

## A New Age Gold Plant Flowsheet for the Treatment of High Grade Ores.

“AusIMM - Metallurgical Plant Design and Operating Strategies Conference April 2002”

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### ABSTRACT

Low capital costs, low environmental impact and maximum return to investors are key parameters for the design of new style "minimalist" gold plants. High grade deposits can offer exciting advantages to operators reflecting often coarse liberation sizes. In a high proportion of these deposits significant economic advantages can be obtained by limiting processing to gravity and intensive leach only.

These advantages include dispensing of the CIP/CIL circuit and associated large tailing dams and potentially increasing grind size to 500 microns. The reduction in footprint, cyanide consumption, containment ponds, and energy consumption clearly have significant impact on capital, operating and environmental costs. Equipment installations and testwork at Kundana provide evidence of the potential for circuits of this style to achieve high recoveries and maximum return.

### INTRODUCTION

The current merger and acquisition activity in the gold sector has seen many Australian gold mining companies merging into large international mining houses. There are now significant opportunities for emerging gold miners to acquire and fund new projects – especially small to medium sized deposits. With the bursting of the dot.com bubble, investors are again returning to the perceived 'old style' businesses such as the gold mining sector.

Comments by business analysts in the media about mining's poor return to investors, due to large capital expenditure coupled with several high profile environmental incidents, have reinforced the sharemarket's shunning of the mining sector. The opportunity now exists with the innovative use of proven technologies to significantly reduce both capital requirements and short and long term environmental liabilities. As a result, the industry is increasingly making the paradigm shift away from capital intensive and conservative investments, to embrace low capital cost and innovative technology initiatives.

In a high proportion of mineral ores, design advantages can be obtained by utilising a gravity and intensive leach circuit only. The circuit incorporates crushing and coarse grinding (often plus 500 $\mu$ m), then gravity recovery followed by intensive cyanidation of the gold concentrate. The gold in solution is then recovered either directly with electrowinning or with activated carbon in columns. Importantly, typically 90% of the tailings will not be exposed to cyanide – a significant consideration for minimising corporate exposure.

## TARGET ORES

The flowsheet described in this paper has been developed in response to the amount of testwork Gekko Systems Pty Ltd has undertaken investigating small to medium deposits, often in environmentally sensitive locations or politically unstable locations, factors that emphasise the need to minimise capital exposure. Deposits which are most suited to treatment by this route exhibit the following characteristics:

- ✓ High gravity gold recovery into a mass yield less than ~20%
- ✓ High amenability to recovery by gravity with liberation above 100  $\mu$ m
- ✓ High proportion of free gold or sulphide associated gold
- ✓ Complex mineralogy giving poor recoveries using conventional technology
- ✓ Environmentally sensitive location.

## PROCESS DESCRIPTION

The flowsheet for the treatment of high-grade gold ores involves utilising proven processing paths. The flowsheet may be divided into four basic steps (Refer to Fig 1).

1. Crushing and grinding
2. Gravity concentration
3. Intensive cyanidation
4. Tailings disposal

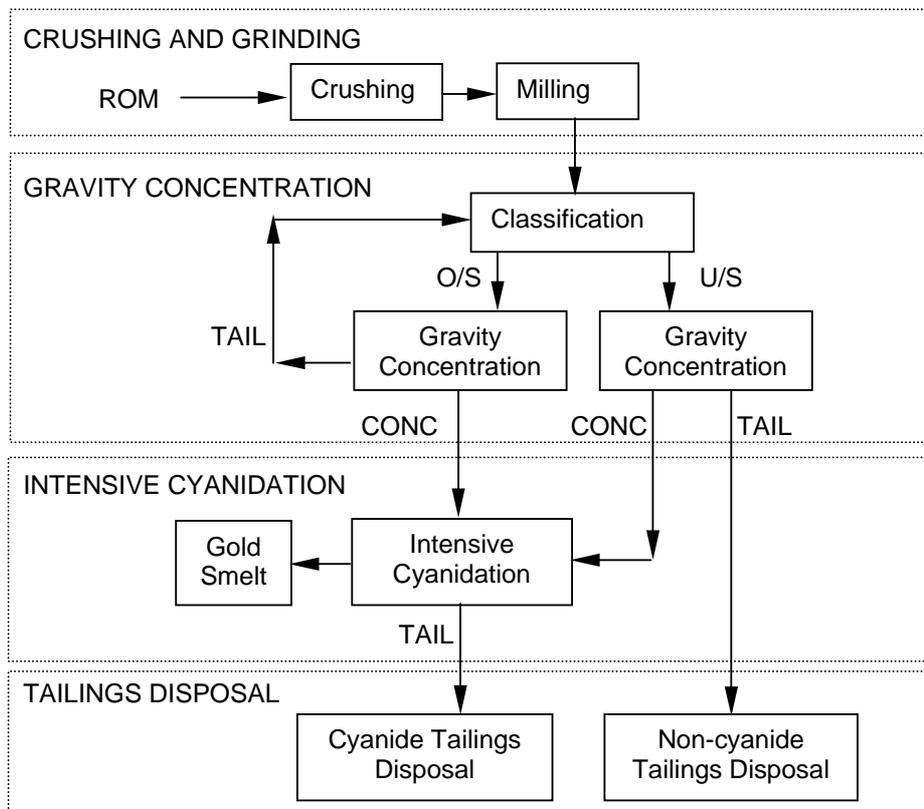


Fig 1: Simplified Flowsheet

## Crushing and grinding

The first stage of the treatment process is the size reduction of the ore particles down to a size giving liberation of the gold/mineral particles. Typically this can incorporate crushing and grinding – however the emphasis needs to be in minimising fines production prior to the gravity concentration stage. It is not necessary for the gold particle to be fully liberated, rather the degree of gold liberation need only be sufficient for it to report to a ‘heavy’ concentrate.

Should the gold particle be ‘over ground’ gravity gold recovery will suffer. If the ore mineral is soft and has a high breakage rate in the mill it must be recovered to gravity as early as possible. The ore mineral should be recovered at its natural size of liberation. Conversely if the ore mineral is soft but ductile – as in the case of ‘free coarse gold’ it will tend to flatten out in the grinding process. In which situation it is not uncommon to see larger flaky material with high aspect ratios exiting the milling circuit.

From experience testing a large range of materials at Gekko Systems Pty Ltd the optimum particle size is in the 300 $\mu$ m to 1000 $\mu$ m range. This results in significant savings in the capital and operating costs of the milling circuit.

As an example, grinding an ore with a Bond Work Index<sup>1</sup> of 20kWhr/t to a P<sub>80</sub> of 500 $\mu$ m requires 7.7kWhr/t, whereas grinding to a P<sub>80</sub> of 75 $\mu$ m requires 21.8kWhr/t. Therefore the 500 $\mu$ m coarse grind power requirement in the milling circuit is only approximately **one third** of what is generally taken as the industry standard of 75 $\mu$ m. In this example there is a **saving of 14.1kWhr/t** in power costs alone.

At such a coarse grind classification may be achieved with either hydrocyclones or vibrating screens. The use of screens has the benefit that the classification is not influenced by the specific gravity of the material.

By using a coarse grind the opportunity of undesirable gangue minerals being mobilised and entering the ecosystem is also reduced. The mineralogy of an ore is generally complex with several gangue minerals being present eg. iron sulphides, copper sulphides, arsenic bearing minerals, etc. The finer the grind the greater the reactivity and the more stringent are the containment methods required. In some cases the mineralogy of these gangue minerals may be such that they are not liberated at the coarser grind, but are fully encapsulated by the host rock.

## Gravity concentration

Recovering gold by gravity is by far the oldest, most cost effective and environmentally friendly method available. Within the gold mining industry the use of gravity equipment until recently was regarded as old technology. As more effective chemical processes have been developed such as CIP/CIL and flotation it was relegated to the treatment of low grade ores due to its low cost, especially alluvial mining.

Used in a conventional CIP/CIL circuit, gravity devices generally offer benefits by reducing gold held in the system, reducing carbon handling costs and reducing losses due to misadventure or insufficient leaching time for slow leaching coarse gold<sup>2</sup>.

The InLine Pressure Jig (IPJ), which has been developed by Gekko Systems Pty Ltd and described in detail by Gray<sup>3</sup> is used extensively in the gold sector. The IPJ utilises a moving screen, modern control technology and is operated under pressure, bringing many operating and metallurgical advantages. A key benefit of the unit is its low water consumption and

capacity to recover fines allowing it, unlike most other jig technologies, to be positively utilised in gold grinding circuits.

The most commonly used gravity device in the gold industry is the Batch Centrifugal Concentrator (BCC), such as the InLine Spinner, Knelson and Falcon to recover free gold concentrates within the milling circuit. However these devices are limited by their maximum mass yield of ~0.1% of feed. This effectively limits their use to the recovery of well liberated free gold only.

### Maximising Gravity Recovery through Continuous Concentrate Technology

The development and application of a continuous concentrate unit such as the InLine Pressure Jig is at the heart of the innovative new flowsheet to produce high gold gravity recoveries at a coarse grind with a manageable mass. The IPJ allows gravity recovery to be optimised for a particular ore by "climbing the recovery curve". This involves producing a continuous stream of high grade 'heavies' resulting in mass yields to concentrate of between one percent to a maximum of 30%, with 10% being typical.

To illustrate this point, figures 2 and 3 show recovery and grade as a function of yield for a typical high grade gold ore sample tested at Gekko Systems Pty Ltd. As mass yield is increased the gold recovery increases. Batch units such as BCC's are limited to mass flow to concentrate of less than 0.05% and accordingly cannot generally achieve the high recovery levels required for a gravity only circuit. For the material tested below, batch units at a yield of 0.1% would be limited to recoveries of around 50%, whereas a continuous unit has the potential to recover over 90% at a yield above 10%.

This extra recovery as yield increases is either poorly liberated gold or gold associated with heavy minerals, typically sulphides. This association with sulphides often leads to difficulties processing such ores through conventional CIP/CIL circuits, however the concentrate usually responds very well to intensive cyanidation. The ability of the IPJ to produce a high yield of sulphide rich concentrate can result in the economic treatment of an extremely complex ore that may otherwise require a treatment route similar to a truly refractory ore.

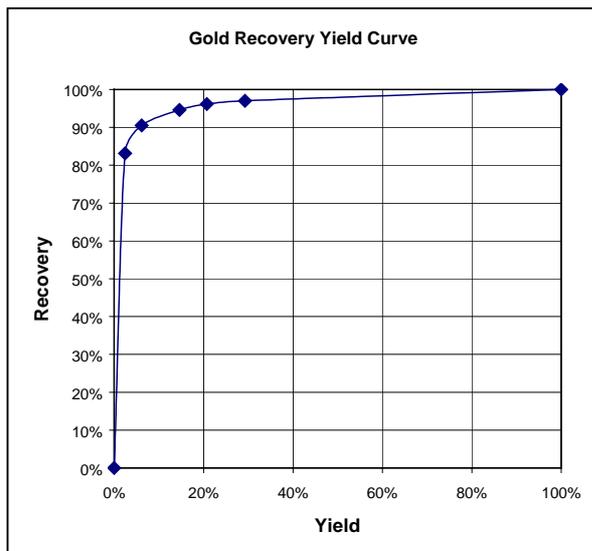


Fig 2: Gold Ore – Recovery Yield Curve

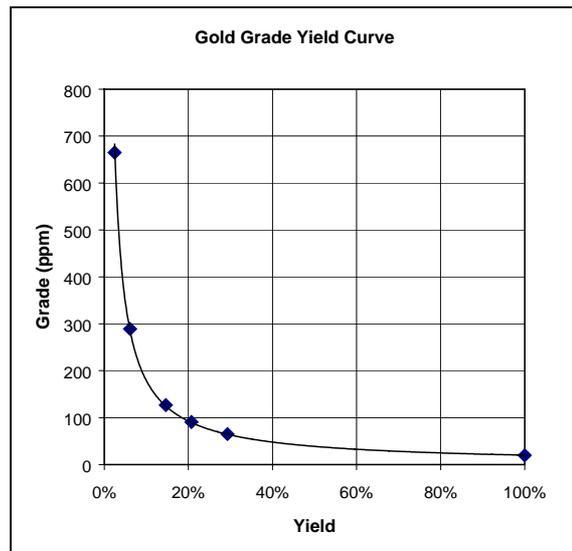
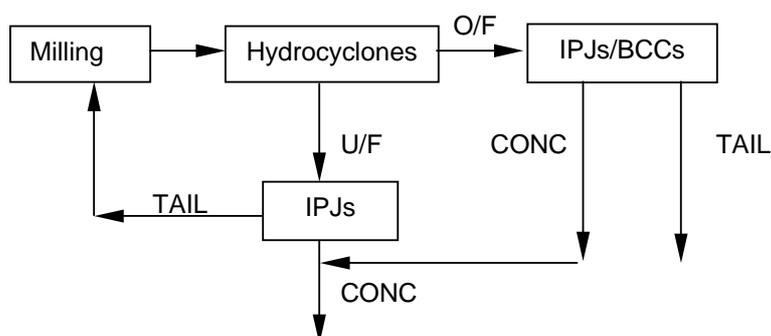


Fig 3: Gold Ore – Grade Yield Curve

The gravity concentration flowsheet that is shown in detail in figure 4 incorporates both IPJ's and BCCs. The IPJs treating the underflow from the hydrocyclones treat the **entire** stream. Since the IPJ tailing is recycled to the mill the gravity concentrators have multiple opportunities to recover the gold minerals before they report to cyclone overflow.

On the overflow stream from the hydrocyclones the IPJs/BCCs are used to scavenge any fine gold minerals; again they treat the entire stream. In this case it is a single pass opportunity to recover the gold minerals.



**Fig 4: Gravity Concentration Flowsheet.**

The mass recovery to concentrate is determined from grade recovery testwork in the laboratory, similar to figures 2 and 3. The sample tested must be from 'Run-of-Mine' (ROM) material – not the hydrocyclone underflow should the sample be from an operating circuit. Testwork based on cyclone underflow is usually heavily biased by the 'heavy' gold minerals preferentially reporting to the cyclone underflow.

The storage requirements for the gravity tailing stream may differ significantly from conventional CIP/CIL tailings or intensive cyanidation tailings. In particular if the ore has a high sulphide content, the gravity concentrators will produce a sulphide rich concentrate and hence a sulphide depleted tailing, significantly reducing the opportunity for acid generation and heavy metal mobilisation. This means there are often significant advantages if the two tails streams are stored separately.

### **Intensive Cyanidation**

Until recently gravity concentrates from BCC's were normally treated by tabling, with the table concentrates being smelted while table middlings and tailings were recycled to the milling circuit for further grinding and leached in the CIP/CIL circuit. Gold recovery on the production tables is relatively low, often only 30%, rarely above 60%. A significant factor in tabling performance is mineralogy but it is often dominated by the operator's experience and ability.

For this process to be viable it is necessary to reliably obtain high recoveries from the gravity concentrate - in excess of 97%. The only proven technology giving high gold recoveries from gravity concentrates is intensive cyanidation coupled with either direct electrowinning or carbon absorption.

The chemistry of cyanidation is proven and well known with the majority of gold operations in Australia using the process. Intensive cyanidation, typically using cyanide levels of 2%, it requires no exotic chemicals or materials and uses standard process operations.

There are over fifteen mines worldwide using InLine Leach Reactors for intensive cyanidation of gravity gold concentrates. These include both batch and continuous units. While batch ILRs are cost effective for small concentrate masses, higher feed rates require a continuous reactor.

For the flowsheet described it is necessary to utilise a continuous intensive cyanidation reactor in order to handle the concentrate masses involved and minimise reagent costs.

### InLine Leach Reactor

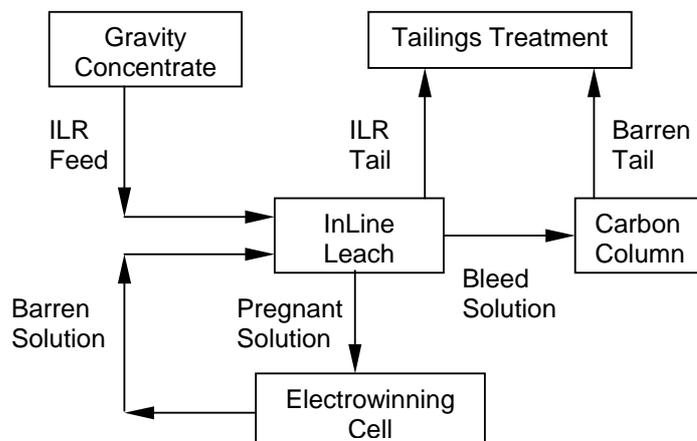
The only commercially produced continuous intensive cyanidation reactor is the InLine Leach Reactor (ILR) manufactured by Gekko Systems Pty Ltd. Continuous ILRs have been successfully operated in Australia, Malaysia, Ghana, Tanzania, Mali and Argentina at throughputs from 50kg/h up to 10t/h.

The ILR is based on the same principle as the laboratory bottle roll. It consists of a horizontal barrel, with internal baffles and lifters, rotating slowly on support rollers to ensure effective contact of the solids with reagents. Solids and solution are fed continuously and overflow continuously. The solution flow rate through the ILR is largely independent of the solids flow rate allowing solution grade to be controlled within fairly wide limits. Gray and Katsikaros<sup>4</sup> have described the ILR in detail.

The ILR operates continuously in conjunction with a dedicated electrowinning cell (or carbon column) with the barren solution recycled back to the ILR to minimise reagent use. For mass balance reasons a small bleed solution is also produced carrying trace amounts of gold which can be recovered via a carbon column. The intensive cyanidation flowsheet shown in figure 5 includes ILR, electrowinning cell and carbon column.

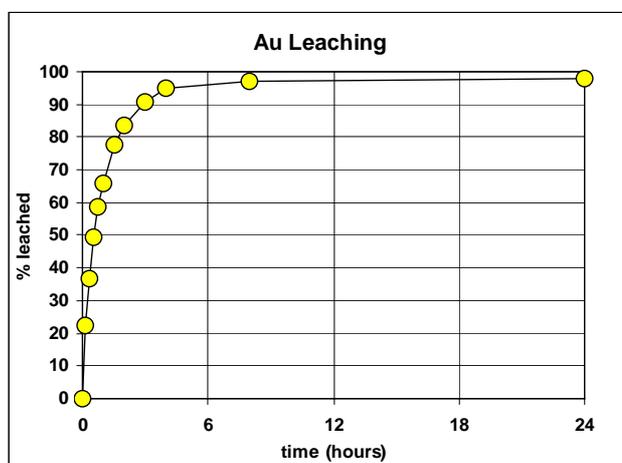
Intensive cyanidation of a gravity concentrate typically gives leach recoveries of over 97%. The aggressive leach conditions with high cyanide and oxidant levels are easily able to treat coarse particles and complex ores that under standard CIP/CIL conditions would give extremely poor leach performance. These conditions give high gold dissolution rates even when there is only minor exposure of the gold surface and in the presence of passivating sulphides.

ILRs are successfully recovering gold from gravity concentrates containing free gold, pyrite, arsenopyrite, mixed sulphides and preg robbing carbon.



**Fig 5: Intensive Cyanidation Flowsheet.**

An intensive cyanidation leach profile is shown in figure 6. This leach profile is typical with very rapid leach rates initially. The size of the ILR is determined from the leach rates and the required throughput. Laboratory tests have proven to be very reliable in predicting full scale performance.



**Fig 6: Intensive Cyanidation Kinetics.**

The leached solids are dewatered continuously, washed if necessary, then transferred to the tailing storage or treatment facility. Dewatering is carried out using a combination of cones, screens and cyclones to take full advantage of the coarse nature of the concentrate. This minimises costs in this potentially very costly process step. Floc is added if required to collect slimes.

The use of an ILR increases security by removing the requirement to handle gold concentrates. The design means high value concentrates are only kept in a single closed vessel with any access and sample points padlocked for security if desired. Once the solids are fed to the reactor they are inaccessible until leached.

### Safety

Cyanide is a highly toxic chemical, with a high recognition factor in the general community. Yet cyanide has been widely used in mining and many other industries for many years; in the most part safely and responsibly.

Paradoxically, the use of intensive cyanidation reduces the overall usage and inventory of cyanide in the plant compared to a conventional CIP/CIL plant treating the same ore. This is due to the reduced mass of material treated and the correspondingly small size of the leach circuit. The high concentration of cyanide requires similar management practices as are used currently in the elution and electrowinning areas of a CIP/CIL plant. Where the ILR is installed indoors, good ventilation, preferably with forced extraction, is recommended as a precaution.

The chances of high levels of hydrogen cyanide are small due to cyanide's high pKa and the high concentration used, which means the natural solution pH is above 11. With the drum fully enclosed and the small area of cyanide solution exposed during operation forced extraction in an indoors installation is straightforward. Lastly the ILR continually monitors pH to prevent the evolution of hydrogen cyanide.

## Tailings Disposal

Of increasing concern to both mining companies and society is the long term liability and risk associated with large tailings storage facilities containing cyanide residues. The gravity concentration and intensive cyanidation process will result in typically 80% to 90% of the tailings being relatively coarse with **no cyanide residues** contained.

With the coarse grind and the sulphide mineralisation removed from the bulk of the tailing material, the potential for mobilisation of heavy metals and acid generation is significantly reduced.

Due to the small volume of gravity concentrate treated by the ILR it is economic to treat the ILR tails via a cyanide destruction and detoxification facility. In this case there are **no tailing ponds containing cyanide residues**.

The ILR tails, being a much smaller volume, may also be stored in a facility that allows for encapsulation of the material to a higher standard than would normally be economic for the complete tailings stream.

These features are extremely important in areas with fragile environments e.g. Alaska, Greenland and adjacent to National Parks. The benefits of restricting cyanide tailings to small volumes which can be easily detoxified or encapsulated should also allow faster approvals by government and environmental agencies, increasing the financial return and reducing risk to investors.

## CAPITAL

As alluded to previously, the gold mining industry is compelled to provide a high return to investors; otherwise they will invest elsewhere. The need is to build plants with reduced capital requirements and to provide a shorter lead time for approval and construction – ensuring a faster return on capital. Both these factors also make it more attractive to build in countries of high political risk, further increasing exploration targets.

The capital cost savings of the proposed flowsheet are considerable. For example the cost of a comminution circuit grinding to a  $P_{80}$  of 500 $\mu$ m compared to a  $P_{80}$  of 75 $\mu$ m will be **50% less**<sup>5</sup>. Capital costs of an IPJ, BCC, ILR and electrowinning flowsheet are 40% lower compared to the traditional leach, CIP and carbon strip circuit. Further savings in tailings containment can be expected.

Additionally, environmental approvals can be expected to be faster due to the reduced cyanide inventory and increased feasibility of completely detoxifying all residues.

## PROJECTS

Examples of two projects using variations to the flowsheet described above, are outlined. One project is Kundana Gold Mine near Kalgoorlie in Western Australia and the other is Novodneprovka Gold Mine in Kazakhstan.

## Kundana

Kundana Gold Mine is located west of Kalgoorlie in Western Australia. The mill treats ore from several sources – being a mixture of oxide and complex sulphides from both open cut and underground. The process plant consists of a single stage crusher feeding a low aspect ratio SAG Mill in closed circuit feeding the CIP circuit.

For many years the process plant had a gravity circuit consisting of a 20" Knelson concentrator (KC20) treating one third of the hydrocyclone underflow and a full size Wilfley table. The concentrate off the table was taken to the goldroom for cleaning and smelting. The table tail and middling streams returned to the mill for further grinding.

Historically the gravity gold recovery had consistently been maintained at 50% to 60%, dependent on grade, mineralogy, equipment availability and the tabling technicians skill. With the discovery of the high grade Raleigh deposit, the mill feed grades are scheduled to be up to 25g/t. Also the mineralogy of the ore body is such that there may be significant blocks of extremely coarse gold at higher grades. Site management knew that without a gravity recovery circuit designed for maximum gold recovery from the grinding circuit spikes in the leach/CIP would occur. This is due to coarse flattened gold particles reporting to the hydrocyclone overflow and subsequently not leaching completely.

Previously when the table tails are returned to a milling circuit there can be high 'spikes' in the hydrocyclone overflow. Figure 7 is an example of this from a gold mine in Western Australia.

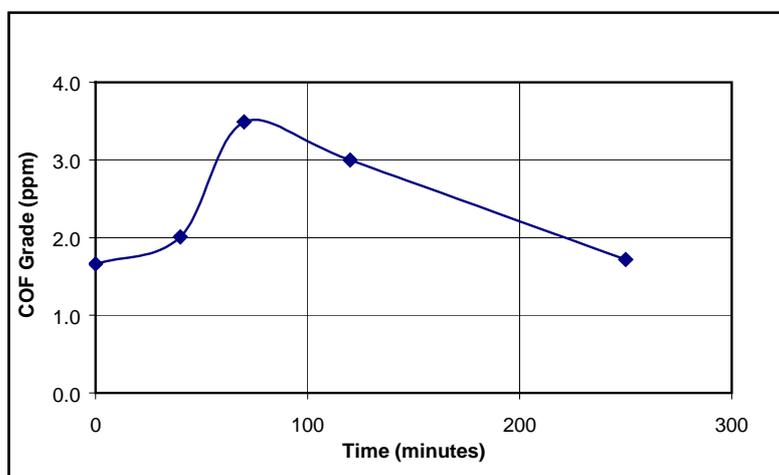


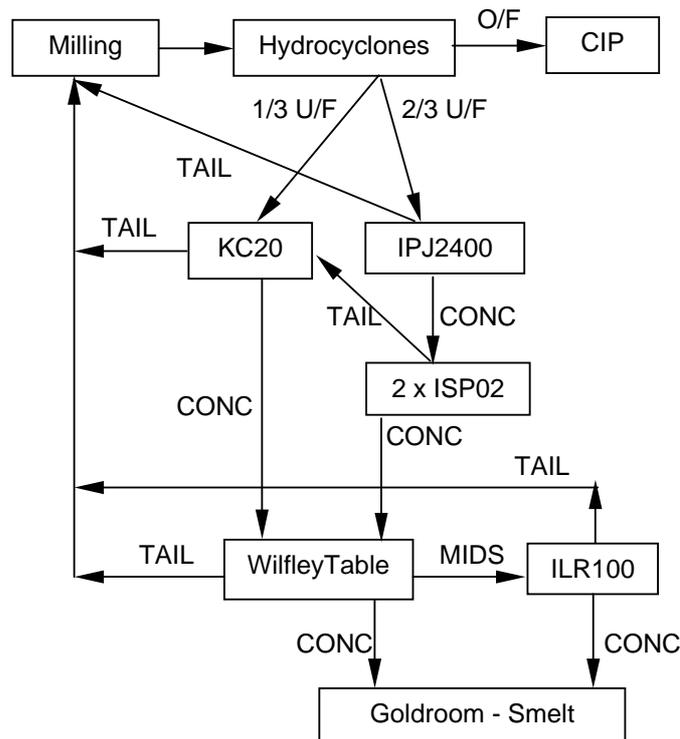
Fig 7: Cyclone Overflow Grades During Tabling.

With one gravity recovery device in circuit, this became a critical piece of equipment. The decision by site management to install a parallel circuit was to ensure that a gravity recovery circuit would be available at all times.

The gravity circuit was upgraded in August, 2001 to incorporate a InLine Pressure Jig (IPJ2400) treating two thirds of the hydrocyclone underflow, with the IPJ2400 gravity concentrate treated in two InLine Spinners (ISP02). The concentrate from the ISP02's is further upgraded on the Wilfley table. The simplified circuit is shown in figure 8.

The tail streams from both the IPJ2400 and the KC20 are returned to the mill feed, whilst the tail from the ISP02's is used to super-charge feed the KC20 (this increases the grade and recovery of the gold minerals).

With the plant treating up to 100tph of new feed and a circulating load of 250% the water balance in the SAG mill is critical. By employing a combination of BCC's (KC20 and ISP02's) and an IPJ2400 it is possible to maintain the SAG mill density whilst treating all the hydrocyclone underflow. This would not have been possible if centrifugal concentrators alone had been used.



**Fig 8: Simplified Kundana Gravity Flowsheet.**

Following installation of the additional equipment, the gravity gold recovery from the table increased from 60% up to 80%. The circuit showed that consistently high recoveries would be won using gravity alone – even when the mill feed grades were low. With average mill feed grades over a period of 3.11g/t the gravity gold recovery from the table was 76.8%<sup>6</sup>.

The middling stream from the table was then leached in the batch ILR100. Leach recoveries are in excess of 99%<sup>7</sup> for each batch, which is completed over a 24 hour cycle.

Installation of the upgraded gravity circuit ensures that at times of high feed grades, the grade of the leach feed will stay below 5g/t. If management had decided not to upgrade the gravity circuit, then substantial expenditure in the leach, CIP and carbon handling would have been required to handle the increase gold grades. Importantly the upgraded gravity circuit was installed for one quarter of the cost and with no disruption to production.

In summary the benefits to Kundana include:

- Reduced gold inventory
- Capital cost reduced by 75%
- Reduced carbon transfer
- Lower operating costs
- Insurance of parallel gravity circuits
- No production disruption during installation
- Reduced gold spikes in mill tails

### **Novodneprovka**

Novodneprovka Gold Mine in Kazakhstan has been traditionally run using gravity only. The plant is in the process of being upgraded to a total gravity/flotation, continuous ILR and detoxification circuit. From a feed of 20tph the gravity/flotation circuit recovers 95% of the gold into 400kg/hr of concentrate<sup>8</sup>. The concentrate will be leached in a continuous ILR1000, giving 98% leach recovery with the gold recovered using a combination of electrowinning and carbon columns. Tailings from the ILR will be treated by a detoxification system to ensure a benign tail is produced from the plant.

Gekko Systems Pty Ltd is supplying the ILR1000 and the detoxification system. Manufacturing time, including commissioning prior to shipment, is only five weeks from time of order. This has significant impact on the cash flow with the units planned to be installed and operating within twelve weeks of the order being placed.

## SUMMARY

The age of the 'minimalist' is now a real and viable option incorporating leaching of only a high grade concentrate. This is in marked contrast to the traditional 'whole ore' treatment route. Maximising return to the shareholders will be significantly increased with reduced capital outlay and risk.

The reduction in lead time, footprint, cyanide consumption, containment ponds, and energy consumption clearly have significant impact on capital, operating and environmental costs.

In many ways the gravity recovery, intensive cyanidation and detoxification flowsheet requires a step change in how metallurgists approach recovery. As metallurgists we must recognise that maximum recovery is not necessarily the best return for an investor if the last few percent of recovery costs more than the return.

The innovative flowsheet outlined above has the opportunity to unlock access to gold ore bodies in areas where environmental and or political factors have until now precluded access.

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**"Don't be afraid to take a big step when one is indicated. You can't cross a chasm in two small jumps"**

**– David Lloyd George.**

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