The Scheduling, Costing and Importance of Metallurgical Testwork Programs in Process Plant Feasibility Studies

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ABSTRACT

The metallurgical testwork program is generally the most important critical path item for the completion of a bankable feasibility study and hence can become the critical parameter for financing of potential mining projects. This paper presents generic detailed testwork programs suitable for bankable feasibility studies for a gold leaching and polymetallic flotation study. The design of the metallurgical testwork program for each of the two differing processes is discussed and the critical factors that effect the selection of the testwork programs are highlighted. The importance of the metallurgical testwork results in predicting the metal recoveries and cash flow prediction for the project is presented. The detail of the testwork programs costing is broken into activity based methods based on the laboratory and management hours/costs, such that generic rule of thumb costing guidelines can be generated. The scheduling, costing and importance of the metallurgical testwork program to process feasibility studies are discussed in this paper.

INTRODUCTION

Generally before a bankable feasibility study (BFS) commences there is some preliminary metallurgical information available that provides guidance to the ore mineralogy, process treatment routes and the direction for future testwork. A metallurgical testwork program for a BFS is normally developed from the recommendations and conclusions of the preliminary testwork investigations.

The metallurgical testwork associated with the BFS represents one of the most important phases of the overall project development. Three of the important objectives of the feasibility metallurgical testwork program are to:

- develop the optimum process economics through the optimum revenue generation based on capital and operating costs;
- reduce the technical risks to the project; and
- keep the investors interested.

Planning the metallurgical testwork program requires careful consideration to providing bankable standard data and should provide the necessary data for the generation of reliable process and environmental design criteria.

SCHEDULING THE TESTWORK PROGRAM WITH THE BFS

The allocated time schedule and sequence of events of the metallurgical testwork are often underestimated during the preliminary execution plan of a BFS, specifically to sample extraction and environmental testwork. The metallurgical testwork program is often the critical path to producing the BFS and needs to be managed correctly. The following lists the sequence of events and the expected timing for each phase of the program:

Sample collection

The geological drilling and definition of the orebody, is expected to be completed to the JORC standard for measured mineral resource estimation. During the geological drilling program the core should be stored and extracted for metallurgical purposes, which reduces costs and time. Diamond drill core, of which there are numerous types, is the preferred material for geological interpretation and metallurgical testing. Generally there are five main sizes of diamond core used for BFS as described below:

- AQ core which is 25 mm - with total costs (including labour, consumables, capping of hole, environmental requirements) of approximately $80 – 120/metre;
- BQ core which is 36.5 mm - with total costs similar to the AQ core;
- NQ core which is 48 mm - with total costs (including labour, consumables, capping of hole, environmental requirements) of approximately $110 – 150/metre;
- HQ core which is 64 mm – with total costs (including labour, consumables, capping of hole, environmental requirements) of approximately $130 – 180/metre; and
- PQ core which is 85 mm – with total costs (including labour, consumables, capping of hole, environmental requirements) of approximately $160 – 300/metre.

The maximum costs for each diamond core can be much higher than indicated here for difficult terrain and conditions. The drilling costs per meter are average costs quoted in 2000-dollar terms.

Reverse Circulation drilling can be used for sighter tests at the beginning of the project. For a feasibility study, the standard size of diamond core required for an accuracy of ±10 per cent, is generally NQ to PQ core. For comminution testwork such as SAG/AG milling, the minimum requirement is PQ core, however for all other testwork HQ and finer core is adequate. In most feasibility studies NQ is preferred if PQ core is not required.

The time taken for the drilling program and extraction of core can vary depending on the size of the orebody, diamond core size required, geological team and previous information. For example on a recent site the extraction and compositing of PQ core samples for a pilot plant run and SAG/AG comminution testwork took approximately six weeks for completion (excluding the mobilisation of the drill team). This is broken down into the following activities:

- mobilisation of the drill team on site can be anywhere from three to eight weeks, depending on the location, drill and team availability within Australia. This includes setting up of temporary messing and accommodation facilities;
- drilling – six to 12 days (with an experienced crew and rig mobilised on-site);
- geological mapping – one day;
- core splitting, logged and bagged - two days;
- freight to testwork facility and unloading – domestically one week; and
- compositing at testwork facility – five to eight days.

In some cases more material is extracted than just core, such as a bulk sample for pilot plant testing, which can be at the site or at a proposed testing facility. Bulk samples require either trenching or accessing the underground resource and can be expensive and time consuming (anywhere from six to 12 months). The use of bulk sampling is required due to a number of factors:

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- the mineralisation could be disseminated and a drilling program would not accurately predict the metallurgical performance;
- in some cases the ore is easily accessible and the sample can be easily extracted. In some circumstances it may be cheaper than a drilling program; and
- if an on-site pilot plant is required due to a new process treatment route that is required, a bulk sample is required for feeding the plant.

Metallurgical testwork program schedule

The process design criteria and mass balances form the basis of the engineering design of the process plant. The process design criteria and mass balances are based on the metallurgical testwork. Hence the metallurgical testwork is normally the critical path for a BFS.

For a 1 to 1.5 Mtpa gold/flotation plant with a seven to ten year life, the draft bankable feasibility study report would be completed within six to eight months. A general estimate of the time it takes to complete a feasibility study can be estimated from the scheduled time of the metallurgical testwork. The draft BFS report is generally completed within six to eight weeks after the metallurgical testwork results are completed. The final BFS report is then completed within two to three weeks after the draft report has been issued. The reason why the BFS schedule is dependent on the metallurgical testwork results, is that the information from the metallurgical testwork program needs to be included into the design criteria. The design criteria forms the basis by which the equipment for the plant is selected. The BFS schedule is then driven by the capital estimate, which is generated from enquiries sent out to vendors and the site layout and elevation drawings. The procedure of the capital estimate, including the site layout drawings, takes between four to eight weeks.

The design criteria can be concurrently developed with the testwork and hence minimise the BFS schedule. However, completing a preliminary design criteria without testwork can lead to overruns in engineering costs. The grinding testwork data is generally completed at the beginning of the metallurgical testwork program, hence the crushing and grinding circuit can be developed as the data becomes available. The site layout of the crushing and grinding can also be completed, which are generally 30 to 40 per cent of the drafting required for a simple gold/flotation plant of 1 Mtpa. By managing the study appropriately, the impact of the metallurgical testwork program on the BFS schedule can be reduced.

Where a gold/flotation plant has further complexities with ore treatment or final product handling, these expected dates could be doubled. The timing also depends on the amount and degree of complexity of the number of process options that have to be evaluated.

A typical BFS schedule is shown in Appendix 1. The schedule shows the starting point of the process plant engineering as the preliminary metallurgical testwork results.

In completing a BFS there are a number of functional areas that are also addressed by specialised subconsultants such as geology, mining, site geotechnical, mining and surface hydrology, infrastructure, financial, legal/regulatory, marketing, tailings and environmental. Most of these subconsultants would have started, by up to two months, their respective sections of the feasibility study prior to the expected finish time of the metallurgical testwork program. In some cases some of the subconsultants could have their respective sections 70 per cent complete, before the metallurgical testwork progam is finished.

The following testwork schedules are typical estimates based on the specified tonnages:

Gold BFS

- for 1.5 Mtpa plant, life of eight years, allow 20 to 24 weeks;
- sample collection six weeks;
- sample preparation two weeks;
- variable/economic grinding size/leach testwork three to six weeks;
- SAG Amenability Testwork;
  - sample preparation of ore and waste one to two weeks;
  - testwork, eg Advance Media Competency (AMC) up to four to six weeks;
- bulk testwork for leach, carbon adsorption four weeks;
- tailings characterisation for tailings dam four weeks; and
- tailings characterisation for environmental kinetic three to five months.

Flotation BFS

- for 1.5 Mtpa plant, life of eight years, allow 21 to 26 weeks;
- sample collection six weeks;
- sample preparation two weeks;
- mineralogy three weeks;
- variable/economic grinding size/ flotation testwork, including locked cycle eight to 12 weeks;
- pilot plant run for bulk tails and concentrate three weeks of approximately 150 to 300 kg/h for 12 hours;
- SAG Amenability Testwork;
  - sample preparation of ore and waste one to two weeks;
  - testwork, eg Advance Media Competency (AMC) up to four to six weeks;
- tailings characterisation for tailings dam four weeks;
- tailings characterisation for environmental kinetic three to five months; and
- concentrate filtration and thickening testwork two to three weeks.

An example of a typical gold metallurgical schedule for an uncomplicated orebody with two ore types, a laterite and an oxide type, is shown in Appendix 2.

The important drivers to the metallurgical testwork schedule and hence the BFS are:

Gold BFS

- sample collection;
- initial tests for size/leach flowsheet optimisation; and
- tailings bulk sample for thickening, tailings dam and environmental testwork.

Flotation BFS

- sample collection;
- head mineralogy/assay;
- initial tests for size/circuit flowsheet optimisation;
- concentrate bulk sample for filtration/thickening testwork; and
- tailings bulk sample for thickening, tailings dam and environmental testwork.

There are a number of management actions that can be used to reduce the metallurgical testwork program and increase the accuracy of the BFS. Three of these actions are presented below:

- The compositing of the metallurgical sample should be collated in close liaison with the geological, mining and metallurgical consultants so that the sample represents the mine production schedule, including the percentage of waste material. The status of the mine production schedule is very important. Using a preliminary mine plan that is likely to change, as a basis for the composite sample preparation can lead to poor correlations between the mine and metallurgical testwork head grades or ore, which can reduce the accuracy of the BFS.

- Use of specialised consultants for some sections of the testwork program, eg filtration and thickening.
- Factorial designed metallurgical testwork can significantly reduce the timing of metallurgical testwork programs due to a number of factors:
  - reduce the amount of sample required per test;
  - reduce the amount of time per test;
  - statistically verify a circuit or reagent regime with a higher level of confidence; and
  - simple to set up.

The level of detail required for the metallurgical testwork program governs the BFS. Generally the data presented above is a good starting point for considering deadlines for the BFS and important points to consider with the schedule of the metallurgical testwork program.

PLAN FOR THE METALLURGICAL TESTWORK PROGRAM

Planning of a metallurgical testwork program requires careful consideration of a number of factors to ensure that the data produced meets that required for a BFS. The metallurgical testwork should also generate sufficient information for the optimisation of the process economics and reliable data to be used in the process plant design.

The initial plan for the testwork will be most likely based on the previous testwork. The following are points that should also be raised at this stage:

- what other orebodies of this type are globally mined?
- what is the process used for extraction?
- who are the experts in this field?
- can operations with similar process unit operations and ore types be contacted to understand their experiences?

In developing the metallurgical testwork program the following should be considered:

- Geological and mineralogical features of the orebody.

  The mineralogical assessment of the orebody is an important initial phase and money invested correctly initially can significantly improve the process economics of the orebody. This is especially the case for flotation studies and the use of diagnostic leaching for gold. There are cases where the same orebody has been proven uneconomical for some companies and proven economical by others due to the mineralogical information. This includes the assessment of the different ore types, grain size of valuable mineral, association of valuable mineral to contaminants and liberation characteristics. The mineralogical program should be compiled to highlight differing ore types and be combined with the geological structure of the ore horizon.

  The geological structures can provide hints to the behaviour of the ore types. For example a drilling program may find that the ore was competent to drill in some sections and drill bits were worn frequently, giving an indication to the hardness/abrasiveness of certain ore zones. Major faults can provide the basis for differing ore types and certain geological zones can contain excessive states of oxidation, which highlights mine to mill planning issues during ore extraction. This can lead to a specific metallurgical testwork program that confirms these preliminary inferences.

- Waste and dilution from mining

  The inclusion of an appropriate percentage of dilution material is important to the development of the physical and chemical testwork program. Particular types of waste material can have deleterious effects on the metallurgical response of ore types, for example the content of a graphitic component in a gold or flotation plant. The inclusion of waste should be representative of the mining plan, eg if the physical testwork is carried out on 30 per cent dilution, yet the mining plan has only 15 per cent dilution, then the testwork can lead to an oversized comminution circuit. Alternatively the inclusion of waste into the program can indicate that from particular ore zones no more than X per cent of the hanging or footwall can be delivered to the process plant. This can then set key performance indicators for the project design for the mine as well as the process plant.

  The selection of the amount of waste/ore ratio that should be included in the sizing of the comminution circuit must be carefully scrutinised. Grinding circuits are generally the highest power user and the highest capital cost item of the plant. In using a too high or low number for the waste/ore ratio in sizing the grinding circuit can result in either an oversized or undersized grinding circuit.

- Composite samples should represent the orebody as mined.

  The number of composite samples selected should be based on the number of different ore types and aim to represent the mining production schedule. One of the important outcomes from the metallurgical testwork program is the predicted cash flow forecast based on the mining production schedule. Hence the metallurgical testwork must represent the expected ore feed grades from the mining schedule for an accurate performance prediction of the metal grade and tonnage produced. Different ore types affect the cash flow generated from the project due to the metal tonnes produced and the operating costs. Hence if different ore types react quite differently and are mined in different periods, the effect of this must be included in the financial model.

  The composite samples should represent the orebody as relevant treatment periods, including any deleterious material that will be expected during the production period.

- Testwork schedule in reference to the BFS requirement

  There are a number of key milestones that need to be met to finish the BFS on time. This becomes very important if a presentation to the decision-makers is required at a set date and the BFS schedule is aimed at this date. This sets the focus on the testwork program output and can define the project success.

- Selection of an appropriate laboratory facility

  There are a number of laboratory facilities with differing capabilities and this can be important in optimising the testwork program data. The criteria for laboratory selection should involve some of the following; delivery of reports, the quality control practices in use, experience with similar types of material, examples of testwork programs being completed on schedule and budget, how often does the company review testwork or brain storm ideas throughout a program. A laboratory can be effective with a gold testwork program but not so with flotation.

- Consideration for tailings disposal

  This is an area that needs special consideration, depending on the location of the project and the environmental considerations. The timing of this type of testwork is also an important factor due to the length of time required for the environmental and backfill testwork, if required. For an underground operation the advantage of storing tailings underground can be very attractive and can improve the mining production schedule and environmental factors. The testwork required for the potential of the sulphide flotation tailings to be acid producing and the detoxification of a cyanide gold tail is very important and needs special consideration.

The tailings treatment can add significant costs to the project, depending on the size, storage requirement, type of tailings and environmental considerations and hence is an important section of any BFS metallurgical program. The curing times for the backfill strength determination can be in the order of 30 to 60 days and this then becomes a critical path item for the testwork program. Hence if backfill testwork is required then a tailings sample may need to be produced as a priority.

Example of a composite sample preparation

On a recent feasibility study, before commencing composite sample preparation, all the drill hole intercepts from the drilling program were listed and those for which samples were available for metallurgical testwork identified. The available intercepts were then reviewed to assess whether they would fall within a mineable zone. This was done in conjunction with the consultant mining engineers.

To meet the mineable criteria an intercept had to:

- include a minimum of 0.5 m hanging wall waste and 0.5 m of foot wall waste to allow for mining dilution;
- have a minimum mining width of 4 m, if necessary by the inclusion of more hanging wall and foot wall dilution;
- after inclusion of the above dilution, exceed a cut-off grade of one per cent Cu; and
- fall within an area that would be mined.

Each 1 m interval was assayed for copper and sulphur and then composite samples of each drill hole were made up from the 1m intervals and included the required percentages of the hanging wall and footwall dilution.

Sample handling

Delivering the sample in the best condition to the laboratory facility requires a number of controlling factors:

- the need for a well defined procedure for sample collection, bagging and delivery to the laboratory;
- a disciplined field team that understands the importance of sample preservation and procedure;
- minimising the amount of times the sample is handled; and
- minimising the movement of the sample in and out of a freezer.

The storage and transportation of the core is very important when dealing with sulphidic ores that are subject to oxidation. Not only does the metallurgical testwork program aim to measure the oxidative effect but the program also requires fresh unoxidised sample. A recent procedure below was used successfully on a highly oxidative ore:

- PQ core extraction and frozen at approximately minus19°C;
- removed from the freezer;
- geological logged;
- samples were then cut for metallurgical testwork;
- each cut metallurgical sample was wrapped in a foil bag, which was purged with nitrogen and then wrapped in cloth. A nametag describing each sample was placed inside the cloth bag.
- the cloth bag was then placed in a drum, and a document placed on top of all the samples in the drum describing what was in the drum;
- the drum was then purged with nitrogen and sealed; and
- a record of which samples were in each drum was displayed on the side of each drum.

These samples arrived at the metallurgical laboratory with no oxidation evident.

Detail of the metallurgical testwork program

Common to both gold and flotation testwork programs are the following:

- size by size head assaying and mineralogical or diagnostic leaching for gold on composite samples and intermediate products;
- specific gravity determination and bulk density of the composites; and
- physical testwork.

  Following the initial leach/float tests the final grind size is determined and from this the Bond Ball Mill Work Indices (BBMWI) can be determined for the various composites. In conjunction with the leach tests other grinding testwork can be started. If SAG milling is to be part of the treatment route than the SAG Mill determination could be carried out, such as the JKTECH Drop Weight Test or Advance Media Competency Test (AMC). If no SAG milling testwork is to be completed then Impact Crushing Work Indices, Unconfined Compression Tests (UCS) and Bond Rod Mill Work Indices (BRMWI) should be determined. For the UCS data it is the type of breakage, axial or cleavage that is important, as well as the number generated. Abrasion Indices (AI) do provide a guide to the type of material, however the method of AI determination results in a wide variation of results.
- Scoping tests based on previous results.

  It is generally a good idea to reproduce the previous test results such that a statistical base line can be developed and subsequently use this for the optimisation tests.
- Optimisation testwork and grade/recovery.
  - use of factorial design; and
  - reagent screening – completed to a level of detail that reduces the risks and optimises the project economics.
- Tailings testwork.
  - backfill testwork, tailings dam and environmental tests can all take considerable time and hence the schedule should highlight these as key milestones.

For a typical Gold BFS the following tests are carried out:

- Leach tests on variable grind size, cyanide or alternative extraction levels, leach times.
  - economic evaluation of the optimum grind size;
  - determines what the grind size for BBMWI determination should be;
  - can compare resin vs carbon;
  - predict the leaching kinetic behaviour of the ore for plant predictions; and
  - determine level of, for example, kerosene required.
- Leach tests with variable degrees of dissolved oxygen levels.
  - determine if supplied oxygen is a requirement.
- Diagnostic leaching to determine gold deportment with size by size analysis.
- Rheology of slurry.

  The rheology of the slurry is important in the design of the layout of the leach tanks due to head losses. The maximum feed density can often be set by the slurry rheology and hence can have a tremendous impact on the volume of cells required. The slurry rheology is also a critical parameter for the design of mixers and interstage screens.

- Carbon adsorption kinetics.

  Determine the amount of carbon per leach tank that is required to produce a targeted final solution gold and/or silver grade.

  Loading of the precious metal onto carbon determines the size of the desorption circuit and the rate of change that this occurs is an important design number.
- Carry out cyanide detoxification testwork on tailings.
  - Determine the amount of reagents and retention time required to reduce the total cyanide to the accepted level.
- Residence Time Distribution techniques

  Aids in determining the retention time required in the leach system and combined with the leach kinetic data can aid in predicting plant behaviour and thus improve the level of confidence of the BFS.

For a typical flotation BFS the following tests are carried out:

- Mineralogical examination of the selected composites

  This is an important phase that can determine the dissemination of minerals and classification of the various ore types. For larger corporations with a technical base, the mineralogical information can be compared with an internal database, which can be very valuable to understanding the ore treatment options. The information is helpful in understanding the association of the valuable mineral with penalty elements and defining these zones within the orebody.
- Factorial design to select optimum conditions
  - only requires 500 grams per test and produces results for reagent screening, pH conditions and grind size determination in a timely manner.
- Batch flotation tests on the selected flowsheets.

  The flowsheet selection is based on the grade/recovery required to achieve a targeted NSR value for the project. For example a 55 per cent Zn grade @ 80 per cent recovery may be good enough but by adding a regrind and cleaning a higher recovery can be achieved, however the cost of the extra installation must be considered. Sometime achieving the highest recovery may be at the detriment of grade and actually result in lower cash flows due to higher treatment and refinery charges. The opposite can occur, when the highest recovery may be lower cash value of the valuable mineral, but higher precious metal recovery and result in higher cash flows.
- Lock cycle tests on the selected flowsheet option.

  Correctly balanced locked cycle tests, based on density and mass flow, can correlate well to the full production plant and produces a guide to the type of recirculating loads expected. The densities in the cycle tests should aim to mimic those expected in the plant, sometimes this is difficult due to the low mass recovery and maintaining balances.
- Specific gravity of concentrate and tails samples.
- Size by size data of concentrate and tailings sample.

  The size-by-size analysis by assay, provides an invaluable guide to the valuable mineral and gangue deportment which can lead to the selection of reagents, determining the optimum grind size and flowsheet.
- Concentrate/tailing filtration and thickening testwork.
  - this generally requires a pilot plant to generate enough sample for concentrate testing. In some cases it could be cheaper to run a pilot plant to generate the quantity of sample required than from batch tests;
  - in some cases the concentrate sample is required for potential buyers to test and analyse;
  - the Transportable Moisture Limit needs to be determined during this testwork and then either pressure or vacuum filtration should be decided upon; and
  - the final per cent moisture is important in determining concentrate transport operating costs and self-heating properties.
- Bulk density of filtered concentrate.

  This information is used for the sizing of the concentrate storage area, which can be a significant cost in some cases. In most studies benchmark numbers are used.
- Regrind of intermediate concentrates.
  - fine grinding testwork can require up to 20 kg of sample for a BFS standard and hence a pilot plant is required.
- Full suite of assays for concentrate analysis.

  Normally an ICP analysis is completed for marketing and evaluating the impact the penalty elements and/or minor payable elements on the sale of concentrate. An accurate picture of the concentrate metal and gangue content is useful as base line assays.
- Use of site and aged water tests.

  The determining of the likely effect of recycling process water is very important to deciding on maximum or minimum water recovery. Recycling of water from tailings and concentrate thickeners can be very important for some operations. If water cannot be recycled or requires alternative treatment before being used, this can add a significant cost to the process design.
- Aged ore tests

  Determine the expected oxidation rate of the ore, which can produce a guide to the type of reagent regime required, if pre-aeration is required and what the live crushed ore stockpile retention times should be. In some cases the size of the ore feed can be defined as a way of trying to reduce the oxidation rate. A highly reactive ore, that is relatively soft, would be best left as coarse as possible until it was ready for processing.

COSTS OF METALLURGICAL TESTWORK PROGRAM

The metallurgical testwork program costs are dependent on the type and number of tests and the required consultants time. The costs, exclusive of GST inclusive of sample preparation, for typical metallurgical testwork are presented in Table 1.

Supervision of the testwork program by the metallurgical consultant requires about 24 to 32 hours per week for a BFS of 1 to 1.5 Mtpa. In addition, the engineer would also be required on a full time basis at beginning of the program for two weeks and towards the end for two weeks.

For a simple gold or flotation orebody (1 to 1.5 Mtpa) where the testwork requirement is standard, with four composites and a bulk composite, the testwork expenditure can be of the order of $A 160 000 to $A 180 000. Some simple gold or flotation testwork programs can be of the order of $A 40 000 to $A 70 000 for smaller orebodies or where the study may be an expansion of an existing facility.

For a complex gold orebody (1 to 1.5 Mtpa) where the testwork requirement includes various process option assessments, such as gravity, flotation, bioleaching, pressure oxidation on four composites the testwork expenditure can vary from $A 180 000 for gravity/flotation option, up to $A 350 000 for pressure oxidation.

For a complex flotation orebody (1 to 1.5 Mtpa) where the testwork requirement includes various process option assessments, such as fine grinding on four composites the testwork expenditure can vary from $A200 000 to $A300 000.

The detail of the costs for completion of one composite for a flotation and gold metallurgical testwork program are shown in Appendix 3. To use these numbers for the prediction of a

TABLE 1

Summary of metallurgical costs per test.

Test	Cost per test ($A)
Advanced Media Competency Test	5400
JKTECH Drop Weight Test	4500
Autogenous Media Competency Test	650- 750
UCS	590
Impact Crushing Work Index	400 - 500
Abrasion Index	200 - 250
BRMWI	1000 - 1200
BBMWI	1000 - 1200
Specific Gravity	25
Thickening	750 - 1000
Pressure Filtration	800 - 1200
Vacuum Leaf Filtration test	300 - 500
Single CIL leach test, including assays for Au and Ag in solution, carbon and residue	380 - 450
Gravity Test	310 - 400
Rougher Flotation Test, includes four assays	450 - 550
Single Cleaner Test, includes four assays	500 - 600
Pilot Plant Run, single run including assays based on 100 - 300 kg/h for a 12 hour run	30 000 - 50 000
Full ICP analysis of Concentrate	150 - 250

metallurgical testwork program, simply multiply the number of composites required for testing. These costs are actual costs from recent studies and reflect recent prices exclusive of GST.

Some further factors that determine the level of testwork required and hence the costs are:

- The corporate company policy on risk management for projects can determine the level of testwork. If the company is conservative and aims to reduce risk then the metallurgical program will most likely be more detailed and hence higher costs. If however the company is prepared to take calculated risks then the costs will be reduced.
- The size of the company and the funding available to carry out a BFS, influences the extent of the testwork program. A small junior exploration company would be prepared to carry out less testwork and rely on 'rule of thumb' numbers for the process design when compared to a major.
- Previous experience with this type of ore or treatment route. Hence if the process is relatively new or parts of the equipment are new then further testing may be required to increase the level of confidence in selecting the flowsheet and equipment sizes.
- Determine if PQ core is required, how many PQ holes, the depth required and the optimum positions. In any core extraction, the dilution or waste material that would be expected in the mining phase needs to be included, eg typical underground base metal mining can range from 12 per cent to 25 per cent dilution.
- The project financing arrangement can also determine the level of testwork required. If a high level of debt will be used to fund the project then lowering the risk may be a priority to the financier and hence a higher testwork program to reduce assumptions. If the company is financing the project or expansion from existing cash flows and there is a technical familiarity of ore treatment, then the testwork requirement may be reduced.
- The complexity of a mineralogical orebody can have a number of ore types and gangue mineralisation that are difficult to treat. These different ore types may require different treatment routes or blending requirement and thus more testwork is required to test these blends or treatment routes.

CONCLUSION

The purpose of carrying out a metallurgical testwork program on an orebody is to develop the process treatment route that provides the owners with the optimum economic return and to develop a process that manages the technical risks.

The timing of the testwork program and the influence on the BFS schedule is important in meeting the dates set by the decision-makers for the financing of the project. The setting of key timing milestones for certain testwork is required to ensure that the BFS deadline to be met. The BFS schedule can be determined from the extent of the metallurgical schedule, which provides a relative time baseline for the length of the BFS required. For a standard gold BFS, the expected time of the metallurgical schedule is in the region of 20 to 24 weeks, hence the BFS completion would be of the order of 27 to 32 weeks. For a standard flotation BFS, the expected time of the metallurgical schedule is in the region of 21 to 26 weeks, hence the BFS would be of the order of 30 to 35 weeks. The standard gold and flotation BFS is based on a 1 to 2 Mtpa project over a seven to ten year life.

The data produced from the metallurgical testwork for a bankable feasibility study must meet the accuracy requirements for the plant design, which is generally within a level of confidence of ±10 per cent. The following points summarise the important points raised in this paper that will ensure that accurate data from the metallurgical testwork is produced:

- ensure that the sample collection method and delivery to the test facility is appropriate for the orebody;
- ensure that the metallurgical composite samples correlate to the mine production plan head grades and ore types;
- ensure an appropriate amount of dilution material is included with the composites; and
- ensure that the experimental plan is developed with the aim of using the data for the development of a process design criteria.

The cost of the metallurgical testwork program is influenced by a number of key factors, which are either set by the client or by the process treatment route required. By applying some of the key points raised in this paper there are ways that the costing to the metallurgical testwork program can be reduced. Some of the average cost for carrying out the metallurgical testwork and detail of the costing for certain types of testwork are presented and these can be used as guidelines for estimating testwork. As a general rule, multiplying the number of tests by $A500 to $A600 provides an approximate estimate of the cost of the metallurgical testwork program.

APPENDIX 1

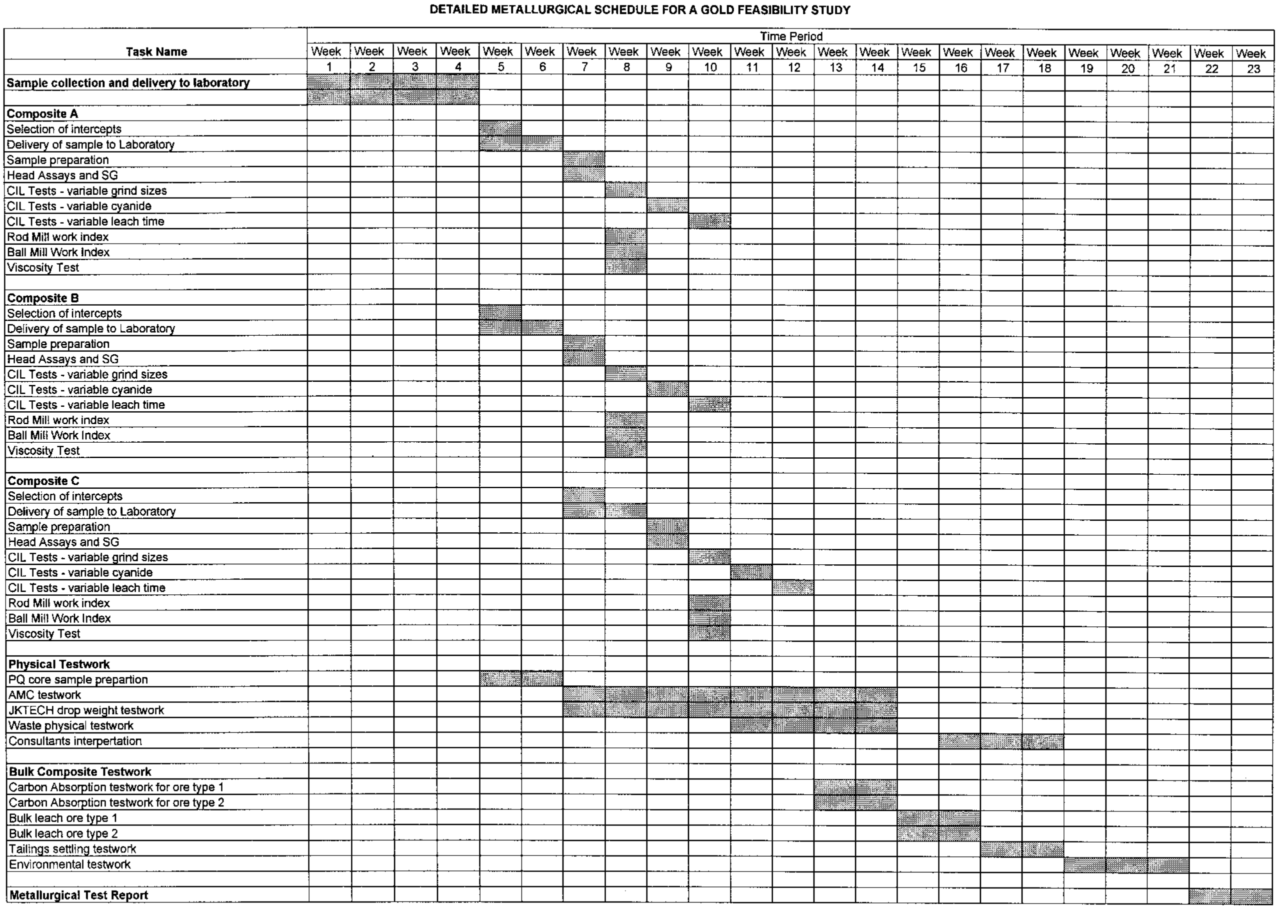
Metallurgical schedule and BFS schedule.

METALLURGICAL SCHEDULE AND BFS SCHEDULE

Task Name	Time Period										
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11
FEASIBILITY STUDY	■	■	■	■	■	■	■	■	■	■	■
Process Plant											
Metallurgy											
Preliminary Metallurgical Test results	■										
Metallurgical Testwork Final Report			■								
Process design criteria	■	■	■								
Prepare final mass balances	■	■	■								
Finalisation of process flowsheets			■	■							
Final concentrate production schedule				■							
Prepare preliminary PIDs					■	■	■				
Prepare process data sheets for major equipment				■							
Process description										■	■
Preliminary control philosophy										■	■
Provide concentrate details to marketing study		■									
Engineering											
Equipment list			■	■							
Preliminary technical spec. for major equipment				■	■						
Preliminary Site layout						■					
Earthworks overall drawing								■	■		
General arrangement drawings plans and elevation								■	■	■	
Pipework layouts									■		
Single line diagrams						■	■				
Capital Cost Estimate											
Quotations for process equipment				■	■	■					
Mechanical estimate						■	■	■			
Earthworks estimate									■	■	
Concrete estimate										■	
Structural steel estimate									■		
Pipework estimate									■		
Electrical/instrumentation estimate									■		
Indirect cost estimate						■					
Working capital etc									■		
Collate capital cost estimate										■	■
Operating Cost Estimate											
Determine consumable requirements					■						
Source reagent consumables suppliers						■	■				
Obtain labour rates								■	■		
Determine operating strategy					■	■					
Mining operating cost input								■			
Environmental operating costs input								■			
Off-site operating costs								■			
Collate operating cost estimate									■	■	
Infrastructure	■	■	■	■	■	■	■	■	■		
Transportation of Concentrates							■				
Financial Analysis											■
Implementation Plan										■	■
Writing and Collation of Study Document									■	■	■

APPENDIX 2

Detailed metallurgical schedule for a gold BFS.



APPENDIX 3

Detailed costs for a gold and flotation testwork program.

GOLD METALLURGICAL TEST PROGRAMME ESTIMATE FOR ONE COMPOSITE

Composite	Description	$/Unit	No.	Total $
A	**Sample Preparation**			
	Riffle -5mm weights for compositing	2.5	360	900
	Crush to -2mm and riffle into 1kg lots	45	4	180
	Prep for head assays	45	1	23
	Head assay - Au in duplicate	22	1	22
	SG	25	1	25
	Cold storage	3	240	720
	Comminution			
	Abrasion work index	300	1	300
	Rod Mill work index	1,050	1	1,050
	Ball Mill work index	1,050	1	1,050
	CIL cyanide leach tests			
	Trial grinds	100	10	1,000
	CIL tests - variable cyanide	334	5	1,670
	CIL tests - variable leach time	334	5	1,670
	Diagnostic leach of selected residues	50	2	100
	Size by size on selected resudues	250	2	500
	Viscosity test	500	1	500
	Gravity/leach test	683	1	683
			Total	10,393

Composite	Description	$/Unit	No.	Total $
Selected Sample	Mineralogy - allowance			5,000
			Total	5,000

Composite	Description	$/Unit	No.	Total $
Selected Sample	AMC testing - ore & waste	5,400	2	10,800
	JKTECH drop weight test	4,500	2	9,000
	Carbon adsorption test	2,000	2	4,000
	Bulk leach for tailings dam and environmental	2,500	1	2,500
	Allowance for cold storage & dispatch	500	1	500
			Total	26,800

Estimated Gold Metallurgical Test Programme Total For One Composite$ 42,193

APPENDIX 3

Detailed costs for a gold and flotation testwork program.

FLOTATION METALLURGICAL TEST PROGRAMME ESTIMATE FOR ONE COMPOSITE

Composite	Description	$/Unit	No.	Total $
A	**Sample Preparation**			
	Riffle -5mm weights for compositing	2.5	360	900
	Crush to -2mm and riffle into 1kg lots	45	4	180
	Prep for head assays	45	1	23
	Head assay - Cu & S in duplicate	44	1	44
	Head assay - Au in duplicate	22	1	22
	Head assay - Zn, Fe,Ag &Co, and ICP scan	60	1	60
	SG	25	1	25
	Cold storage	3	240	720
	Comminution			
	Abrasion work index	300	1	300
	Rod Mill work index	1,050	1	1,050
	Ball Mill work index	1,050	1	1,050
	Flotation Testing			
	Trial grinds	100	6	600
	Staged Ro./Scav. baseline test	290	5	1,450
	Staged Ro./Scav. optimisation tests	290	30	8,700
	Prep. of samples for mineralogy	90	2	180
	Ro./Regrind/Cleaner	360	12	4,320
	Trial regrind	100	6	600
	Site water test	370	2	740
	Sample ageing tests	290	3	870
	Product assays	22	120	2,640
	Locked cycle test(Ro, 3 stages of cleaning)	1,500	1	1,500
	Product assays	22	28	616
	Full scan on conc. & tail, & SG	125	2	250
	Sizing of conc. & tail	80	2	160
	Prep. of size fractions	2	20	40
	Assays of size fractions - Cu & S	22	20	440
			Total	27,480

Composite	Description	$/Unit	No.	Total $
Penalty Element Tests	**Sample Preparation**			
	Crush to -2mm and riffle into 1kg lots	45	2	90
	Prep for head assays	45	1	23
	Head assay - Cu & S in duplicate	44	1	44
	Head assay - Au in duplicate	22	1	22
	Head assay - Zn, Fe,Ag &Co, and ICP scan	60	1	60
	SG	25	1	25
	Cold storage	3	30	90
	Flotation Testing			
	Trial grinds	100	3	300
	Staged Ro./Scav. optimal test	290	1	290
	Staged Ro./Scav. tests	290	2	580
	Ro./Regrind/Cleaner	360	2	720
	Product assays	22	20	440
	Full scan on conc.	50	1	50
			Total	2,734

APPENDIX 3

Detailed costs for a gold and flotation testwork program.

FLOTATION METALLURGICAL TEST PROGRAMME ESTIMATE FOR ONE COMPOSITE

Composite	Description	$/Unit	No.	Total $
A	Mineralogy - allowance			8,000
			Total	8,000

Composite	Description	$/Unit	No.	Total $
Pilot Test for Backfill	Allow 1200kg pilot run			50,000
			Total	50,000

Composite	Description	$/Unit	No.	Total $
A	AMC testing - ore & waste	5,400	2	10,800
	Allowance for cold storage & dispatch	500	1	500
			Total	11,300

Composite	Description	$/Unit	No.	Total $
Final concentrate	Flocculant testing, thickening	850	1	850
Final concentrate	Filtration	1,000	1	1,000
Final concentrate	Transportable moisture limit	350	1	350
Final tailings	Flocculant testing and thickening	850	2	1,700
	Tailings dam and environmental	1,000	1	1,000
			Total	3,900

Estimated Flotation Metallurgical Test Programme For One Composite Total $ 103,413