ \text{CEALNI} = \text{BACLNI} \]

\[ \text{ACLU} = \text{COPRD} \times 83.33/\text{DOO} \times 41 \]

\[ \text{NAACLCU} = \text{ACLU} \]

\[ \text{BACLCL} = \text{NAACLCL} \]

\[ \text{IF} = (\text{BACLCL} \ .LT. \text{ACLU}) \times \text{BACLCL} = \text{BACLCL} + 1 \]

\[ \text{CEALCU} = \text{BACLCL} \]

\[ \text{ACLCO} = \text{COPRD} \times 83.33/\text{DOO} \times 27 \]
3970 NACLCO=ACLCO
3980 BCLCO=BCLCO
3990 IF (BCLCO .LT. ACLCO) BCLCO=BCLCO+1
4000 CELCO=ACLCO
4010 CCNI= (17.9+ (7.1*ALABFAC)) * CELNI
4011 CCCC= (14.6+ (5.9*ALABFAC)) * CELCU
4012 CCCE= (21.6+ (8.7*ALABFAC)) * CELCO
4020 CCW=(1077*(MTMETA/44541)**0.7) + (CCNI+CCCU+CCCO) * (CEINDX/238)
4030 KCW=CCW
4040 CPLW=((MTMETA/19440)**0.6)*30.4
4050 NCPLW=CPLW
4060 DCPLW=NCPLW
4070 IF (DCPLW .LT. CPLW) DCPLW=DCPLW+1
4080 PEPLW=DCPLW
4090 ALABRW=PEPLW*WAGE*ALABFAC/1000
4100 IALABRW=ALABRW
4110 AMAINEW=(CCEW*0.044) + (CCEU*0.044*ALABFAC)
4120 IMAINEW=AIMAINEW
4130 STMECE=STMEW*STMCST/1000
4140 EFWEW=(CELD*60.7) + (CELW*60.4) + (CELG*67.7) + 323
4150 MFREW=EFWEW
4160 EFWECS=EFWEW*AKW*7.92
4170 IEFEWS=EFWECS
4180 AMISEC=CCEW*0.005
4190 EECO=STMECST+AMISEC
4200 ISTEW=ECCO
4210 OCCW=ALABRW+AMAINEW+STMECST+EFWECS+AMISEC
4220 KCW=OCCW
4230 GENERAL OFFICE
4240 CGEN=4465*(CEINDX/238)
4250 PEGEN=279*(CEINDX/239)
4260 EGEN=24
4270 EPICST=EPGEN*AKU*7.92
4280 IOGAEW=EPICST
4290 OCW=PEGEN*EPICST+AMGEN
4300 MISCELLANEOUS AUXILIARY PLANTS
4310 PFAUXW=502*(CEINDX/239)
4320 IGOAL=PEGEN+PFAUXW
4330 EFAUXW=664*(THRTPUT/311.4)
4340 EPACST=EPFAUXW*AKU*7.92
4350 IOGAFA=EPACST
4360 AMMAUXW=134*(CEINDX/239)
4370 IGAOAL=AMMGEN+AMMAUXW
4380 OAUXW=PFAUXW+EPACST+AMMAUXW
4390 CCAXW=(21500*(THRTPUT/311.4)**0.7) *(CEINDX/238)
4400 AASOC=CCSTM+CCFU+CCD2+CCNH4+CCQAS+CCOAS+CCGEN
4410 IF (NFUEL .EQ. 1) AASOC=AASOC+CCPET
4420 IF (NFUEL .EQ. 2) AASOC=AASOC+CCBIL
4430 IF (NFUEL .EQ. 3) AASOC=AASOC+CCOAL
4440 JCCAS=CCAS
4450 OCAS=COCGEN+OCOUX
4460 JOCA=OCAS
4470 TTPW=EPSTM+EPFU+EPCU+EPFH+EPWRO+EPWRL+EPWRX+
&EPWEX+EPFEG+EPFAW+EPWWR
4480 IF (NFUEL .EQ. 1) TTPW=TTPW+EPPET
4490 IF (NFUEL .EQ. 2) TTPW=TTPW+EPBIL
4500 IF (NFUEL .EQ. 3) TTPW=TTPW+EPBAL
4510 NTTPW=TTPW
4520 JTODC=KCCOR+LCCRS+LCCLO+JCCSX+KCCEW+JCCAS
4530 SUMMARY OF CAPITAL COSTS
4540 SFASES=JTODC*0.032
4550 TRANS=JTODC*0.24
4560 ENGR=JTODC*0.187
4570 CONST=JTODC*0.245
4580 Tindr=JTODC+SFASE+TRANS+ENGR+CONST
4590 CONT=TIDRIND*0.2
4600 CONT=(TIDRIND+CONT)*0.03
4610 WC=JTOTIC*0.175
4620 TICINV=TIIRD+CONT+CONTR+WC
4630 LSPRE=SPARES
4640 LTRAN=TRANS
4650 LENGR=ENGR
4660 LCONS=CONST
4670 LCONT=CONT
4680 LCONTR=CONTR
4690 LUC=UC
4700 LTCINV=LTCINV
4710 JTOTIND=JTOTIC+LSPRE+LTRAN+LENGR+LCONS
4720 LTAOC=KOCORE+LOCRE+JOCX+KOCW+JOCAS
4730 NFV ANALYSIS
4740 KREV=NIPRD*2*ANIPR+K0PRD*2*C0PR+KUPRD*2*CUPR
4750 MINE=R0MFED*0RECST*7.92
4751 NREV1=(0.5*KREV)-LTAOC-(0.5*MINE)
4752 NREV2=(0.8*KREV)-LTAOC-(0.8*MINE)
4753 NREV3=KREV-LTAOC-MINE
4770 SPCAF=(1+RATE)**NLS
4771 SF=1+RATE
4780 ISW=1
4790 KHANG(ISW)=0
4800 NAMES(ISW)=14
4810 VALUE(ISW)=0
4820 DEPR=(LTCINV-LUC)/15
4821 IF(NREV1.GT.DEPR) CF1=(NREV1-DEPR)*((1-TAX)+DEPR)
4822 IF(NREV1.LE.DEPR) CF1=NREV1+DEPR
4823 IF(NREV2.GT.DEPR) CF2=(NREV2-DEPR)*((1-TAX)+DEPR)
4824 IF(NREV2.LE.DEPR) CF2=NREV2+DEPR
4830 CF3=(NREV3-DEPR)*((1-TAX)+DEPR)
4831 CF4=NREV3*(1-TAX)
4835 EX=NLS+2
4836 EX1=EX-18
4840 BASENFV=-(0.6*LTCINV)-(0.3*LTCINV*(1/SF**1))-(0.1*LTCINV)*
4841 +(1/SF**2)+(CF1*(1/SF**3)+(CF2*(1/SF**4))
4842 +(SF**12-1)/(RATE*SF**12)+(CF4*(1/SF**18))
4843 +(SF**EX1-1)/(RATE*SF**EX1)+LUC*(1/SF**EX)
4845 NFV(ISW)=SPCAF-1/(RATE*SPCAF)*CF3-LTCINV-(LUC*(1/SF**18))
4860 NEQU(ISW)=NFV(ISW)
4870 ISW=ISW+1
4880 DCVAL=NFV(ISW-1)
4890 ARATE=RATE
4900 IF(DCVAL)72,73,74
4910 72 ARATE=ARATE-.001
4920 ASF=1+ARATE
4930 DCFROR=-(0.6*LTCINV)-(0.3*LTCINV*(1/ASF**1))-(0.1*LTCINV)*
4931 +(1/ASF**2)+(CF1*(1/ASF**3)+(CF2*(1/ASF**4))
4932 +(SF**12-1)/(RATE*SF**12)+(CF4*(1/ASF**18))
4933 +(SF**EX1-1)/(RATE*SF**EX1))+LUC*(1/ASF**EX)
4934 IF(DCFROR .LT. 0.) GO TO 72
4950 73 DCFROR=ARATE
4960 GO TO 75
4970 74 ARATE=ARATE+.001
4980 ASF=1+ARATE
4990 DCFROR=-(0.6*LTCINV)-(0.3*LTCINV*(1/ASF**1))-(0.1*LTCINV)*
5000 +(1/ASF**2)+(CF1*(1/ASF**3)+(CF2*(1/ASF**4))
5001 +(SF**12-1)/(RATE*SF**12)+(CF4*(1/ASF**18))
5002 +(SF**EX1-1)/(RATE*SF**EX1))+LUC*(1/ASF**EX)
5003 IF(DCFROR .GT. 0.) GO TO 74
5010 DCFROR=ARATE
5020C SENSITIVITY ANALYSIS
5030C CAPITAL COST SENSITIVITY
5040 75 DO 80 I=1,4
5050 NAMES(ISW)=1
5060 IF(I.EQ.4) GO TO 79
5070 IF(I.EQ.3) GO TO 78
5080 IF(I .EQ. 2) GO TO 77
5100 LTCINV= LTCINV*1.2
5110 KI NGH (ISU)=20
5120 76 NFV (I) =((SPCAF-1)/(RATE*SPCAF)*CF3)-LTCINV+(LWC1*(1/SPCAF))
5130 NECU (ISU)=NFV (I)
5140 VALUE(ISU)=LTCINV
5150 ISU=ISU+1
5160 GO TO 80
5170 77 LTCINV=LTCINV*1.1667
5180 KI NGH (ISU)=40
5190 LWC1=LWC*1.4
5200 GO TO 76
5210 78 LTCINV=LTCINV*0.5714
5220 KI NGH (ISU)=40
5230 LWC1=LWC*0.8
5240 GO TO 76
5250 79 LTCINV=LTCINV*0.75
5260 KI NGH (ISU)=40
5270 LWC1=LWC*0.6
5280 GO TO 76
5290 80 CONTINUE
5300 LTCINV=LTCINV*1.6667
5310 OPERATING COST SENSITIVITY
5320 MLTAOC=MLTAOC+MINE
5330 DO 87 J=1,6
5340 NAMES(ISU)=J
5350 IF( I .EQ. 6) GO TO 86
5360 IF( I .EQ. 5) GO TO 85
5370 IF( I .EQ. 4) GO TO 84
5380 IF( I .EQ. 3) GO TO 83
5390 IF( I .EQ. 2) GO TO 82
5400 MLTAOC=MLTAOC*1.1
5410 KI NGH (ISU)=10
5420 81 CF5= (KREV-MLTAOC-DEPR) *(1-TAX)+DEPR
5430 NFV(J) =((SPCAF-1)/(RATE*SPCAF)*CF5)-LTCINV+(LWC1*(1/SPCAF))
5440 NECU (ISU)=NFV (J)
5450 VALUE(ISU)=MLTAOC
5460 ISU=ISU+1
5470 GO TO 87
5480 82 MLTAOC=MLTAOC*1.0909
5490 KI NGH (ISU)=20
5500 GO TO 81
5510 83 MLTAOC=MLTAOC*1.0834
5520 KI NGH (ISU)=30
5530 GO TO 81
5540 84 MLTAOC=MLTAOC*0.6923
5550 KI NGH (ISU)=-10
5560 GO TO 81
5570 85 MLTAOC=MLTAOC*0.8889
5580 KI NGH (ISU)=-20
5590 GO TO 81
5600 86 MLTAOC=MLTAOC*0.875
5610 KI NGH (ISU)=-30
5620 GO TO 81
5630 87 CONTINUE
5640 MLTAOC=MLTAOC*1.4286
5650 ALL METAL PRICE SENSITIVITY
5660 DO 94 K=1,6
5670 NAMES(ISU)=K
5680 IF( K .EQ. 6) GO TO 93
5690 IF( K .EQ. 5) GO TO 92
5700 IF( K .EQ. 4) GO TO 91
5710 IF( K .EQ. 3) GO TO 90
5720 IF( K .EQ. 2) GO TO 89
5730 KREV=KREV*1.1
5740    KHANG(ISU)=10
5750    88 CF6=(KREV-MLTAOC-DEPR)*(1-TAX)+DEPR
5760    NFV(K)=((SPCAF-1)/(RATE*SPCAF)*CF6)-LTCINV+(LWC*(1/SPCAF))
5770    NEQU(ISU)=NFU(K)
5780    VALUE(ISU)=KREV
5790    ISW=ISW+1
5800    GO TO 94
5810    89 KREV=KREV*1.0909
5820    KHANG(ISU)=20
5830    GO TO 88
5840    90 KREV=KREV*1.0834
5850    KHANG(ISU)=30
5860    GO TO 88
5870    91 KREV=KREV*0.6923
5880    KHANG(ISU)=-10
5890    GO TO 88
5900    92 KREV=KREV*0.8889
5910    KHANG(ISU)=-20
5920    GO TO 88
5930    93 KREV=KREV*0.875
5940    KHANG(ISU)=-30
5950    GO TO 88
5960    94 CONTINUE
5970    KREV=KREV*1.4286
5980    NICKEL PRICE SENSITIVITY
5990    DO 101 L=1,6
6000    NAMES(ISU)=4
6010    IF(L.EQ.6)GO TO 100
6020    IF(L.EQ.5)GO TO 99
6030    IF(L.EQ.4)GO TO 98
6040    IF(L.EQ.3)GO TO 97
6050    IF(L.EQ.2)GO TO 96
6060    ANIPR=ANIPR*1.1
6070    KHANG(ISU)=10
6080    95 KREV=NIPRD*2*ANIPR+KUPRD*2*COPR+KUPRD*2*CUPR
6090    CF7=(KREV-MLTAOC-DEPR)*(1-TAX)+DEPR
6100    NFV(L)=((SPCAF-1)/(RATE*SPCAF)*CF7)-LTCINV+(LWC*(1/SPCAF))
6110    NEQU(ISU)=NFU(L)
6120    VALUE(ISU)=ANIPR
6130    ISW=ISW+1
6140    GO TO 101
6150    96 ANIPR=ANIPR*1.0909
6160    KHANG(ISU)=20
6170    GO TO 95
6180    97 ANIPR=ANIPR*1.0834
6190    KHANG(ISU)=30
6200    GO TO 95
6210    98 ANIPR=ANIPR*0.6923
6220    KHANG(ISU)=-10
6230    GO TO 95
6240    99 ANIPR=ANIPR*0.8889
6250    KHANG(ISU)=-20
6260    GO TO 95
6270    100 ANIPR=ANIPR*0.875
6280    KHANG(ISU)=-30
6290    GO TO 95
6300    101 CONTINUE
6310    ANIPR=ANIPR*1.4286
6320    COBALT PRICE SENSITIVITY
6330    DO 108 M=1,6
6340    NAMES(ISU)=5
6350    IF(M.EQ.6)GO TO 107
6360    IF(M.EQ.5)GO TO 106
6370    IF(M.EQ.4)GO TO 105
6380    IF(M.EQ.3)GO TO 104
6390    IF(M.EQ.2)GO TO 103
6400  COPR=COFR*1.1
6410  KHANG(ISU)=10
6420  102  KREV=NIFR*2*ANIPR+KOPRD*2*COFR+KUPRD*2*CUPR
6430  CF8=(KREV-MLTAOC-DEPR)*(1-TAX)+DEPR
6440  NPV(M)=((SPCAF-1)/(RATE*SPCAF)*CF8)-LTCINV+(LUC*(1/SPCAF))
6450  NEQU(ISU)=NPV(M)
6460  VALUE(ISU)=COFR
6470  ISU=ISU+1
6480  GO TO 108
6490  103  COFR=COFR*1.0909
6500  KHANG(ISU)=20
6510  GO TO 102
6520  104  COFR=COFR*1.0834
6530  KHANG(ISU)=30
6540  GO TO 102
6550  105  COFR=COFR*0.6923
6560  KHANG(ISU)=-10
6570  GO TO 102
6580  106  COFR=COFR*0.8889
6590  KHANG(ISU)=-20
6600  GO TO 102
6610  107  COFR=COFR*0.875
6620  KHANG(ISU)=30
6630  GO TO 102
6640  108  CONTINUE
6650  COFR=COFR*1.4286
6660  COPPER PRICE SENSITIVITY
6660  C
6661  IF(CUCOMP .EQ. 0.0) GO TO 116
6670  115  N=1,6
6680  NAMES(ISU)=6
6690  IF(N .EQ. 6) GO TO 114
6700  IF(N .EQ. 5) GO TO 113
6710  IF(N .EQ. 4) GO TO 112
6720  IF(N .EQ. 3) GO TO 111
6730  IF(N .EQ. 2) GO TO 110
6740  CUPR=CUPR*1.1
6750  KHANG(ISU)=10
6760  109  KREV=NIFR*2*ANIPR+KOPRD*2*COFR+KUPRD*2*CUPR
6770  CF9=(KREV-MLTAOC-DEPR)*(1-TAX)+DEPR
6780  NPV(N)=((SPCAF-1)/(RATE*SPCAF)*CF9)-LTCINV+(LUC*(1/SPCAF))
6790  NEQU(ISU)=NPV(N)
6800  VALUE(ISU)=CUPR
6810  ISU=ISU+1
6820  GO TO 115
6830  110  CUPR=CUPR*1.0909
6840  KHANG(ISU)=20
6850  GO TO 109
6860  111  CUPR=CUPR*1.0834
6870  KHANG(ISU)=30
6880  GO TO 109
6890  112  CUPR=CUPR*0.6923
6900  KHANG(ISU)=-10
6910  GO TO 109
6920  113  CUPR=CUPR*0.8889
6930  KHANG(ISU)=-20
6940  GO TO 109
6950  114  CUPR=CUPR*0.875
6960  KHANG(ISU)=30
6970  GO TO 109
6980  115  CONTINUE
6990  CUPR=CUPR*1.4286
7000  NICKEL METAL RECOVERY SENSITIVITY
7010  116  DO 119 11=1,10
7020  NAMES(ISU)=7
7030  IF(II .GE. 6) GO TO 118
7040  ANIREC=ANIREC+0.02
7050    KANG(ISU)=2*II
7060   117 ANIPRD1=PLTFED*ANICMF*ANIREC
7070   NIPRD1=ANIPRD1
7080   NIPRD1=ANIPRD1
7090   KREV1=NIPRD1*2*ANIPFR+KOPRD*2*COFR+KUPRD*2*CUPR
7100   CF10=(KREV1-MLTACO-DEPR)*(1-TAX)+DEPR
7110   NPV(II)=(SPCAF-1)/(RATE*SPCAF)*CF10-LTCINV+(LW*(1/SPCAF))
7120   NEQU(ISU)=NPV(II)
7130   VALUE(ISU)=ANIREC*100.
7140   ISU=ISU+1
7150  GO TO 119
7160  118 IF(II .EQ. 6)ANIREC=ANIREC-0.10
7170  ANIREC=ANIREC-0.02
7180   KANG(ISU)=2*(II-5)
7190  GO TO 117
7200  119 CONTINUE
7210   ANIREC=ANIREC+0.1
7220   DO 122 JJ=1,10
7230   NAMES(ISU)=8
7240   IF(JJ .GE. 6)GO TO 121
7250   COREC=COREC+0.02
7260   KANG(ISU)=2*II
7270  120 COF'RD1=PLTFED*COCOMP*COREC
7280   KOPRD1=COPRD1
7290   KREV1=NIPRD1*2*ANIPFR+KOPRD1*2*COFR+KUPRD*2*CUPR
7300   CF11=(KREV1-MLTACO-DEPR)*(1-TAX)+DEPR
7310   NPV(JJ)=(SPCAF-1)/(RATE*SPCAF)*CF11-LTCINV+(LW*(1/SPCAF))
7320   NEQU(ISU)=NPV(JJ)
7330   VALUE(ISU)=COREC*100.
7340   ISU=ISU+1
7350  GO TO 122
7360  121 IF(JJ .EQ. 6)COREC=COREC-0.10
7370  COREC=COREC-0.02
7380   KANG(ISU)=-2*(JJ-5)
7390  GO TO 120
7400  122 CONTINUE
7410   COREC=COREC+0.1
7420   123 ANICMF=ANICMF*1.1
7430   KANG(ISU)=10
7440   124 ANIPFRD1=PLTFED*ANICMF*ANIREC
7450   NIPRD1=ANIPFRD1
7460   NIPRD1=ANIPFRD1
7470   KREV1=NIPRD1*2*ANIPFR+KOPRD1*2*COFR+KUPRD*2*CUPR
7480   CF12=(KREV1-MLTACO-DEPR)*(1-TAX)+DEPR
7490   NPV(KK)=(SPCAF-1)/(RATE*SPCAF)*CF12-LTCINV+(LW*(1/SPCAF))
7500   NEQU(ISU)=NPV(KK)
7510   VALUE(ISU)=ANICMF*100.
7520   ISU=ISU+1
7530  GO TO 127
7540  125 ANICMF=ANICMF*1.0909
7550   KANG(ISU)=20
7560  GO TO 123
7570  126 ANICMF=ANICMF*0.75
7580   KANG(ISU)=-10
7590  GO TO 123
7600  127 CONTINUE
7610  128 ANICMF=ANICMF*1.0909
7620   KANG(ISU)=20
7630  GO TO 123
7640  129 ANICMF=ANICMF*0.8889
7650   KANG(ISU)=-20
7660  GO TO 123
7670  128 CONTINUE
7680  129 ANICMF=ANICMF*1.25
7700  COBALT GRADE SENSITIVITY
7700  DO 132 LL=1,4
7720  NAMES(ISW)=10
7730  IF(LL .EQ. 4) GO TO 131
7740  IF(LL .EQ. 3) GO TO 130
7750  IF(LL .EQ. 2) GO TO 129
7760  COC0MP=COC0MP*1.1
7770  KHA NG(ISW)=10
7780  128 CP R D1 = P LTFED * C O C 0 M P * C O R E C
7790  KOPRD1=KOPRD1
7800  KREV=KREV + BP RF1 * 2 * ANICMP * ANIREC + BCPRD1 * 2 * C0PR + BCPRD2 * 2 * CUPR
7810  CF14 = (KREV - M LTAD1 - DEPR) * (1 - TAX) + DEPR
7820  NPV(LL) = ((SPCAF - 1) / (RATE * SPCAF) * CF14) - LTCINV + (LWC * (1 / SPCAF))
7830  NEQU(ISW) = NPV(LL)
7840  VALUE(ISW) = COC0MP * 100.
7850  ISW = ISW + 1
7860  GO TO 132
7870  129 COC0MP = COC0MP * 1.0909
7880  KHA NG(ISW)=20
7890  GO TO 128
7900  130 COC0MP = COC0MP * 0.75
7910  KHA NG(ISW)= -10
7920  GO TO 128
7930  131 COC0MP = COC0MP * 0.8889
7940  KHA NG(ISW)= -20
7950  GO TO 128
7960  132 CONTINUE
7970  COC0MP = COC0MP * 1.25
7980  IF(NFUEL .NE. 2) GO TO 138
7990  TFUEL = TFUEL + FUEL4 + FUEL0 + FUEL R
8000  TFUEL1 = TFUEL
8010  TFUEL1 = TFUEL
8020  DO 137 MM=1,4
8030  NAMES(ISU)=11
8040  IF(MM .EQ. 4) GO TO 136
8050  IF(MM .EQ. 3) GO TO 135
8060  IF(MM .EQ. 2) GO TO 134
8070  TFUEL1 = TFUEL * 1.2
8080  KHA NG(ISW)=20
8090  133 M LTAD1 = M LTAD1 - TFUEL + TFUEL1
8100  CF14 = (KREV - M LTAD1 - DEPR) * (1 - TAX) + DEPR
8110  NPV(MM) = ((SPCAF - 1) / (RATE * SPCAF) * CF14) - LTCINV + (LWC * (1 / SPCAF))
8120  NEQU(ISW) = NPV(MM)
8130  VALUE(ISW) = TFUEL1
8140  ISW = ISW + 1
8150  GO TO 137
8160  134 TFUEL1 = TFUEL * 1.4
8170  KHA NG(ISW)=40
8180  GO TO 133
8190  135 TFUEL1 = TFUEL * 1.6
8200  KHA NG(ISW)=60
8210  GO TO 133
8220  136 TFUEL1 = TFUEL * 1.8
8230  KHA NG(ISW)=80
8240  GO TO 133
8250  137 CONTINUE
8260  IF(NN .EQ. 3) GO TO 141
8270  IF(NN .EQ. 2) GO TO 140
8280  BPLTFED = BPLTFED * 0.9
8290  KHA NG(ISW)= -10
8300  139 BNPFRD = BPLTFED + ANICMP + ANIREC
8310  BCOPRD = BPLTFED * COC0MP * COREC
8320  BCUPRD = BPLTFED * COC0MP * CUR E C
8330  CF01 = BNPFRD * 2 * ANICPR + BCOPRD * 2 * C0PR + BCUPRD * 2 * CUPR
\[ C_{15} = (K_{REV1-MLTAOC-DEPR} \times (1-TAX) + DEPR \times L_{TICINVN} + (LWC \times (1/S_{CAF1})) \]

\[ NPV(NN) = \frac{(S_{CAF1} - 1)}{(RATE \times S_{CAF1}) \times C_{15}} - L_{TICINVN} + (LWC \times (1/S_{CAF1})) \]

\[ NEQ(ISU) = NPV(NN) \]

\[ VALUE(ISW) = BPLTFED \]

\[ ISU = ISU + 1 \]

GO TO 142

\[ BPLTFED = BPLTFED \times 0.8889 \]

\[ KHANG(ISU) = -20 \]

GO TO 139

\[ BPLTFED = BPLTFED \times 0.875 \]

\[ KHANG(ISU) = -30 \]

GO TO 139

CONTINUE

**DISCOUNT RATE SENSITIVITY**

DO 147 I3 = 1, 4

IF (I3 .EQ. 4) GO TO 146

IF (I3 .EQ. 3) GO TO 145

IF (I3 .EQ. 2) GO TO 144

IF (I3 .EQ. 1) GO TO 147

RATE1 = RATE + 0.03

KANG(ISU) = 3

SPCAF1 = (1+RATE1)^NLS

\[ NPV(13) = \frac{(S_{CAF1} - 1)}{(RATE1 \times S_{CAF1}) \times C_{15}} - L_{TICINVN} + (LWC \times (1/S_{CAF1})) \]

\[ NEQ(ISU) = NPV(13) \]

\[ VALUE(ISW) = RATE1 \]

\[ ISU = ISU + 1 \]

GO TO 147

RATE1 = RATE1 + 0.03

KANG(ISU) = 6

GO TO 143

RATE1 = RATE1 - 0.09

KANG(ISW) = -6

GO TO 143

RATE1 = RATE1 - 0.03

KANG(ISU) = -6

GO TO 143

CONTINUE

ISW = ISW - 1

ANI_REC = ANIREC*100

CORE = COREC*100

CURE = CUREC*100

ANICMP = ANICMP*100

COCOMP = COCOMP*100

F = FE*100

SIO2 = SIO2*100

AL2O3 = AL2O3*100

OMG = OMG*100

CAO = CAO*100

B = BROM*100

BMOIST = BROM*100

\[ INPUT DATA LOGSHEET \]

\[ 'PROJECT IDENTIFICATIONS' \]

\[ 'ANNUAL PLANT THROUGHPUT DRY SHORT TONS' \]

\[ 'NICKEL DRY' \]

\[ 'COBALT DRY' \]

\[ 'COBALT RECOVERY' \]

\[ 'IRON DRY' \]

\[ 'SI02 DRY' \]

\[ 'AL2O3 DRY' \]

\[ 'SO2 DRY' \]

\[ 'CAO DRY' \]

\[ 'OVERSIZE FRACTION' \]

\[ 'FEED MOISTURE' \]

\[ 'RELATIVE LABOR RATE' \]

\[ 'PROJECT IDENTIFICATION' \]

\[ 'ANNUAL PLANT THROUGHPUT DRY SHORT TONS' \]

\[ 'NICKEL DRY' \]

\[ 'COBALT DRY' \]

\[ 'COBALT RECOVERY' \]

\[ 'OVERSIZE FRACTION' \]

\[ 'FEED MOISTURE' \]

\[ 'RELATIVE LABOR RATE' \]
ANCILLARIES AND SUPPORT FACILITIES

TOTAL DIRECT COSTS
SPARE PARTS
ENGINEERING AND
CONSTRUCTION EXPENSES
TOTAL DIRECT AND INDIRECT COSTS
SPARE PARTS
TRANSPORTATION
ENGINEERING AND CONSTRUCTION EXPENSES
TOTAL DIRECT AND INDIRECT COSTS
CONTINGENCY
CONTRACTORS FEE
WORKING CAPITAL
TOTAL CAPITAL INVESTMENT

SUMMARY OF DIRECT OPERATING COSTS
ORE PREPARATION AND HANDLING
ROASTING AND OFF-GAS
LEACHING AND WASHING
SOLVENT EXTRACTION
ELECTROWINNING
AUXILIARIES ANCILLARIES AND SUPPORT FACILITIES
TOTAL ANNUAL OPERATING COST
TOTAL POWER REQUIREMENT KWH

AREA 20 ORE PREPARATION AND HANDLING
THROUGHPUT STPH DRY MTPH DRY
CRUSHED GROUND STOCKPILE 248,700 UET TONNES
DRYING TYPE ROTARY KILN
NUMBER OF DRYERS DRYER FEED RATE
FEED MOISTURE PRODUCT MOISTURE DRYING TEMPERATURE DEG C DRYER DUST CARRYOVER
CAPITAL COST POWER REQUIREMENT

AREA 30 ROASTING AND OFF-GAS TREATMENT
THROUGHPUT STPH DRY MTPH DRY
ROASTER FEED RATE ORE INLET TEMPERATURE DEG C ORE EXIT TEMPERATURE DEG C OFF GAS TEMPERATURE DEG C RESIDENCE TIME

AREA 40 LEACHING AND WASHING
SOLIDS SIZE DISTRIBUTION
WET CYCLONE FEED SOLIDS CYCLONE OVERFLOW SOLIDS LEACHING STAGES FLOW COUNTER-CURRENT TEMPERATURE DEG C PRESSURE

POWER REQUIREMENT KWH

WRITE(6,174) FF ROMFED ROMFDM ROMFEU ROMFUM NUMDYR
WRITE(6,230) IEPOCST IFUELOyIALABRO yAMMO yICONS yICAMG KOCORE
WRITE(6,175) FF RSTCAL RSTCLM
WRITE(6,176) FF RSTCAL RSTCLM
WRITE(6,177) FF RSTIN RSTINM NUMRST RSTFER RSTFTR LCCRST JEPWR
WRITE(6,178) FF RSTCAL RSTCLM
WRITE(6,179) FF RSTCAL RSTCLM
WRITE(6,180) FF RSTCAL RSTCLM
WRITE(6,181) FF RSTCAL RSTCLM
WRITE(6,182) FF RSTCAL RSTCLM
WRITE(6,183) FF RSTCAL RSTCLM
WRITE(6,184) FF RSTCAL RSTCLM
WRITE(6,185) FF RSTCAL RSTCLM
WRITE(6,186) FF RSTCAL RSTCLM
WRITE(6,187) FF RSTCAL RSTCLM
WRITE(6,188) FF RSTCAL RSTCLM
WRITE(6,189) FF RSTCAL RSTCLM
WRITE(6,190) FF RSTCAL RSTCLM
WRITE(6,191) FF RSTCAL RSTCLM
WRITE(6,192) FF RSTCAL RSTCLM
WRITE(6,193) FF RSTCAL RSTCLM
WRITE(6,194) FF RSTCAL RSTCLM
WRITE(6,195) FF RSTCAL RSTCLM
WRITE(6,196) FF RSTCAL RSTCLM
WRITE(6,197) FF RSTCAL RSTCLM
WRITE(6,198) FF RSTCAL RSTCLM
WRITE(6,199) FF RSTCAL RSTCLM
WRITE(6,200) FF RSTCAL RSTCLM
WRITE(6,201) FF RSTCAL RSTCLM
WRITE(6,202) FF RSTCAL RSTCLM
WRITE(6,203) FF RSTCAL RSTCLM
WRITE(6,204) FF RSTCAL RSTCLM
WRITE(6,205) FF RSTCAL RSTCLM
WRITE(6,206) FF RSTCAL RSTCLM
WRITE(6,207) FF RSTCAL RSTCLM
WRITE(6,208) FF RSTCAL RSTCLM
WRITE(6,209) FF RSTCAL RSTCLM
WRITE(6,210) FF RSTCAL RSTCLM
WRITE(6,211) FF RSTCAL RSTCLM
WRITE(6,212) FF RSTCAL RSTCLM
WRITE(6,213) FF RSTCAL RSTCLM
WRITE(6,214) FF RSTCAL RSTCLM
WRITE(6,215) FF RSTCAL RSTCLM
WRITE(6,216) FF RSTCAL RSTCLM
WRITE(6,217) FF RSTCAL RSTCLM
10520 A14X,'60 MINUTES/STAGE',/,'18X,'SOLIDS,WEIGHT %',/,'13X,'
10530 &'20',/,'18X,'THICKNER UNDERFLOW SOLIDS',/,'3X',/,'50 WT %',/,'/
10540 &'18X,'PREGNANT LIQUOR ANALYSIS',/,'37X,'NI',/,'4X',/,'12.0',/,'1X',/,'G/L')
10550 IF(CUCOMP .EQ. 0.0) GO TO 178
10560 WRITE(6,177)
10570 177 FORMAT(37X,'CU',/,'5X',/,'3.6 G/L')
10580 178 WRITE(6,179)LCLCH+LEFWRL
10590 179 FORMAT(37X,'CO',/,'5X')
10600 &'0.55 G/L',/,'37X,'NH3',/,'3X',/,'75.',/,'3X',/,'G/L',/,'37X','CO2',/,'3X',
10610 &'50.',/,'3X',/,'G/L',/,'18X,'WASHING STAGES',/,'14X',/,'5/',/
10620 &'18X,'FLOW',/,'24X,'COUNTER-CURRENT',/,'18X,'TEMPERATURE',/,
10630 &'18X,'AMBIENT',/,'18X,'PRESSURE',/,'20X,'ATMOSPHERIC',/,'18X',
10640 &'THICKNER UNDERFLOW SOLIDS',/,'3X',/,'50 WT %',/,'18X',
10650 &'WASH RATIO',/,'18X',/,'1.0',/,'18X,'EFFICIENCY',/,'18X',/,'97 %',/
10660 &'12X,'CAPITAL COST',/,'(000)',/,'12X',/,'16/',/
10670 &'12X,'POWER REQUIREMENT',/,'KWH',/,'17X'
10680 WRITE(6,180)IEPLCST,IMAGO,IALABRL,IAMAINL,ICDNSL,ICHEML,L0CLC
10690 WRITE(6,181)FF
10700 180 FORMAT(1X,A4,9X,'AREA 50 SOLVENT',/)
10710 &'EXTRACTION',/,'18X','PAGE 6',//
10720 IF(CUCOMP .EQ. 0.0) GO TO 182
10730 WRITE(6,181)
10740 181 FORMAT(15X,'NICKEL COPPER EXTRACTION')
10750 GO TO 184
10760 182 WRITE(6,183)
10770 183 FORMAT(15X,'NICKEL EXTRACTION')
10780 184 WRITE(6,185)
10790 185 FORMAT(18X,'EQUIPMENT',/,'17X','COVERED MIXER-SETTLERS',/,,
10800 &'44X,'WITH TURBINE',
10810 &'TYPE',/,'44X,'PUMPING MIXERS',/,'18X,'MIXER RESIDENCE',
10820 &'TIME',/,'6X',/,'3 MINUTES',/,'18X,'NUMBER OF STAGES',/,'10X',/,'3',/,,
10830 &'FLOW',/,'22X,'COUNTER-CURRENT',/,'18X,'Q:RATIO',
10840 &'WITHOUT',/,'21X,'INTERNAL RECYCLE',/,'7X',/,'2.51/',/,,
10850 &'Q:RATIO WITH',/,'21X,'INTERNAL RECYCLE',/,'7X',
10860 &'111',/,'18X,'NI EXTRACTION',/,'3X',/,'100 %')
10870 IF(CUCOMP .EQ. 0.0) GO TO 187
10880 WRITE(6,186)
10890 186 FORMAT(18X,'CU EXTRACTION',/,'13X',/,'100 %')
10900 187 WRITE(6,188)
10910 188 FORMAT(18X,'AQUEOUS ENTRAINMENT',/,'21X,'BY ORGANIC',/,'13X',/,'0.5 VOL.%',/,,
10920 &'OF ORGANIC',/,'18X,'NH3 ABSORBED BY DILUENT',/,'3X',
10930 &'0.5 % OF AQUEOUS CONTENT',/,,
10940 WRITE(6,189)
10950 189 FORMAT(15X,'AQUEOUS FEED ANALYSIS',/,'21X,'NI',
10960 &'7X',/,'12.0 G/L')
10970 IF(CUCOMP .EQ. 0.0) GO TO 191
10980 WRITE(6,190)
10990 190 FORMAT(18X,'CU EXTRACTION',/,'13X',/,'100 %')
11000 191 WRITE(6,192)
11010 192 FORMAT(21X,'CO',/,'8X',/,'0.55 G/L',/,'21X','NH3',/,'6X',/,'75.0 G/L',/,,
11020 &'3X',/,'ORGANIC FEED',/,,
11030 &'18X','THE ORGANIC FEED IS A 25 VOL./VOL.%',/,,
11040 &'SOLUTION OF GENERAL MILLS LIX-65N IN KEROSENE',/,,
11050 &'18X','MAXIMUM NI LOADING',/,'8X',/,'5.6 G/L')
11060 IF(CUCOMP .EQ. 0.0) GO TO 194
11070 WRITE(6,193)
11080 193 FORMAT(18X,'MAXIMUM CU LOADING',/,'8X',/,'1.9 G/L')
11090 194 WRITE(6,195)
11100 195 FORMAT(18X,'DESIGN NI LOADING',/,'9X',/,'5.0 G/L')
11110 IF(CUCOMP .EQ. 0.0) GO TO 197
11120 WRITE(6,196)
11130 196 FORMAT(18X,'DESIGN CU LOADING',/,'9X',/,'1.5 G/L')
11140 197 WRITE(6,198)
11150 198 FORMAT(18X,'NI CONTENT',/,'16X',/,'0.2 G/L')
11160 IF(CUCOMP .EQ. 0.0) GO TO 201
11170 WRITE(6,199)
11180  199 FORMAT(18X"CU CONTENT",16X",0.05 G/L")
11190  WRITE(6,200)
11200  200 FORMAT(15X"AMMONIA SCRUBBING NICKEL-COPPER CIRCUIT")
11210  GO TO 203
11220  201 FORMAT(15X"AMMONIA SCRUBBING NICKEL CIRCUIT")
11230  GO TO 204
11240  202 FORMAT(15X"EQUIPMENT",17X"PACKED TOWER",/18X"FLOW",22X,
11250  &"COUNTER-CURRENT",/18X"DISPERSED PHASE",/11X"AMBIENT",/18X"AMMONIA SCRUBBING NICKEL CIRCUIT")
11260  GO TO 203
11270  &"TEMPERATURE",/15X"AMBIENT",/18X"PRESSURE",/18X,
11280  &"50 PSIG(345 K PA)"/18X"RESIDENCE TIME",/12X,"2 MINUTES")
11290  &"8X"0:1 A RATIO WITHOUT","/21X"INTERNAL RECYCLE",/7X,
11300  &"5:1"/18X"0:1 A RATIO WITH","/21X"INTERNAL RECYCLE",/7X,
11310  &"7X"1S1","/18X"AMMONIA SCRUBBING EFFICIENCY","/21X"BY ORGANIC",/13X,
11320  &"0.5 VOL.% OF ORGANIC")
11330  WRITE(6,205)
11340  205 FORMAT(15X"NICKEL STRIPPING",/21X,
11350  &"EQUIPMENT","/44X"WITH TURBINE","/44X"PUMPING MIXERS",/18X"MIXER RESIDENCE",/18X"NUMBER OF STAGES",/10X,"4",/,
11360  &"FLOW",/22X"COUNTER-CURRENT",/18X"0:1 A RATIO",/,
11370  &"WITHOUT","/21X"INTERNAL RECYCLE",/7X,"3.75:1",/,
11380  &"8X"0:1 A RATIO WITH","/21X"INTERNAL RECYCLE",/7X,
11390  &"1S1","/18X"NI TRANSFER TO AQUEOUS","/18X"Ni TRANSFER TO ORGANIC","/4X",/18X"AQUEOUS ENTRAINMENT","/18X"BY ORGANIC","/13X,
11400  &"0.5 VOL.% OF ORGANIC")
11410  WRITE(6,206)
11420  206 FORMAT(15X"COPPER STRIPPING",/18X"MIXER RESIDENCE",/18X"NUMBER OF STAGES",/10X,"3",/,
11430  &"FLOW",/22X"COUNTER-CURRENT",/18X"0:1 A RATIO",/
11440  &"WITHOUT","/21X"INTERNAL RECYCLE",/7X,"5:1",/,
11450  &"1S1","/18X"CU TRANSFER TO AQUEOUS","/18X"CU TRANSFER TO ORGANIC","/4X",/18X"AQUEOUS ENTRAINMENT","/21X"BY ORGANIC",/13X,
11460  &"0.5 VOL.% OF ORGANIC")
11470  IF(CUCOMP .EQ. 0.0)GO TO 207
11480  WRITE(6,207)
11490  207 FORMAT(15X"COBALT REDUCTION",/18X"EQUIPMENT",/
11500  &"SHREDDED COBALT","/18X"CATHODES AND SCRAP","/18X"RESIDENCE",/18X"UPFLOW",/18X"TEMPERATURE",/15X,
11510  &"1MINUTE",/18X"PRESSURE",/18X"ATMOSPHERIC")
11520  WRITE(6,208)
11530  208 FORMAT(15X"COBALT EXTRACTION",/18X"MIXER RESIDENCE",/18X"NUMBER OF STAGES",/10X,"3",/,
11540  &"FLOW",/22X"COUNTER-CURRENT",/18X"0:1 A RATIO",/
11550  &"WITHOUT","/21X"INTERNAL RECYCLE",/7X,"1S1",/,
11560  &"1S1","/18X"CO EXTRACTION","/18X"100 VOL.%","/18X"AQUEOUS ENTRAINMENT","/21X"BY ORGANIC",/13X,
11570  &"0.5 VOL.% OF AQUEOUS CONTENT")
11580  WRITE(6,209)
11590  209 FORMAT(15X"ORGANIC FEED","/18X"THE ORGANIC FEED IS A SOLUTION OF 3 VOL.% GENERAL MILLS","/18X"X1-51 WITH 94 % KEROSENE AND 3 % ISODECONAL")
11600  WRITE(6,210)
11610  210 FORMAT(15X"ORGANIC FEED","/36X")
11620  &"PAGE 8","/18X"THE ORGANIC FEED","/18X"MILLS","/18X"X1-51 WITH 94 % KEROSENE AND 3 % ISODECONAL"]
211 FORMAT(15X,'AMMONIA SCRUBBING COBALT CIRCUIT',/)
212 FORMAT(15X,'COBALT STRIPPING',/)
214 FORMAT(1X,'A',/,'9X','AREA 60 ELECTROWINNING',21X)
215 FORMAT(15X,'ELECTROLYTE',12X,'FREQUENT',12X,'SPENT',/)
216 FORMAT(15X,'NICKEL ELECTROWINNING',/)
217 FORMAT(15X,'CELL TYPE',17X)
218 FORMAT(15X,'DIAPHRAGM',/)
219 FORMAT(15X,'CATHODES PER CELL',9X,'42',/)
220 FORMAT(15X,'ANODES PER CELL',/,'11X',43,/,18X,'ANODE TYPE',16X)
221 FORMAT(15X,'CALCUL-LEAD',/)
222 FORMAT(15X,'CURRENT DENSITY',/)
223 FORMAT(15X,'CATHODE PULL WEIGHT',21.6 L.B(9.8 KG))
224 FORMAT(15X,'COPPER ELECTROWINNING',/)
225 FORMAT(15X,'ELECTROWINNING',/)
226 FORMAT(15X,'ELECTROLYTE',12X,'FREQUENT',12X,'SPENT',/)
227 FORMAT(15X,'NICKEL ELECTROWINNING',/)
228 FORMAT(15X,'CELL TYPE',17X)
229 FORMAT(15X,'DIAPHRAGM',/)
230 FORMAT(15X,'CATHODES PER CELL',9X,'42',/)
231 FORMAT(15X,'ANODES PER CELL',/,'11X',43,/,18X,'ANODE TYPE',16X)
232 FORMAT(15X,'CALCUL-LEAD',/)
233 FORMAT(15X,'CURRENT DENSITY',/)
234 FORMAT(15X,'CATHODE PULL WEIGHT',7X,'21.6 LB(9.8 KG))
235 FORMAT(15X,'NICKEL STARTER SHEET PREPARATION',/)
236 FORMAT(15X,'ELECTROWINNING',/)
237 FORMAT(15X,'ELECTROLYTE',12X,'FREQUENT',12X,'SPENT',/)
238 FORMAT(15X,'NICKEL ELECTROWINNING',/)
239 FORMAT(15X,'CELL TYPE',17X)
240 FORMAT(15X,'DIAPHRAGM',/)
241 FORMAT(15X,'CATHODES PER CELL',9X,'42',/)
242 FORMAT(15X,'ANODES PER CELL',/,'11X',43,/,18X,'ANODE TYPE',16X)
243 FORMAT(15X,'CALCUL-LEAD',/)
244 FORMAT(15X,'CURRENT DENSITY',/)
245 FORMAT(15X,'CATHODE PULL WEIGHT',7X,'21.6 LB(9.8 KG))
246 FORMAT(15X,'NICKEL ELECTROWINNING',/)
247 FORMAT(15X,'CELL TYPE',17X)
248 FORMAT(15X,'DIAPHRAGM',/)
249 FORMAT(15X,'CATHODES PER CELL',9X,'42',/)
250 FORMAT(15X,'ANODES PER CELL',/,'11X',43,/,18X,'ANODE TYPE',16X)
251 FORMAT(15X,'CALCUL-LEAD',/)
252 FORMAT(15X,'CURRENT DENSITY',/)
253 FORMAT(15X,'CATHODE PULL WEIGHT',7X,'21.6 LB(9.8 KG))
254 FORMAT(15X,'NICKEL ELECTROWINNING',/)
255 FORMAT(15X,'CELL TYPE',17X)
256 FORMAT(15X,'DIAPHRAGM',/)
257 FORMAT(15X,'CATHODES PER CELL',9X,'42',/)
258 FORMAT(15X,'ANODES PER CELL',/,'11X',43,/,18X,'ANODE TYPE',16X)
259 FORMAT(15X,'CALCUL-LEAD',/)
260 FORMAT(15X,'CURRENT DENSITY',/)
261 FORMAT(15X,'CATHODE PULL WEIGHT',7X,'21.6 LB(9.8 KG))
262 FORMAT(15X,'NICKEL ELECTROWINNING',/)
263 FORMAT(15X,'CELL TYPE',17X)
264 FORMAT(15X,'DIAPHRAGM',/)
265 FORMAT(15X,'CATHODES PER CELL',9X,'42',/)
266 FORMAT(15X,'ANODES PER CELL',/,'11X',43,/,18X,'ANODE TYPE',16X)
CURRENT EFFICIENCY: 95 %

WEIGHT: 162.9 LB (73.9 KG)

CATHODE DAYS IN CELL: 6

6' CURRENT EFFICIENCY '95 Z

WEIGHT: 162.9 LB (73.9 KG)

CATHODE DAYS IN CELL: 6

6' CURRENT EFFICIENCY '95 Z

WEIGHT: 23.4 LB (10.6 KG)

CATHODE DAYS IN CELL: 2

GO TO 222

ELECTROLYTE

PREGNANT

SPECIAL

ELECTROLYTE

PREGNANT

SPECIAL

Temperature Degr. C: 50

55

218 FORMAT

COPPER SHEET

PREPARATION

CELL TYPE

CONVENTIONAL

CATHODES PER CELL: 42

ANODES PER CELL: 43

ANODE TYPE: CALCIUM-LEAD

CELL VOLTAGE: 2.1 VOLTS

CURRENT DENSITY: 20 A/FT2 (215 A/M2)

CURRENT EFFICIENCY: 95 %

CATHODE PULL WEIGHT: 23.4 LB (10.6 KG)

CATHODE DAYS IN CELL: 2

GO TO 222

COBALT ELECTROWINNING

PAGE 11

CURRENT EFFICIENCY: 95 %

WEIGHT: 150.8 LB (68.4 KG)

CATHODE DAYS IN CELL: 6

WRITE (6, 226)

ELECTROLYTE

PREGNANT

SPECIAL

Temperature Degr. C: 60

65

13 FORMAT

COBALT ELECTROWINNING

PAGE 11

CURRENT EFFICIENCY: 95 %

WEIGHT: 150.8 LB (68.4 KG)

CATHODE DAYS IN CELL: 6

WRITE (6, 226)

ELECTROLYTE

PREGNANT

SPECIAL

Temperature Degr. C: 60

65
THE NET PRESENT VALUE (NPV) OF THIS INVESTMENT AT THE MINIMUM ACCEPTABLE RATE OF RETURN OF $4.1\%$ IS $8.1\%$. THE ANNUAL CASH FLOW FOR THE PROJECT IS $1\%F4.1\%IX'%.'

C: SORTING FOR SENSITIVITY ANALYSIS

DO 235 KLOP=1,ISW

BNPV(KLOP)=NEQU(KLOP)

IF(T=0)

CNPV=NEQU(1)

DO 240 KK=1,ISW

IF(BNPV(KK)-LT.BIGNPV)GO TO 236

BIGNPV=BNPV(KK)

IF(T=KK)

CONTINUE

BNPV(IPT)=-1000000.0

JNO=NAMES(IPT)

PCHA=(BNPV-CNPFV)/CNPFV*100.

PNTNPV=BASENPV*(PCHA/100)

IF(MNS.EQ.1)GO TO 237

NPMEN(MNS)=NPMEN(MNS-1)+PNTNPV

PSNOD(MNS)=PNTNPV

MNS=MNS+1

GO TO 238

NPMEN(MNS)=PNTNPV

PSNOD(MNS)=PNTNPV

MNS=MNS+1

GO TO 238

IF(KO.EQ.27)WRITE(6,233)FF

WRITE(6,239)K0,(NMNPV(JB*JNO),JB=1,6),KANG(IPT),VALUE(IPT),

&FNPV+FCHA

CONTINUE

MEAN PROFITABILITY

MNS=MNS-1

MEAN=NPMEN(MNS)/MNS

CTEST=0

DO 241 MSW=1,MNS

ATEST=(PSNOD(MSW)-MEAN)

BTEST=(ATEST)**2

CTEST=CTEST+BTEST

CISW=ISW-1

STDEV=SQRT(CTEST/CISW)

CVP=STDEV/MEAN

IPAGE=IPAGE+1
WRITE(*,242) IF, IPAGE, MEAN, STDEV, CV
242 FORMAT(1X,A4,////////////////////////, 63X, 'PAGE', 1X, I2, '/', 29X, 'PROJECT PROFIT',
        1X, 'ABILITY', '/\15X, 'THE MEAN PROFITABILITY VALUE ',
        1X, 'FOR THE PROJECT IS ', I1, '/\15X, 'WITH A STANDARD DEVIATION ',
        1X, 'OF ', F8.1, '\15X, 'THE COEFFICIENT OF VARIATION ',
        1X, 'IN PROFITABILITY', '/\15X, 'OF THE PROJECT IS', I1, F6.2)
WRITE(*,243) IF
243 FORMAT(1X, A4)
STOP 1
END
APPENDIX III

EQUIPMENT LISTS
## Equipment List: Ore Preparation

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>kw</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion Air Blower</td>
<td>4</td>
<td>2388</td>
<td>95,000 SCFM</td>
</tr>
<tr>
<td>Dried Ore Storage Bin</td>
<td>1</td>
<td></td>
<td>36'D x 36'H</td>
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<tr>
<td>Fine Ore Storage Silo</td>
<td>4</td>
<td></td>
<td>49'D x 49'H</td>
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<tr>
<td>Double Roll Crusher</td>
<td>1</td>
<td>298</td>
<td>4.5'D x 6'</td>
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<tr>
<td>Hammermill</td>
<td>2</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Coarse Ore Conveyor</td>
<td>1</td>
<td>416</td>
<td>3.5'W x 2000'L</td>
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<tr>
<td>Coarse Ore Stacker</td>
<td>1</td>
<td>25</td>
<td>3.5'W x 3000'L; 500 TPH</td>
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<tr>
<td>Dryer Discharge Conveyor</td>
<td>4</td>
<td>16</td>
<td>2.0'W x 102'L; 104 TPH</td>
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<tr>
<td>Dried Ore Conveyor</td>
<td>2</td>
<td>30</td>
<td>3.0'W x 250'L; 220 TPH</td>
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<tr>
<td>Dryer Fines Conveyor</td>
<td>1</td>
<td>2</td>
<td>32 TPH; 50'L</td>
</tr>
<tr>
<td>Fine Ore Elevator</td>
<td>1</td>
<td>37</td>
<td>320 TPH; 90'H</td>
</tr>
<tr>
<td>Fine Ore Screw Conveyor</td>
<td>4</td>
<td>16</td>
<td>320 TPH; 50'L</td>
</tr>
<tr>
<td>Bucket Elevator</td>
<td>8</td>
<td>48</td>
<td>40 TPH; 90'H</td>
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<tr>
<td>Dryer Cyclone</td>
<td>4</td>
<td></td>
<td>135,000 SCFM</td>
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<tr>
<td>Dryer Baghouse</td>
<td>4</td>
<td></td>
<td>135,000 SCFM</td>
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<tr>
<td>Ball Mill Baghouse</td>
<td>1</td>
<td></td>
<td>447,000 SCFM</td>
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<tr>
<td>Ore Dryer</td>
<td>4</td>
<td>300</td>
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<td>Dryer Off-Gas Fan</td>
<td>4</td>
<td>2388</td>
<td>219,000 SCFM</td>
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<tr>
<td>Ball Mill Exhaust Fan</td>
<td>1</td>
<td>597</td>
<td>235,000 SCFM</td>
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<tr>
<td>Dryer Pan Feeder</td>
<td>4</td>
<td>4</td>
<td>176 TPH</td>
</tr>
<tr>
<td>Item</td>
<td>Quantity</td>
<td>kw</td>
<td>Size</td>
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<tr>
<td>----------------------</td>
<td>----------</td>
<td>-----</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Front End Loader</td>
<td>2</td>
<td></td>
<td>20 ft³ capacity</td>
</tr>
<tr>
<td>Ball Mill</td>
<td>1</td>
<td>1864</td>
<td>14'D x 25'L</td>
</tr>
<tr>
<td>Grizzly Screen</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed Hopper</td>
<td>4</td>
<td></td>
<td>190 yd³</td>
</tr>
<tr>
<td>Reclaimer</td>
<td>1</td>
<td>25</td>
<td>520 TPH</td>
</tr>
<tr>
<td>Coarse Ore Transfer</td>
<td>1</td>
<td>6</td>
<td>520 TPH</td>
</tr>
<tr>
<td>Conveyor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item</td>
<td>Quantity</td>
<td>kw</td>
<td>Size</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>----------</td>
<td>-----</td>
<td>-------------------</td>
</tr>
<tr>
<td>Quench Tank Agitator</td>
<td>8</td>
<td>152</td>
<td></td>
</tr>
<tr>
<td>Air Blower, Roaster Preheater</td>
<td>8</td>
<td>80</td>
<td>11,200 SCFM</td>
</tr>
<tr>
<td>Air Blower, Cyclone Gasifier</td>
<td>8</td>
<td>1496</td>
<td>2,300 SCFM</td>
</tr>
<tr>
<td>Additive Bin</td>
<td>8</td>
<td>0</td>
<td>1.5'D x 3'H</td>
</tr>
<tr>
<td>Fine Ore Surge Bin</td>
<td>8</td>
<td>0</td>
<td>16'D x 33'H</td>
</tr>
<tr>
<td>Peat Surge Bin</td>
<td>8</td>
<td>0</td>
<td>9'D x 18'H</td>
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<tr>
<td>Hot Cyclone</td>
<td>8</td>
<td>0</td>
<td>47,000 SCFM</td>
</tr>
<tr>
<td>Cyclone, Additive Feed</td>
<td>8</td>
<td>0</td>
<td>64 lb/hr feed rate</td>
</tr>
<tr>
<td>Cyclone, Peat Feed</td>
<td>8</td>
<td>0</td>
<td>8 TPH feed rate</td>
</tr>
<tr>
<td>Ore Screw Conveyor</td>
<td>8</td>
<td>40</td>
<td>39 TPH</td>
</tr>
<tr>
<td>Peat Screw Conveyor</td>
<td>8</td>
<td>8</td>
<td>8 TPH</td>
</tr>
<tr>
<td>Additive Screw Conveyor</td>
<td>8</td>
<td>4</td>
<td>55 lb/hr</td>
</tr>
<tr>
<td>Cyclone Burner, Gasifier</td>
<td>8</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Calcine Cooler</td>
<td>8</td>
<td>448</td>
<td>10'D x 85'L</td>
</tr>
<tr>
<td>Quencher Ore Slurry Pump</td>
<td>8</td>
<td>96</td>
<td>550 GPM</td>
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<tr>
<td>Additive Storage Tank</td>
<td>4</td>
<td>0</td>
<td>220,000 gal</td>
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<tr>
<td>Miscellaneous Additive Equipment</td>
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<tr>
<td>Gas Compressor</td>
<td>2</td>
<td>186</td>
<td></td>
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<tr>
<td>Hearth Roaster</td>
<td>8</td>
<td>208</td>
<td>17 hearth; 26'O.D.</td>
</tr>
<tr>
<td>Item</td>
<td>Quantity</td>
<td>kw</td>
<td>Size</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>----------</td>
<td>----</td>
<td>-----------------</td>
</tr>
<tr>
<td>Quench Tank</td>
<td>8</td>
<td>0</td>
<td>7'D x 7'H</td>
</tr>
<tr>
<td>Slag Granulator</td>
<td>8</td>
<td>0</td>
<td>3'D x 3'L</td>
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<td>Slag Sump Tank</td>
<td>1</td>
<td>0</td>
<td>6'D x 6'H</td>
</tr>
<tr>
<td>Venturi Scrubber Hold</td>
<td>8</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Tank Agitator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demister</td>
<td>8</td>
<td>0</td>
<td>0.49' thick</td>
</tr>
<tr>
<td>Off-Gas Fan</td>
<td>8</td>
<td>896</td>
<td>28,300 SCFM</td>
</tr>
<tr>
<td>Solution Cooler</td>
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<td>0</td>
<td></td>
</tr>
<tr>
<td>Venturi Scrubber Pump</td>
<td>8</td>
<td>60</td>
<td>176 GPM</td>
</tr>
<tr>
<td>Venturi Scurbber</td>
<td>8</td>
<td>0</td>
<td>45,300 SCFM</td>
</tr>
<tr>
<td>Venturi Scrubber Hold</td>
<td>8</td>
<td>0</td>
<td>8'D x 8'H</td>
</tr>
<tr>
<td>Tank</td>
<td></td>
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</table>
## Equipment List: Leaching and Washing

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>kw</th>
<th>Size</th>
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<tbody>
<tr>
<td>Leach 1 Agitator</td>
<td>1</td>
<td>107</td>
<td></td>
</tr>
<tr>
<td>Leach 2 Agitator</td>
<td>1</td>
<td>89</td>
<td></td>
</tr>
<tr>
<td>Reslurry Agitator</td>
<td>5</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Air Compressor</td>
<td>1</td>
<td>1865</td>
<td>19,700 SCFM</td>
</tr>
<tr>
<td>Ground Calcine Wet Cyclone</td>
<td>10</td>
<td>0</td>
<td>20 inch</td>
</tr>
<tr>
<td>Pregnant Liquor Polish Filter</td>
<td>2</td>
<td>0</td>
<td>538 ft²</td>
</tr>
<tr>
<td>Leach Cooler</td>
<td>2</td>
<td>0</td>
<td>37,000 ft²</td>
</tr>
<tr>
<td>Quenched Calcine Ball Mill</td>
<td>1</td>
<td>1864</td>
<td>15'D x 32'L</td>
</tr>
<tr>
<td>Cyclone Feed Pump</td>
<td>1</td>
<td>447</td>
<td>7300 GPM</td>
</tr>
<tr>
<td>Leach 1 Cooler Circulation Pump</td>
<td>1</td>
<td>600</td>
<td>24,900 GPM</td>
</tr>
<tr>
<td>Leach 1 Overflow Pump</td>
<td>1</td>
<td>56</td>
<td>3070 GPM</td>
</tr>
<tr>
<td>Leach 1 Underflow Pump</td>
<td>1</td>
<td>30</td>
<td>1300 GPM</td>
</tr>
<tr>
<td>Leach 2 Cooler Circulation Pump</td>
<td>1</td>
<td>190</td>
<td>9200 GPM</td>
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<tr>
<td>Leach 2 Overflow Pump</td>
<td>1</td>
<td>23</td>
<td>2400 GPM</td>
</tr>
<tr>
<td>Leach 2 Underflow Pump</td>
<td>1</td>
<td>19</td>
<td>1290 GPM</td>
</tr>
<tr>
<td>Wash Underflow Pump</td>
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<td>76</td>
<td>1290 GPM</td>
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<tr>
<td>Wash Overflow Pump</td>
<td>5</td>
<td>110</td>
<td>2400 GPM</td>
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<tr>
<td>Tails Slurry Pump</td>
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<td>38</td>
<td>1300 GPM</td>
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<tr>
<td>Thickener</td>
<td>7</td>
<td>49</td>
<td>240'D</td>
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<tr>
<td>Item</td>
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<tr>
<td>---------------------------</td>
<td>----------</td>
<td>----</td>
<td>---------------</td>
</tr>
<tr>
<td>Cyclone Feed Surge Tank</td>
<td>1</td>
<td>0</td>
<td>23'D x 23'H</td>
</tr>
<tr>
<td>Leach Tank</td>
<td>2</td>
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<td>42'D x 42'H</td>
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<tr>
<td>Reslurry Tank</td>
<td>5</td>
<td>0</td>
<td>19'D x 19'H</td>
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</table>
# Equipment List: Nickel-Copper Extraction Circuit

<table>
<thead>
<tr>
<th>Item</th>
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<th>kw</th>
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</thead>
<tbody>
<tr>
<td>Pregnant Liquor Surge Tank</td>
<td>1</td>
<td>0</td>
<td>25'D x 25'</td>
</tr>
<tr>
<td>Surge Tank Pump</td>
<td>1</td>
<td>15</td>
<td>1390 GPM</td>
</tr>
<tr>
<td>Mixer-Settler</td>
<td>3</td>
<td>141</td>
<td>39' x 123' x 3'</td>
</tr>
<tr>
<td>Barren Liquor Coalescer</td>
<td>1</td>
<td>0</td>
<td>8'D x 26'</td>
</tr>
<tr>
<td>Barren Liquor Pump</td>
<td>1</td>
<td>45</td>
<td>1390 GPM</td>
</tr>
<tr>
<td>Barren Liquor Surge Tank</td>
<td>1</td>
<td>0</td>
<td>25'D x 25'</td>
</tr>
<tr>
<td>LIX-65N Make-up Tank</td>
<td>1</td>
<td>0</td>
<td>6'D x 6'</td>
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<tr>
<td>LIX-65N Pump</td>
<td>1</td>
<td>0.5</td>
<td>22 GPM</td>
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<tr>
<td>Kerosene Makeup Tank</td>
<td>1</td>
<td>0</td>
<td>8'D x 10'</td>
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<tr>
<td>Kerosene Metering Pump</td>
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<td>0.5</td>
<td>44 GPM</td>
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<tr>
<td>Loaded Organic Surge Tank</td>
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<td>26'D x 26'</td>
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<tr>
<td>Loaded Organic Pump</td>
<td>1</td>
<td>93</td>
<td>3480 GPM</td>
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<td>Coalescer</td>
<td>2</td>
<td>0</td>
<td>13'D x 26'</td>
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<tr>
<td>Ammonia Scrubber</td>
<td>1</td>
<td>0</td>
<td>10'D x 59'</td>
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# Equipment List: Nickel Stripping Circuit

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<th>Item</th>
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<th>Size</th>
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</thead>
<tbody>
<tr>
<td>Mixer-Settler</td>
<td>4</td>
<td>252</td>
<td>35' x 115' x 3'</td>
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<tr>
<td>Spent Nickel Electrolyte Surge Tank</td>
<td>1</td>
<td>0</td>
<td>21'D x 21'</td>
</tr>
<tr>
<td>Spent Nickel Electrolyte Pump</td>
<td>1</td>
<td>6</td>
<td>930 GPM</td>
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<tr>
<td>Pregnant Nickel Electrolyte Surge Tank</td>
<td>1</td>
<td>0</td>
<td>21'D x 21'</td>
</tr>
<tr>
<td>Pregnant Nickel Electrolyte Pump</td>
<td>1</td>
<td>19</td>
<td>930 GPM</td>
</tr>
<tr>
<td>Coalescer</td>
<td>1</td>
<td>0</td>
<td>7'D x 26'</td>
</tr>
<tr>
<td>Stripped Organic Pump</td>
<td>1</td>
<td>19</td>
<td>3480 GPM</td>
</tr>
<tr>
<td>Stripped Organic Surge Tank</td>
<td>1</td>
<td>0</td>
<td>26'D x 26'</td>
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</table>
### Equipment List: Copper Stripping Circuit

<table>
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<th>Item</th>
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</thead>
<tbody>
<tr>
<td>Mixer-Settler</td>
<td>3</td>
<td>189</td>
<td>35' x 115' x 3'</td>
</tr>
<tr>
<td>Electrolyte Surge Tank</td>
<td>3</td>
<td>0</td>
<td>20'D x 20'</td>
</tr>
<tr>
<td>Pregnant Copper Electrolyte Pump</td>
<td>1</td>
<td>15</td>
<td>700 GPM</td>
</tr>
<tr>
<td>Spent Copper Electrolyte Pump</td>
<td>1</td>
<td>4</td>
<td>700 GPM</td>
</tr>
<tr>
<td>Stripped Organic Pump</td>
<td>1</td>
<td>19</td>
<td>3480 GPM</td>
</tr>
<tr>
<td>Coalescer</td>
<td>1</td>
<td>0</td>
<td>7'D x 23'</td>
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### Equipment List: Cobalt Extraction and Stripping Circuit

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<th>Item</th>
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<th>Size</th>
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<tr>
<td>Extraction Mixer-Settler</td>
<td>3</td>
<td>57</td>
<td>25' x 80' x 3'</td>
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<tr>
<td>Stripping Mixer-Settler</td>
<td>3</td>
<td>39</td>
<td>15' x 55' x 3'</td>
</tr>
<tr>
<td>Cobalt Reduction Tower</td>
<td>1</td>
<td>0</td>
<td>8'D x 20'</td>
</tr>
<tr>
<td>Scrap Makeup Hopper</td>
<td>1</td>
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<td>Ammonia Scrubber Recycle Pump</td>
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### Equipment List: Electrowinning Plant

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<td>Nickel Electrolyte Exchanger</td>
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