# Transforming Flowsheet Design with Inert Grinding - the IsaMill

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## ABSTRACT

The IsaMill was developed for fine-grained ores that required at least double the grinding efficiency of ball or tower milling to be economic. This was achieved, but in practice, the benefits of using inert media (eg sand, slag, ore, ceramic) have proven to be at least as important as the higher grinding efficiency. Flotation selectivity and rate was improved for all particles, particularly fines. This allowed a dramatic simplification of the Mount Isa lead zinc flotation circuit – adding 6 MW of ultrafine grinding power *reduced* reagent addition and flotation volume and increased plant energy efficiency. This was quite unexpected.

This paper examines four orebodies that were enabled by inert grinding – McArthur River, George Fisher and Black Star Open Cut Mines (complex fine-grained lead zinc orebodies in Australia), and the Western Limb Tailings Retreatment plant (a PGM operation in South Africa). In a unique case history, the operating performance of the Mt Isa lead zinc concentrator is explained by size-by-size mineralogical data collected over 25 years, systematically explaining the impact of declining ore quality, and the effects of additional conventional grinding, inert grinding, and circuit and reagent redesign.

The mineralogical case histories are so compelling that it is argued that the advantages of inert grinding should not be confined to difficult, fine-grained orebodies. The availability of large-scale efficient inert grinding mills could have profound impact on circuit design for many orebodies.

## INTRODUCTION

The IsaMill was developed by MIM (now Xstrata) to enable the development of the McArthur River Orebody in the Northern Territory of Australia. This ultra-fine grained ore needed a grind size of 80% passing 7 microns to produce a saleable concentrate. Such a fine grind was not economic with conventional ball or tower milling. Below about 25 microns the low energy efficiency and high media consumption of these mills is prohibitive. Critically, the high steel consumption and associated change in pulp and surface chemistry also seriously affects flotation metallurgy.

Figure 1 demonstrates the need for stirred milling to reduce power consumption for fine grinding of a pyrite concentrate. A grind P80 of 12 microns requires over 120 kwh/t in a ball mill using 9mm balls, but only 40 kwh/t in an IsaMill with 2mm media. The curve demonstrates the difference between "conventional" grinding and fine grinding. The Bond Work Index is developed for the flat "A" section of the curve, but does not apply to the exponential increase in grinding energy after the "knee", section "B". Here, very small changes in target P80 mean huge increases in power requirement, which cannot be achieved with conventional mills.

The key to efficient fine grinding is fine grinding media. A charge of 2mm media has 91 times more particles than the same volume of 12mm media; the same charge of 1 mm media has 730 times more particles. More particles means more breakage events, but to build a practical mill to use fine media requires three things:

- The small media particles need sufficient momentum to quickly break small ore particles. Slow stirring speeds may still grind efficiently, but the slow breakage rates will make the mill size prohibitive.
- An economic source of fine media.

- A practical means for the mill to retain media and pass target size product.

The IsaMill achieves these needs by combining high power intensity (280 kw/m3, compared with about 20kw/m3 for a ball mill), high stirring speed (22 m/s tip speed), and a centrifugal discharge to retain the media. The screenless centrifugal discharge allows low cost media to be used – eg granulated slag, silica sand, gravel fractions of the ore.

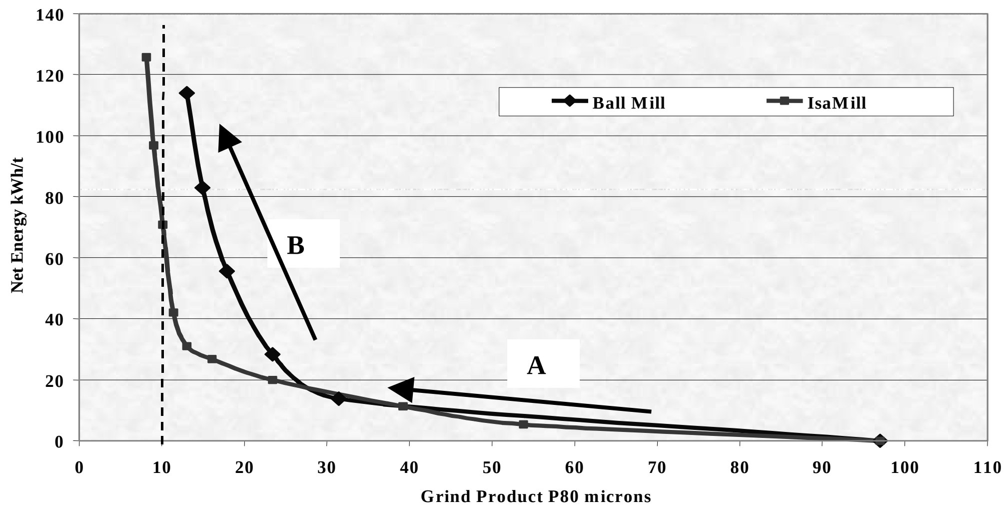



**Figure 1: Grinding Energy vs Product size for a pyrite concentrate**

The grinding mechanism and high power efficiency of the IsaMill is discussed elsewhere (Pease 2004). This paper will focus on another aspect of the technology that has been equally important in enabling orebodies – the impact of high intensity, inert grinding on flotation performance. Compared with steel grinding, inert grinding profoundly changes fines flotation, demolishing many common theories about fines behaviour. For example, at McArthur River, 96% of the individual particles recovered are less than 2.5 micron, and they are recovered at high grade and recovery using conventional cells. At Mt Isa, recovery from cleaner feed is above 95% for all size fractions from 1 micron to 37 micron, also using conventional (second hand) flotation cells (Pease 2004). Contrary to the common belief that "slimes don't float", the best performance, above 98% cleaner recovery, is in the 4 to 16 micron fraction.

A key question is – are the metallurgy gains of inert grinding confined to fines flotation? Until recently this was a hypothetical question – there was no practical technology for inert grinding at coarser sizes. This paper contends that recent developments have changed that – the availability of large scale (2.6MW) IsaMills and low cost ceramic grinding media have extended the gains in power efficiency and metallurgy to coarser grinds. In 1995 stirred milling "crossed over" from industrial manufacturing to the ultrafine mineral grinding. It is now ready for a more significant crossover to coarse mineral applications.

## IMPACT OF STEEL GRINDING ON FLOTATION

Historically fine grinding applications use conventional ball or Tower Milling. As well as the high cost and low power efficiency, the chemical impacts of steel grinding on flotation offset the benefits of better liberation. Operations often respond to the poor flotation chemistry by using higher reagent additions or intensive conditioning to clean mineral surfaces, and pre-aeration steps to increase pulp potential and mineral hydrophobicity. These responses are expensive and only partly effective, and do not address the root cause.

In the early 1960s investigations by Ray and Formanek looked at beneficial effects on flotation of grinding lead-zinc ore in porcelain mills compared with grinding in iron mills or the addition of iron powder to porcelain mills (Kocabag, 1985). This work was confirmed by Fahlstrom (1960) and Thornton (1973) on chalcopyrite, galena and sphalerite ores. Later work by Greet (2004), Cullinan (1999 and 1999b), Pietrobon (2004), Grano (1994) and Johnson (2002) and Fleahy (1994) supported the benefits of inert grinding for a wide range of ores including nickel.

If a mineral or metal is immersed in water it assumes an electrical potential with respect to the water. The principal reactions are oxidation of the mineral to form metal ions and elemental sulphur, oxidation of xanthates to dixanthogens, and reduction of oxygen to hydroxyl ions (Figure 2).

| | | |
|---|---|---|
| Oxidative reaction: | $MS \rightarrow M^{2+} + S^0 + 2e^-$ | oxidation of mineral sulphide |
| | $2X^- \rightarrow X_2 + 2e^-$ | oxidation of xanthate |
| Reductive reaction: | $\frac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2OH^-$ | reduction of $O_2$ |

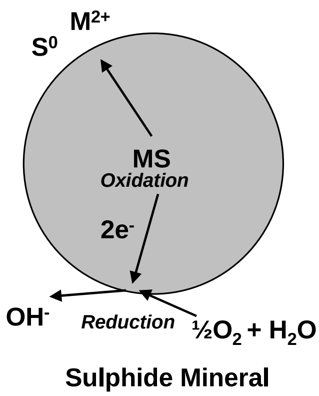



**Figure 2: The anodic and cathodic domains in a mineral system**

Sulphide minerals are semi-conductors. When they are brought into contact with steel media an electrochemical cell is formed (Figure 3). The steel media has the highest rest potential and is the anode; the sulphide mineral is the cathode.

| | | |
|---|---|---|
| Oxidative Reaction: | $Fe \rightarrow Fe^{2+} + 2e^-$ | oxidation of steel media: anode |
| Reductive Reaction: | $2e^- + H_2O + \frac{1}{2} O_2 \rightarrow 2OH^-$ | reduction of oxygen: cathode |

Further reduction of Fe ions from solution results in iron hydroxide deposits on the mineral surface, as shown in Figure 3.

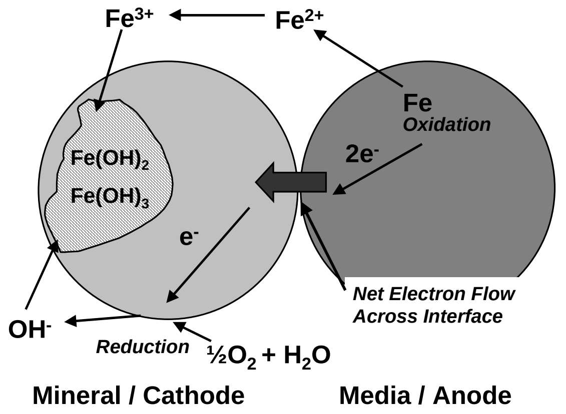


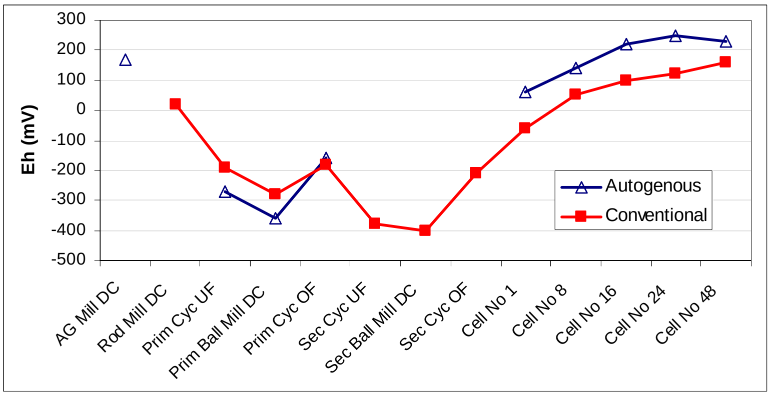

**Figure 3: The galvanic cell in a mineral / media system**

As a result, grinding in a steel media environment has several detrimental effects:

- ***The Eh effect***: the reducing environment lowers dissolved oxygen and Eh of slurry. Since collector adsorption is Eh dependent and may require oxidation of xanthates to dixanthogen, this will reduce floatability. Providing pre-aeration steps before flotation reduces this impact, but is unlikely to completely reverse it. This effect of grinding media on Eh and floatability has been well documented by Trahar (1984).

- Oxidation of steel grinding media causes ***iron hydroxide coatings on mineral surfaces.*** This reduces flotation selectivity in all sizes, but particularly for fine particles. This is even evident at the coarse sizes of autogenous grinding (figures 4-6). The impact is more significant in secondary and regrinds mills, as more fines are created and steel consumption is much higher

- Oxygen reduction on mineral surfaces promotes ***precipitation of hydrophyllic, insoluble metal hydroxides on the surface of sulphide minerals***. The impact on flotation is more pronounced for fine particles (Figure 6). Surface coatings can be offset by higher reagent addition, but at the cost of lower selectivity for clean minerals, as well as the higher reagent cost.



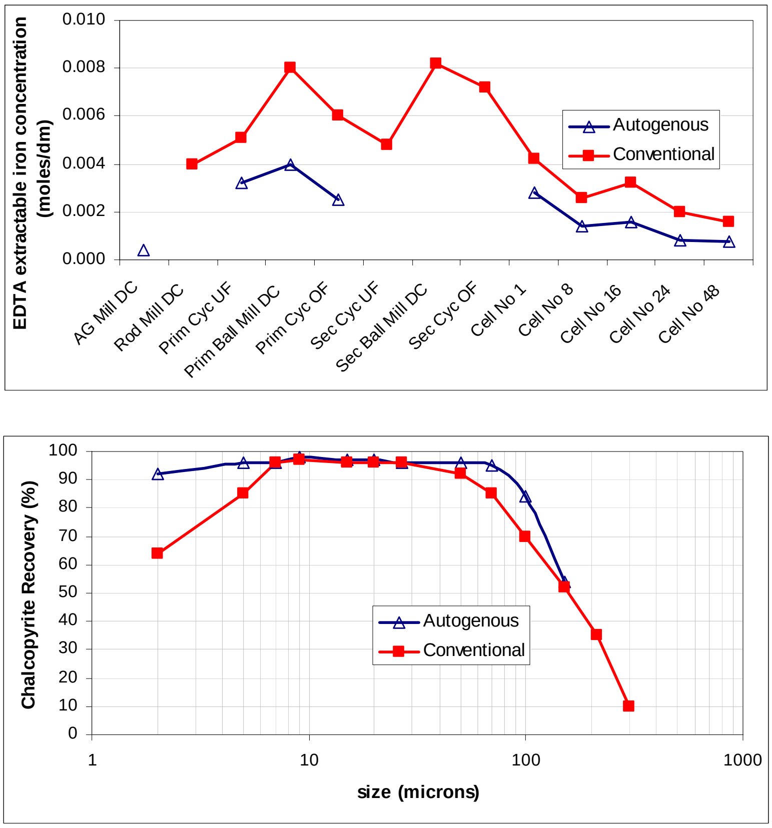



**Figure 4-6: The effect of grinding media on flotation conditions and recovery (Grano et al 1994)**

Some of the flotation impacts of steel media can be overcome by increasing pH and higher reagent addition. But flotation selectivity will still be low – some coarser minerals will have clean surfaces and will suffer from higher reagents, but the coated fines surfaces will demand them. Further, some flotation circuits require low pH (ie: pyrite/arsenopyrite/gold flotation circuits).

A much better solution is to address the root cause of the problem – keep all mineral surfaces clean by using inert media. While the benefits of high chrome media over forged steel media have been well documented, ceramic media has a much greater impact. Table 1 (Greet, 2004b) shows that changing from forged steel to high chrome media reduces the surface atomic composition of iron from 16.6% to 10.2%. Griding with ceramic media reduces this surface iron measure to below 0.1%. Considerable work has been done to demonstrate the flotation advantages of high chrome media. By contrast, little commercial based work has been done on fully inert media since it has not been a practical option until recently.

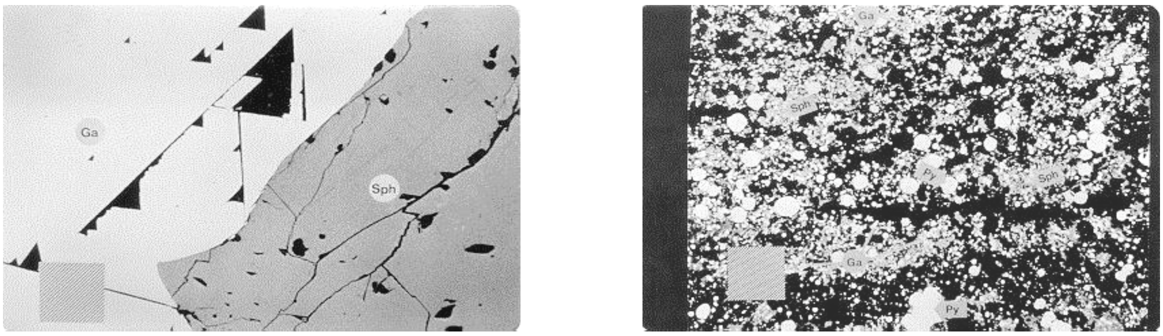
With steel media, the liberation benefits of grinding are offset by the chemistry impacts – a case of “two steps forward and one step back”. For grinding below 25 microns the chemical impact may be dominant – grinding is “one step forward, but two steps back”. The availability of large scale inert grinding allows operators to improve both liberation and flotation performance, getting full value from the installed grinding power.

**Table 1: Composition determined via XPS, of the unetched surfaces of Rapid Bay Galena ground with different media (Greet 2004b, Cullinan 1999)**

| Media Type | Surface Atomic Composition (%) | | | |
|---|---|---|---|---|
| | **O** | **Pb** | **Fe** | **S** |
| Forged Steel | 53.1 | 15.6 | 16.6 | 14.7 |
| High Chrome | 50.0 | 20.6 | 10.2 | 19.2 |
| Ceramic | 33.6 | 32.0 | <0.1 | 34.4 |

## CASE STUDY 1: MCARTHUR RIVER MINING (MRM)

The McArthur River orebody was discovered in 1955, with a resource of 227 Mt at 9.2% Zn and 4.1% Pb. However it remained undeveloped for forty years since existing technology could not economically treat the extremely fine grained minerals (Figure 7). The IsaMill was developed specifically to treat this orebody. It allowed economic regrinding to 80% passing 7 microns, fine enough to reduce silica in bulk concentrate to marketable levels.




Broken Hill Ore McArthur River Ore

**Figure 7: Different Grain Size of Broken Hill and McArthur River Ores (Grey Square is 40um)**

The plant started mid 1995 with 4 IsaMills regrinding rougher concentrate. Media for the mills was screened ore gravel from the SAG mill discharge – a fully autogenous ultra-fine grind! , Two more mills were installed to increase production and recovery (in 1998 and in 2001). In 2004 the media was changed from ore gravel to screened sand – the higher efficiency of the sand increased mill capacity, and reduced wear on mill components at the higher throughput.

Table 2 shows production performance at MRM – very high concentrate grades are achieved at over 80% recovery for the fine grind. The concentrate sizing is P80 7 microns, and P50 2.5 microns. Looking at this from the perspective of a flotation bubble, 50% by weight means that 96% of the particles in MRM concentrate are finer than 2.5 microns. So 96% of the successful particle-bubble collisions at MRM happen for particles finer than 2.5 microns. This is achieved in conventional flotation cells – the selection criteria was to design for adequate lip length, then buy the cheapest cells available.

Fines float extremely well if they have fresh clean surfaces.

**Table 2: Performance of McArthur River since commissioning**

| MINING | | | METALLURGY | | | |
|---|---|---|---|---|---|---|
| Year | Tonnes | Head Grade | Tonnes | Zn Recovery | Con Grade | |
| | | | | | %Zn | %Pb |
| 1995/96 | 707,994 | 12.9% | 759,519 | 66.4% | 39.3% | 11.2% |
| 1996/97 | 1,035,222 | 14.4% | 1,026,150 | 73.5% | 43.5% | 11.0% |
| 1997/98 | 1,127,000 | 16.1% | 1,139,000 | 74.3% | 43.3% | 11.9% |
| 1998/99 | 1,222,238 | 16.4% | 1,220,957 | 79.5% | 45.0% | 12.7% |
| 1999/00 | 1,254,227 | 16.3% | 1,262,639 | 80.9% | 46.9% | 12.0% |
| 2000/01 | 1,226,499 | 15.4% | 1,270,319 | 82.4% | 46.8% | 11.2% |
| 2001/02 | 1,398,109 | 14.9% | 1,404,539 | 82.7% | 46.8% | 11.1% |
| 2002/03 | 1,505,306 | 12.7% | 1,511,856 | 82,4% | 46.6% | 10.5% |
| 2004 | 1,523,243 | 12.7% | 1,579,762 | 80.0% | 47.1% | 10.3% |

## CASE STUDY 2: GEORGE FISHER OREBODY AT MOUNT ISA

The changes to the Mount Isa circuit as part of the "George Fisher Project" are detailed elsewhere (Young & Gao, 2000, Young, Pease & Fisher, 2000). In summary, the project involved adding a further 6 IsaMills, to regrind lead rougher concentrate to $P_{80}$ of 12 µm, most zinc rougher concentrate to 12 µm, and a zinc regrind to $P_{80}$ of 7 µm (Figure 8). Lead performance increased by 5% concentrate grade and 5% recovery (equivalent to 10% increase in lead recovery at the same grade). Zinc recovery increased by 10%, in two steps, and zinc concentrate grade by 2% (equivalent to 16% increase in zinc recovery at the same grade). The story of zinc metallurgy is told in Figures 8, 9 and 10.

The project predicted 5% higher zinc recovery (and no extra concentrate grade) due to extra liberation. Figure 9 shows this was achieved instantly. The surprise was the "second wave" of a further 5% zinc recovery increase and the 2% increase in zinc concentrate grade. This was because fines flotation improved after grinding finer.

It took about 6 months to discover how much better the fines could perform because we were so used to flotation after conventional grinding rather than after IsaMilling. Our three biggest mistakes were:

- Expecting to need a lot more reagents after IsaMilling due to the huge new surface area created. Some reagent additions were forecast to triple.
- Not taking the depressant (lime to pH 11) off the zinc cleaners.
- "Pulling" flotation harder because we thought flotation rates of the fines would be slower.

To our surprise, even though we introduced 6MW of extra grinding power, operating cost per tonne of feed did not increase. This was because of:

- Lower reagent additions
- Elimination of circulation loads between roughing and cleaning – a lot of power (and flotation capacity) is wasted in conventional circuits by pumping circulating loads of 100%-300%.
- Virtual elimination of spillage – due to new designs for pump boxes and pumps, the lower reagents, and especially the reduction in circulating loads.

The reduction in reagents was most unexpected, but perfectly logical in hindsight. During mill commissioning we increased reagents because we were increasing mineral surface area threefold. We were wrong. While more surface means more collector on the surface, this doesn't necessarily mean more collector in the pulp. If surface coatings mask mineral surfaces, then high collector in solution is needed to drive the diffusion through the coating to the surface. But if surfaces are truly clean – something that is never seen in a conventional steel grinding circuit but can be achieved by grinding in an inert environment – lower solution concentrations can achieve high surface coverage. Flotation after inert grinding is profoundly different – we had to forget everything we had learnt in our circuit and start with a "clean slate". Later we realised that the answers we needed were in the classic flotation texts. Bubble contact angles in clean mineral systems may not seem relevant to the plant operator who has badly altered mineral surfaces. But they are quite relevant in a system that quickly creates fresh clean surface.

The new circuit cut circulating loads from 200-300% to less than 50%. Liberated minerals with clean surfaces in a narrow size distributions respond predictably. They don't form large circulating loads of "undecided" particles. This creates a virtuous circle – lower circulating loads in cleaning means lower density, which gives better dilution cleaning. It also means less flotation cells are needed – eliminating a 100% circulating load doubles residence time. Mt Isa had to shut down some zinc cleaning capacity after installing the IsaMills.

The reduction in reagents and reduction in circulating loads almost eliminated spillage. This is another virtuous circle – returning spillage disrupts a circuit, creating new circulating loads and spillage.

Figure 10 shows the recovery by size in the zinc cleaning circuit at Mt Isa after IsaMilling (the recovery with respect to rougher concentrate, which is the feed to IsaMilling). Recovery is above 95% for all size fractions from 1micron to 37 micron. Recovery drops above 37 microns but there are very few particles here – these are composite that the circuit directs to regrinding to fine liberated, high recovery fractions. The highest recovery, over 98%, is in the 4-16 micron range. This size range is sometimes called "slimes", and it is often said that "slimes don't float". Indeed, after steel grinding they often don't.

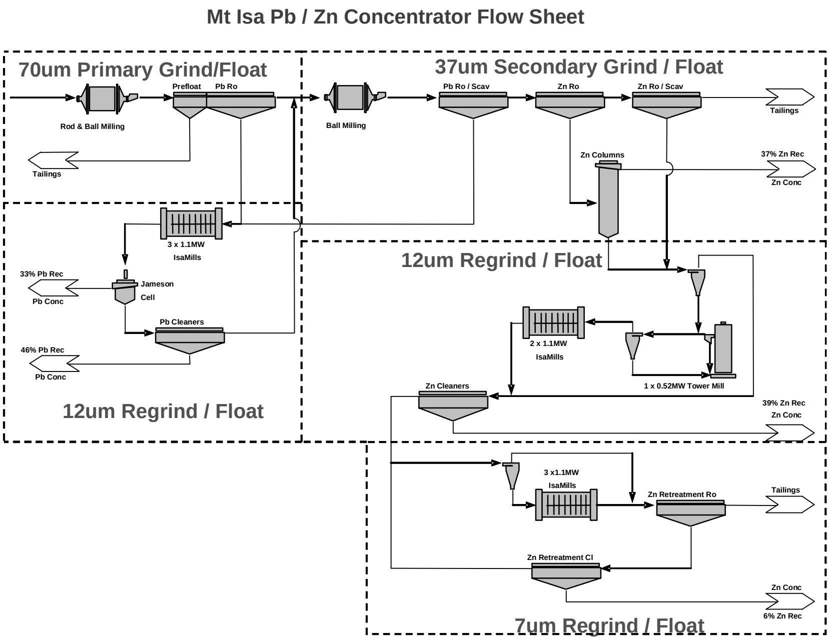



**Figure 8: Mt Isa Pb/Zn Concentrator Flow Sheet**

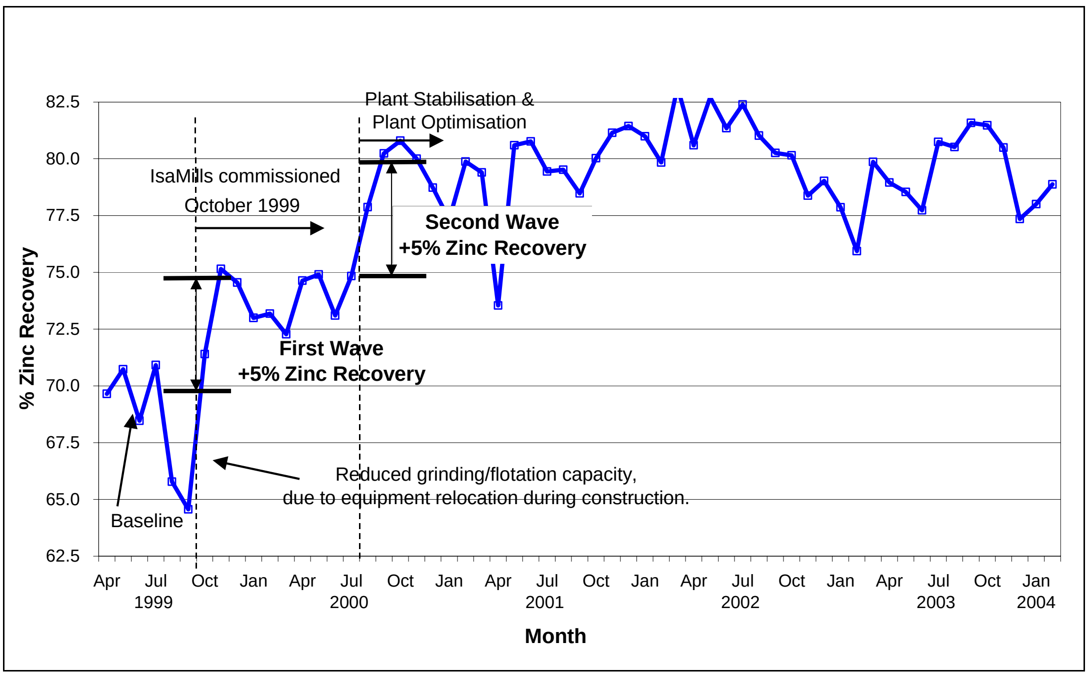



**Figure 9: Zinc Recovery Increase from IsaMilling**

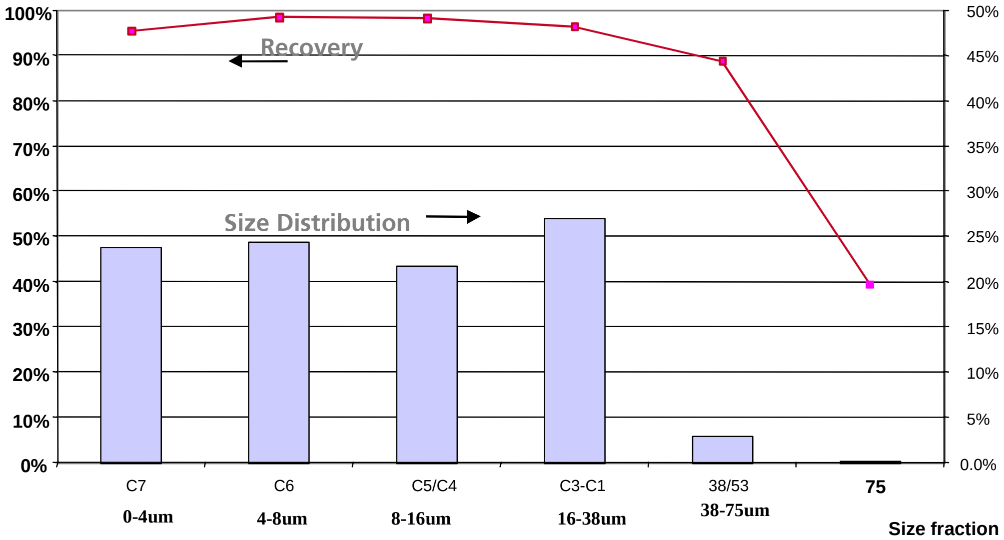



**Figure 10: Mt Isa Zinc Recovery from Rougher Concentrate by Size**

**The Big Picture – Mineralogy, Liberation, Chemistry and Recovery Explained**

Figure 11 is a graphic summary of the impacts of ore type, liberation, steel grinding, inert grinding and chemistry changes unfolding over twenty years at the Mt Isa operation. Each month Mt Isa collects inventory samples of all feed and exit streams. Each exit stream is sized and cyclosized, and size fractions are submitted for quantitative mineralogy. A huge amount of data is generated about different mineral classes in different size fractions. However one summary variable plotted in Figure 11 tells a compelling story. It plots sphalerite liberation in "recalculated feed" and sphalerite recovery. "Recalculated feed" is created by mathematically combining all the plant exit streams according to their relative tonnage. Therefore it captures the impact of all the grinding and regrinding stages of the circuit. The Mt Isa journey unfolds in four stages, as described below.

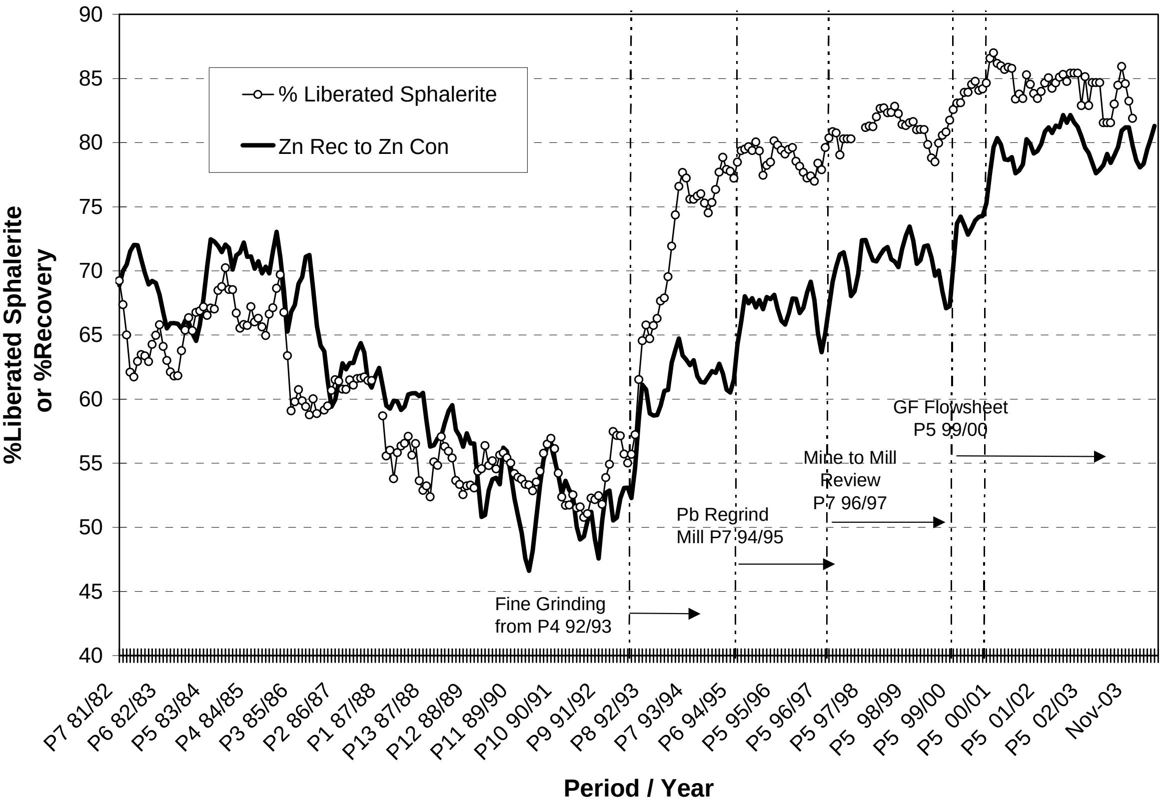
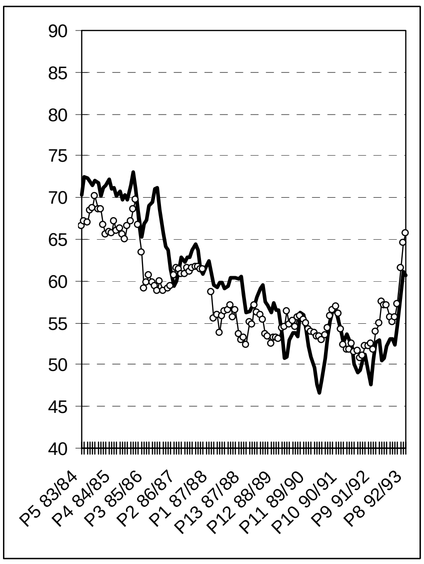



**Figure 11: The Mt Isa Story: Zn Recovery and Sphalerite Liberation**

## Stage 1: The sickening decline

During the 1980's ore sources became increasingly fine grained. Liberation declined, and recovery inexorably declined with it. Like most operators under profit pressure we increased feed tonnage. This increased revenue but further reduced liberation. We tried dozens of reagents, dozens of circuit changes, and dozens of metallurgists. Finally we accepted we were just "shuffling the deck chairs on the Titanic" – reagents don't grind. A fundamental rule seemed to guide plant performance in spite of our metallurgical endeavours – recovery equals liberation plus 10%. A small amount of composite particles can be accepted into concentrate , until the quality constraint on impurities is reached.

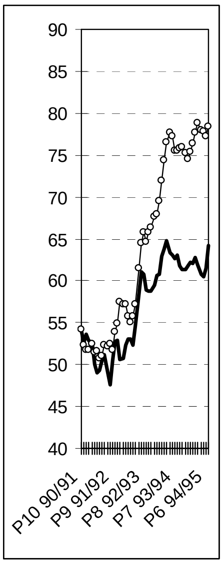



Liberation dropped by 15%

Recovery dropped by 20%

**Stage 2: Use a bigger hammer**

We had to increase liberation to increase recovery. The only available technology was conventional ball milling, and the then emerging Tower Milling. We installed 6MW of ball and Tower Mills, effectively doubling the grinding capacity. While we knew this would increase liberation, we also knew there was a downside – creating finer particles using so much steel media would create surface chemistry problems. As expected, this delivered two steps forward from liberation, and one step backward from surface chemistry. Liberation increased by 18%, while zinc recovery increased by 7%. The old rule "recovery is liberation plus 10%" had broken down, but this was the inevitable price of grinding fine with steel media.



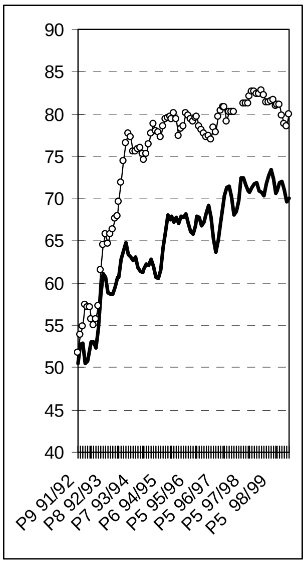

Liberation increased by 18%

Recovery increased by 7%

Concentrate grade unchanged (not shown)

**Stage 3: A pleasant surprise**

The IsaMill technology for McArthur River was developed in the Mt Isa concentrator. The first installations were to regrind lead cleaner feed. The intent was to liberate some of the galena/sphalerite binaries to reject some zinc from lead concentrate. This was achieved, though the total effect on sphalerite liberation was small. However zinc recovery to zinc concentrate increased by 4%. This was because the clean surfaces after IsaMilling allowed us to improve flotation chemistry – we were able to reject fine liberated sphalerite particles that had previously misreported to lead concentrate. We had achieved what no amount of chemistry or circuit changes had been able to achieve in the past – increasing recovery increase without significantly changing liberation.

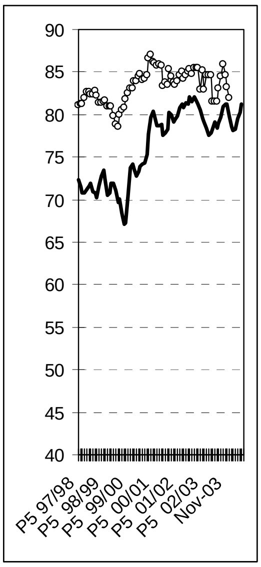



Liberation change negligible

Recovery increased by 4%

**Stage 4: Cooking with Gas**

Breaking the quandary between increasing liberation and harming surface chemistry was a revelation. With steel milling we had reached to stage of one step forward from liberation, but two steps back from chemistry. Suddenly a new option was available – improve both liberation and chemistry in the same step. We put 4 MW IsaMills into the zinc circuit. Liberation increased 4 %, but recovery increased by 10%. Concentrate grade also increased by 2% - we could have taken this as an extra 6-8% recovery, but the higher grade was more profitable. Making the higher grade had not been possible in the past.




Liberation increased by 4%

Recovery increased by 10%

Concentrate grade increased 2% (not shown)

Figure 10 shows that fine sphalerite recovery is over 95% after IsaMilling (ie: recovery of sphalerite from rougher concentrate). Figure 11 however shows total circuit sphalerite is still only 80% with respect to plant feed. Of the 18% sphalerite losses, 7% reports to lead concentrate, and 11% reports to tailing. In the tailings about half is in coarse composites and half in fine liberated particles. If a particle is too coarse, or too badly surface altered by steel grinding, then it doesn't float in the roughers, and doesn't get a chance to see the IsaMills.

Undoubtedly rougher performance would be better after inert grinding, but the technology was not available when we installed the extra secondary grinding. Mount Isa is now considering the feasibility of a large open cut operation which would necessitate building a new concentrator. Our design for that concentrator uses large IsaMills (3.3MW or bigger) in place of ball mills to grind rougher feed, and further mills to regrind rougher concentrate. This reduces footprint, reduces capital cost, increases energy efficiency, and will achieve higher recovery with lower reagent additions than the current circuit.

**CASE STUDY 3: MT ISA BLACK STAR OPEN CUT**

Surface resources at Mt Isa had long been a target for open cut mining. However the poor metallurgical response was always a barrier to production. Much of the ore is "transitional" between surface oxides and deeper primary sulphides. The transition ore is lower grade than primary ore, has fine grained mineralogy, and leaching has activated pyrite and sphalerite, leading to non-selective flotation. Constant attempts over the last 80 years failed to make the ore economic, with flotation unable to make smelter quality concentrates at any recovery.

The development of the IsaMills and the flowsheet to treat George Fisher ore changed this. The fine grinding achieves mineral liberation and cleans the mineral surfaces by attrition, and the combination of high intensity inert grinding and the correct water chemistry in flotation stops re-activation of unwanted minerals. The impact is shown by the grade recovery curve in Figure 12 - target concentrate grades can now be made at acceptable recoveries.

As a result, IsaMill inert grinding technology enabled production from the Black Star Open Cut resource. Production commenced in the first half of 2005, targeting 1.5M t/y to supplement underground production, produced from a mineral resource of 25Mt at 5.1%Zn and 2.7%Pb. This represents only a small portion of the potential open cut resources at Mt Isa. The success to date has led reassessment of the economics of the entire open cut resource and future production scale at Mt Isa.

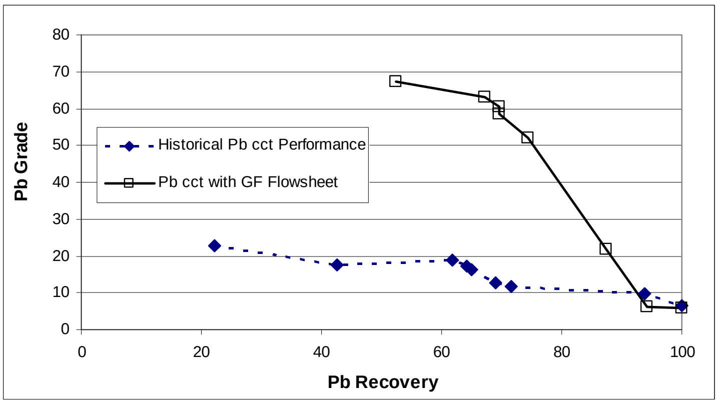



**Figure 12: Pb Grade/Recovery Curve – ISA Lead-Zinc Transition Ore**

## CASE STUDY 4 : MERENSKY PLATINUM TAILINGS RETREATMENT PLANT

In 2001 Anglo Platinum assessed the retreatment of dormant tailings dams in the Rustenberg area in South Africa. These tailings contained economic amounts of Platinum Group Minerals (PGMs) if new technology could address two issues:

- The fine grained mineralisation of the PGMs in tailings (why it wasn't recovered first time)
- Surface oxidation and oxidation products which harmed flotation – some of the tailings were placed over 100 years ago.

Anglo Platinum and Xstrata Technology worked together to find an economic treatment route. To achieve economies of scale for the project the IsaMill was successfully scaled up from 1,000 kW to 2,600kW. This proved to be the enabling technology for this project due to:

- The ability to grind fine at low cost – the mill operates in open circuit, and uses cheap local sand as the grinding media.
- The clean mineral surfaces resulting from the inert grinding environment. This was crucial to achieve target grades and recoveries after regrinding.

Figure 13 shows the improvement made by an IsaMill regrinding rougher concentrate before cleaning (Buys et al, 2004). The mill increases flotation kinetics in cleaning, just as it does at Mt Isa and McArthur River. This is in contrast with the common observation that regrinding in a steel mill slows kinetics of all minerals.

Anglo Platinum commissioned the Western Limb Tailings Retreatment Plant in 2004. At the end of 2004 they concluded that (Buys, 2004):

- IsaMill technology was enabling for the WLTR project since it allowed acceptable concentrate grades to be made from oxidised slow floating tailings.
- Flotation kinetics improved after fine grinding due to both extra liberation and the removal of iron oxide surface coatings. Inert fine grinding of rougher concentrate was necessary.
- The scale up to the M10,000 IsaMill (from 1 MW to 2.6 MW) was successful.

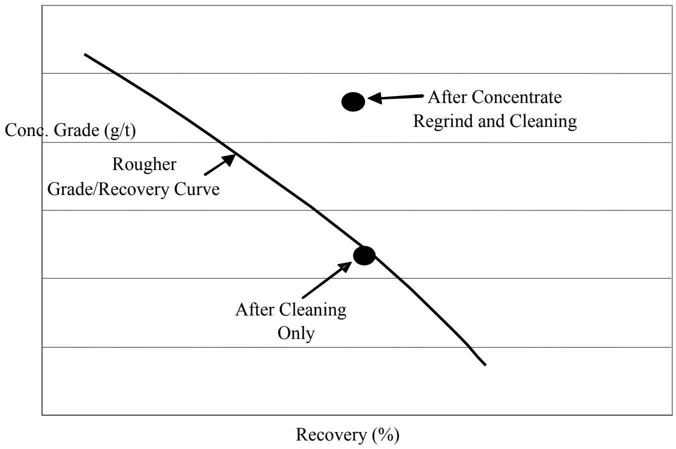



**Figure 13: Improvement in Platinum Grade/Recovery After IsaMilling for Western Limb Tailings Retreatment**

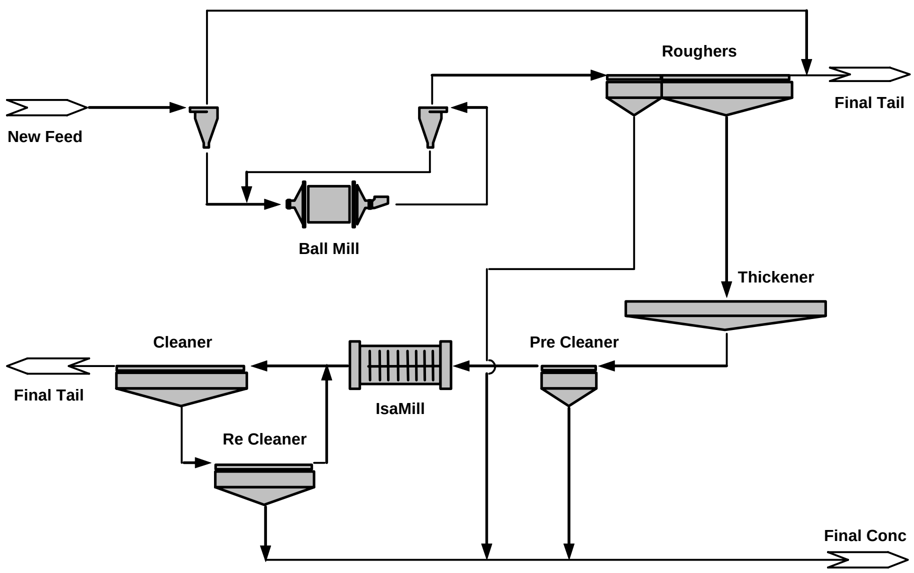



**Figure 14: Western Limb Tailings Retreatment Flowsheet**

## INERT GRINDING BEFORE LEACHING

Just as the ability to grind to 10 microns in an inert grinding environment has been the enabling technology for the flotation of fine grained ore bodies so to this ability has been an enabling step for several hydrometallurgical technologies. The high surface area of fine particles means high leaching rates at relatively low temperature and pressure, reducing capital and operating costs. High intensity fine grinding also reduces the activation energy required to leach minerals by creating a highly stressed surface, reducing the crystalline nature to amorphous phases. This effect of mechanical (or mechanochemical) activation of minerals is well reported (Balaz, 2000; Juhasz and Opoczky,1990; Grelach et al 1989), and it means that minerals leach under much less aggressive conditions. The higher power intensity of grinding would enhance this effect. Several emerging leaching processes have been based on fine grinding of feed – the Activox process, the UBC/Anglo process, the Phelps Dodge Process, and Xstrata's Albion Process.

In flotation the chemical benefits of inert grinding can be dramatic. In leaching there is a lesser, but still important impact. Conventional grinding before leaching will directly input steel to the leach feed. This may require additional preoxidation of leach feed, and also result in higher reagent consumption. An IsaMill will soon be trialed to replace a ball mill regrinding concentrate before gold cyanidation. The ball mill is currently consuming 10t/day of steel media, which enters leach feed. This will provide a future case study of the impact of inert grinding on leach performance and reagent consumption.

## THE CROSSOVER TO COARSER GRINDING

The principles learnt for fines flotation also apply for coarser particles (above 30 microns). The impact of steel on flotation is not as dramatic as it is for fines, but it is still there. This is why so much work has been done on the use of high chrome media. The principles of floating with clean surfaces, in narrow size distributions, with fast kinetics, low reagents and low circulating loads are vital to achieve good fines recovery, and will also improve flotation of coarser particles.

Until recently the prospect of inert grinding at coarse sizes was generally impractical. This has changed with IsaMills now operating at 2.6 MW, and the availability of low cost, high efficiency ceramic (MT1) developed specifically for stirred milling (Curry and Clermont, 2005). Pilot work on coarser feeds (eg 200 microns) consistently shows that IsaMills with ceramic media have significantly higher power efficiency and lower capital cost installations (eg open circuit) than conventional ball milling. The crossover to coarse grinding may be a "transformational" technology change, delivering lower capital, higher efficiency grinding, as well as better metallurgy.

The pilot predictions need to be demonstrated at full scale. The first industrial application of a 2.6 MW IsaMill with MT1 ceramic will be commissioned in late 2005, at Centerra Gold's Kumptor operation in the Kyrgyz Republic. This operation which produces 500,000 oz/y gold will use the IsaMill to grind rougher concentrate before leaching. This application will allow full scale comparison of grinding rates and size distributions achieved by SAG mills, ball mills and IsaMills.

Another full scale coarse grind application is currently under design, and is expected to be operating in late 2006. This will involve a 3.3 MW IsaMill using MT1 grinding rougher tailings in open circuit, from 150 micron to 55 micron. Based on current plant data, an 8 MW conventional ball mill in closed circuit would be required to match this grinding performance. Ball milling cannot be justified for this application due both to the high capital cost and the relatively poor metallurgy compared with inert grinding.

## CONCLUSION

Necessity was the mother of invention for ultra-fine grained orebodies. They were simply intractable with conventional ball and Tower milling. High intensity stirred milling was the breakthrough that transformed the economics – low capital and installation cost, low media cost, high power efficiency, simple installations, sharp size distributions in open-circuit, and inert attrition of mineral surfaces.

It is most unlikely that only fine grained ores will benefit from these features. The rapid increase in scale to 3.3 MW enables large scale coarser grinding applications for IsaMills. Several projects are under design to transfer this technology to the mainstream.

The performance of these projects will answer the question: is this the next big thing in grinding?

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