SAGDESIGN TESTING REVIEW – CASE STUDIES

By

J.H. Starkey, D. Meadows, P. Thompson, A. Senchenko

Contact author:

Mr. John H. Starkey
Starkey & Associates
212-151 Randall St.
Oakville, ON
L6J 1P5, Canada
Tel: (1) 905 849 6111
Fax: (1) 905 844 5297
Email: john.starkey@sagdesign.com

Mr. David Meadows
Freeport-McMoRan Copper & Gold Inc.
1 North Central Avenue,
Phoenix, AZ
85004, USA
Email: David_Meadows@FMI.com

Mr. Arkady Senchenko
Research and Design Institute "TOMS"
1/83 Lermontov str.
Irkutsk, Post Box 303
664074, Russia
Email: "Arkady Senchenko" lab@toms.irkutsk.ru

Mr. Philip Thompson
Dawson Metallurgical Laboratories Inc.
70-2030 Redwood Rd.
Salt Lake City, Utah
84116, USA
Email: "Phil Thompson" DMLMETLAB@aol.com

SAGDesign Testing Review – Case Studies

By

J.H. Starkey, D. Meadows, P. Thompson and A. Senchenko

ABSTRACT

SAGDesign™ Testing for grinding mill design was introduced commercially in 2004. Up to January 2008, 18 projects have been completed and 99 samples have been tested using this method. Two papers have been published describing the patented test procedure and one of these shows how the results compare with other grinding test methods. This paper will briefly discuss the theory on which this technology is based, and explain the procedures used to develop the calibration equation. Case studies are also included to demonstrate the effectiveness of the test work being done.

These case studies show how the SAGDesign test is being used today: to design new grinding circuits for commercial full scale use; to calculate throughput in existing mills for production planning; and to accurately define grinding mill requirements at the scoping, pre-feasibility or feasibility study stage of project development, in order to economically identify the size and cost of the grinding mills that will be needed for the project. This is important because if the full recommended SAGDesign testing program is done at an early stage in the project, the definitive cost for a guaranteed throughput, grinding mill design (by Outotec if their mills are purchased) is available.

New grinding mill design for final engineering will be represented by the test work done on the Climax Molybdenum Project for Phelps Dodge (now FMI) in Colorado, USA. The SAG mill and ball mill for Climax are now in fabrication with project start up in late 2009. Next, the sizing of grinding mills at the scoping, pre-feasibility or feasibility study stage of mine development will be represented by a large metal mining property in Russia. Finally, calculation of the throughput for existing mills will be represented by work done at a base metal mine, in eastern Canada.

Test work for designing SAG mills is now done in four laboratories at the time this paper was written. One in the USA at Dawson Metallurgical Laboratories, Inc. in Salt Lake City, two in Russia at the TOMS Research and Design Institute and at the Irgiredmet Research Institute, both in Irkutsk, and a fourth mill has been installed in Australia at AMMTEC Limited's lab in Perth. A fifth SAGDesign test mill for radioactive ores has been built by Starkey & Associates, specifically for testing uranium ores and can be moved to any licensed lab in the world on a project basis.

Key words: Grinding mill design, SAGDesign, Calibration, SAG mill, Ball mill

INTRODUCTION

Direct measurement of the required grinding mill pinion energy started years ago when Fred Bond developed the now famous Bond Ball Mill and Rod Mill Work Index (Wi) tests in small diameter laboratory mills. With the advent of SAG milling, new techniques to determine the required energy were necessary. The continuous dry grinding MacPherson test uses a 1.5 ft diameter SAG mill and a combination of interpretation techniques that allows the prediction of the required commercial mill pinion energy to be determined. JKMRC then developed the drop weight tester which measures the fragmentation that results from a known force being applied to the ore pieces being tested. This technique requires modelling to compare the resulting particle size distribution with previously known ores and thus the required pinion energy to be predicted.

In 1991, the SAG Power Index (SPI) test was invented to provide a cost effective way to directly measure the pinion energy needed for a SAG mill to grind an ore. This technique has rightly been described as a power based hardness test. But while the SPI test on a 2 kg sample of ore is good to determine hardness variability in an ore deposit by doing many tests, a single test was not robust enough to provide a good design power number to design a 40 ft diameter SAG mill, which today can cost over $30 000 000 US to purchase.

The advent of the low cost SPI test opened the doors to geo-metallurgical analysis of SAG hardness variability in an ore body, which variability was much greater than had previously been supposed. It then became attractive to measure and record all geo-metallurgical information as inputs to a block model of the mine ore reserves. This now can include metal assays, SAG pinion energy, Bond Ball and Rod Mill Work Indices, flotation rate parameters, mineralization, and any other measured feature that allows better understanding of an ore body and the best way to process the ore.

But the author's elusive goal had still not been achieved. The SPI test was good but not good enough to be used as a stand alone grinding design test. There were a number of technical reasons for this and the only proper solution was to go back to first principles and build a test that could be understood by all. In addition, in order to prevent mistakes in designing SAG mills, a more cost effective, accurate test was needed to ensure that junior mining companies could afford to do the required testing. The failure to do comprehensive testing has often been involved in the failure of a grinding circuit to perform up to design expectations.

In 2004, following two years of development by Starkey and Dawson Lab, the Standard Autogenous Grinding Design (SAGDesign) test was patented (by Outotec) and introduced for commercial use by Starkey & Associates who own the rights to use this patented technology. A full description of this test was presented at the 2006 SAG Conference in a paper entitled SAGDesign Testing – What It Is and Why It Works (please see References). This paper therefore examines the theory and calibration work that was completed prior to 2004 and presents case studies to show some of the current work that is being done to provide well engineered solutions to our client's grinding design needs.

THEORY AND PRACTICE

There are some fundamental principles that have been discovered and used in developing the SPI and SAGDesign tests. The bond Ball Mill Work Index test was developed using feed carefully prepared to 100% minus 6 mesh (3 mm) and about 80% passing 12 mesh US. It is also true that the Bond BM Wi test has been used for over 50 years as the industry standard way to design Ball mills. The first objective in designing a SAG test to measure required SAG pinion energy input, was to determine the energy needed to grind from the normal SAG feed size of 80% passing 152 mm to 80% passing 1.7 mm (12 mesh US). This prevents overlap in the energy measurement between SAG and Ball mill tests and results in the obvious situation where:

1) SAG pinion energy + Ball Mill pinion energy = Total Grinding pinion energy

By measuring these two components which can be called coarse and fine grinding parameters, the total grinding pinion energy can be determined. But this is only part of the story.

It was also learned from SAG mill benchmarking programs done in the period 1994 to 2000, that there is no observable difference in energy consumption in the SAG mill or Ball mill in the range of SAG product size adjustments from 0.4 mm to 3.5 mm. The SAG mill transfer size T80 can be adjusted using the Bond Work Index, for product sizes coarser or finer than the basic SAG product (T80) of 1.7 mm. More specifically, in the T80 range of 0.4 to 3.5 mm, the energy required to move between transfer sizes in this range is accurately described by applying Bond's energy equation, as noted below:

2) $$W = 10\ Wi / (P80)^{0.5} - 10\ Wi / (F80)^{0.5}$$

Where: *Wi is the Bond Ball Mill Work Index*
P 80 is the comminution step product size
F 80 is the comminution step feed size

Because there is no difference in energy consumption in the SAG mill and the Ball mill in the above noted adjustment size range, the T80 can be adjusted to give a desired power split between the SAG mill and the Ball mill. As a result, the calculation of mill sizes can now be done as an engineering exercise using first principles and relative measurements instead of relying on modelling techniques that derive their validity from other ores. This concept for balancing power between the SAG and ball mills, was first introduced and used in the formulation of the energy equations for CEET (Comminution Economic Evaluation Tool) by the author in 1999.

Control of the transfer size in a plant is very important. The use of a 12 mm trommel screen is not adequate if a finer T80 than 3.5 mm has been selected. Vibrating screens and/or cyclones are best used for this purpose.

Another factor in good ball mill design is the relationship between Bond Wi on crushed ore vs SAG ground ore. The latter measurement is required because the ball mills in SAG plants grind SAG discharge material and the grinding test should mirror the plant flowsheet. The SAG ground Wi is about 1 unit higher than a crushed Wi. In our design procedure, Starkey & Associates uses the Bond ball mill diameter correction factor to design ball mills. In spite of the fact that benchmarking programs consistently show the relevance of Bond's diameter correction factor, many engineering firms do not use it because the crushed Bond Wi value is too low and poor design would result.

SAGDESIGN TEST CALIBRATION

The SAGDesign test was designed to incorporate the concept of doing a Bond Ball Mill Wi test on SAG ground ore from the first or SAG stage of the test. The SAG stage therefore had to use enough material to do the Bond Wi test. To ensure this, the SAGDesign SAG mill was designed to be 488 mm (19.2") in diameter and 163 mm (6.4") long (EGL).

Other design parameters for the SAGDesign SAG mill were selected to duplicate commercial operating parameters and are summarized as follows:

SAGDesign test		2 stage - SAG followed by Bond BM Wi
	SAG test	Batch - with charge screening after each cycle
	Bond BM Wi	Conventional except uses SAG ground ore
SAG	Mill D/L ratio	3:1
	Diameter	488 mm
	Feed size	80% passing 19 mm (¾ inch)
	Product size	80% passing 1.7 mm (12 Mesh US Standard)
	Ore load	4.5 litres (constant volume)
	Operating load	26% by volume
	Steel load	11% by volume or 16 kg
	Critical speed	76%

Deliverables: Revolutions of the mill to reach 80% passing 1.7 mm and
Kilograms of material tested.
Calculated kWh/t to grind the ore to P80 1.7 mm
Bond Work Index in kWh/t

In order to prevent "cushioning" (that is encountered in the SPI test), minus 1.7 mm fines are removed from each grinding cycle until only 40% by weight of the original ore charge remains. The test is then run to completion by adding more revolutions and cycles, until the specified fineness is achieved. This change in procedure (compared to the SPI test) has resulted in a straight line calibration equation. This makes good sense since one revolution of the mill inputs a specific amount of energy to the charge.

Empirical calibration

The calibration of the test was done by testing a suite of 8 samples for the SPI value (expressed in kWh/t to 1.7 mm P80) and then performing the SAGDesign Test (consisting of a SAG and Bond Wi test on SAG ground material). Since the SPI tests had known energy results to achieve the same fineness, it was possible to calculate the SAGDesign equation coefficient that would give the same result. It was seen from the data reproduced in Fig. 1, that the straight line relationship was valid and the 'noise' in the data points was probably caused by the lower accuracy of the SPI test. Calculated adjustments to the data were made to allow for the extra energy that the heavy ore tested had caused the mill to draw, and for the extra weight because the same revolutions on a heavy ore indicates lower kWh/t than for a light ore even though the power draw will be a little higher.

The resulting calibration equation for the SAGDesign test is given below:

$$kWh/t = Revs * (g + 16\,000)/(447.3g)$$

Where: *kWh/t is the SAG pinion energy required to grind from F80 152 mm to P80 1.7 mm*
Revs is the mill revolutions to grind the ore to 80% - 1.7 mm,
g is the weight of the ore tested (4.5 litres) in grams,
16 000 is the steel load in grams and
447.3 is calculated coefficient from empirical tests.

Theoretical calibration

In order to confirm the equation developed above, a theoretical analysis was done to determine how much energy the test mill will draw per revolution when operating and what weight of ore was ground to the specified size in the test. It was estimated that the amount of energy consumed in the lab test was about 78% of that needed in a large mill and that by extrapolating the actual grinding function to 80% passing 1.7 mm that the actual straight line intercept would be about 81% of the total revolutions recorded in the test. When this was done, the estimated energy from the test analysis was remarkably close to that determined with the calibration equation. This was regarded as satisfactory proof that the calibration was accurate.

Benchmark calibration

A benchmark calibration result was presented in the SAG 2006 paper. The measured kWh/t in a pilot plant 5.5 ft diameter SAG mill checked very closely to the SAGDesign result. The reproducibility reported in the SAG 2006 paper was within 3% for duplicate SAG tests on the same sample. Our conclusion is that the absolute accuracy of the test is in this order of magnitude.

Patent details

Based on the favourable results from the calibration work done and the accuracy of the test results, Outotec (formerly Outokumpu Technology) requested to patent the SAGDesign test. At the same time it was agreed that Starkey owned the rights to use the test. Outotec had helped to fund the development and offered to guarantee throughput and grind for mills purchased from them if Starkey designed the grinding circuit. For this reason, the SAGDesign program is the first of its kind in the world where a mill manufacturer will support a technical design procedure. We are honoured by this support and the open technology which has resulted from the patent.

The relationship between the various companies engaged in the performance of SAGDesign test work and grinding mill design needs to be explained. The SAGDesign Consulting Group has three founding members. They are:

Starkey & Associates Grinding Design and Process Engineering (Head Office)
Dawson Metallurgical Laboratories Inc.
Outotec (Canada) Inc. (formerly Outokumpu Technology)

Starkey directs the work and writes the design reports, Dawson developed the test procedure details and trains the new members how to do the tests, and Outotec maintains the patent and offers process guarantees for mills designed by Starkey and purchased from them as noted above. Satellite Members of the SAGDesign Consulting Group include TOMS who joined in 2006, and Irgiredmet Research Institute in Russia and Ammtec Limited in Australia, both joining in late 2007. Outotec operates at arms length from the other members of the group while these other members work closely together to provide the best quality of testing and mill design available.

THREE CASE STUDIES

The case studies presented here were done in 2007. The case involving mill design for commercial full scale use includes data from the Climax Molybdenum project which is being put back into production using SAG grinding technology. SAGDesign test work, on 10 ore samples, selected for the purpose of final design, was done at Dawson Metallurgical Laboratories in Salt Lake City, USA. The other two case studies for prefeasibility design and existing mill performance prediction, represent SAGDesign test work done at the TOMS Research and Design Institute in Irkutsk, Russia and Dawson, USA respectively. In all, 6 SAGDesign projects were completed in 2007, three each at TOMS and Dawson.

Mill design for commercial full scale use

This assignment was done in two phases. The first or preliminary exercise was done using four samples of crushed rock from the mine. The hardest two samples were used for design to determine the likely power requirements and the average of these two was about 11% higher for total grinding energy than the average of the four samples. Design SAG grinding pinion energy to grind the F80 152 mm feed to T80 1.7 mm was 8.0 kWh/t and the total energy was determined to be 15 kW/t to complete the grind to a P80 of 150 microns.

Ten additional samples were then selected by Phelps Dodge for the final design. In this case the 80^{th} percentile of hardness variability gave energy requirements of 7.9 and 15.0 kWh/t for the SAG mill and total grinding energy requirements respectively. However, it was noticed that the hardest sample was 15% harder than the usual design at the 80^{th} percentile, and since the ore hardness increased with depth, it was recommended to use the hardest ore as the design point. All test results are given in Table 1. These results are analysed in Figure 2 to show increasing hardness with depth and in Figure 3 to show the hardness variability function for the samples tested.

For this project, Starkey & Associates did not take the samples and so we take no responsibility for the representativeness nor the reliability of the samples that were selected for testing. In cases where an Outotec process guarantee is required, Starkey travels to the site and takes responsibility for the selection of relevant samples. Only then will Outotec guarantee the result.

Finally, the mill selection sizes recommended are presented in Table 2. These mills were sized to grind 10 000 000 SDTPA at 90% availability, to a product size of P80 = 150 µ. The recommended mills (with no pebble crusher) are a 17 000 HP SAG mill and a 12 000 HP ball mill.

The final design work conclusively duplicated the original analysis on the four preliminary samples and allowed a slight refinement that includes an allowance for increasing hardness with depth. The recommended grinding circuit from Table 2 is therefore shown as the third option.

The mills ordered by Freeport-McMoRan Copper & Gold Inc. (FMI) for the Climax project are shown in the last option in Table 2. The power and length on the SAG mill were increased by FMI for contingent reasons and the ball mill length was also increased in recognition that the final mill loading may be a little less than allowed for in the design. The final design work was well supported by the FMI purchase order.

Pre-feasibility study design

This SAGDesign testing was done by TOMS in Irkutsk, Russia, to determine the basic grinding parameters for this Murmansk Region ore at the pre-feasibility stage of the project. Results from testing six samples are included here. If the project moves to a full feasibility study, it is the client's intention to do more test work to accurately confirm the size of the grinding mills required.

In this case John Starkey did go to the site to assist the client's geologist and metallurgist in selecting the samples. Existing core was used but since a number of key ore intersections had already been removed for previous metallurgical testing, it was not possible to take all of the samples that would have been chosen had the core been available.

Observation of the core in the racks indicated that the ore was extremely hard and the SAGDesign testing confirmed this to be true. The SAG pinion energy to grind the ore to T80 1.7 mm ranged from 16 to 19 kWh/t and the total pinion energy required to produce a final product P80 of 70 microns varied from 35 to 37 kWh/t. Table 3 shows the basic hardness of the ore tests and the calculated pinion energies corresponding to these measurements. A remarkable feature of this data suite is that the Bond work index is relatively constant even though the SAG hardness varies. Figure 4 compares these results by sorting the values by increasing order of hardness. The SAG hardness variability is greater than for the Ball mill.

The variability in these samples was remarkably small compared to other projects. This was probably due to the fact that the samples chosen for testing represented long drill core intersections, not just point hardness measurements over short distances. But due to the hard values measured, it is possible that the variability is not a big factor and the samples do give a good measure of the grinding energy required.

The grinding mills for this project are shown in Table 4. They were sized to process 8 340 000 tonnes per year at 91% availability, to a product size of P80 = 70 µ. A pebble crusher is recommended because the ore is so hard. An 18 MW vari-speed SAG mill and two 13 MW ball mills are recommended as noted in Option 3 Table 4.

Existing mill performance prediction

This project was a Canadian base metal producer and the SAGDesign tests were done at Dawson. Four SAGDesign tests were done on samples from two different ore bodies. The purpose of the work was to ascertain the maximum throughput possible using several different configurations of the existing equipment. In addition to a 2000 HP SAG mill, there were three ball mills of 2500, 1000 and 800 HP capability - any two of which could be made available. The target grind was 80% passing 30 microns.

SAGDesign test results are shown in Table 5 and the variability analysis for this data is given in Figure 5. The target throughput was 134.4 t/h. At 93 % availability this is equivalent to an average throughput of 3000 t/d. It was known that 3000 t/d could not be ground to the specified fineness but in order to understand future needs it was necessary to know what the real capacity of the circuit was.

A series of calculations were done showing the effect of fine crushing on the feed and using different configurations of ball mills. These calculations are shown in Table 6. The only option that could produce the required tonnage was to use the three existing ball mills and buy a new pebble crusher and two new regrind mills. It was therefore concluded that to meet production schedules it would be best to purchase a new SAG mill.

SUMMARY

This is the first publication of the calibration data. We submit that the accuracy of the SAGDesign test makes it superior to any other method by comparison. When combined with supervised sample selection on a mine site, it is the most accurate and cost effective way to determine new mill sizing and throughput for existing mills. The reason for recommending 10 samples (minimum) for the guaranteed program is that it gives statistical robustness and accuracy to the analysis that is lacking when less work is done.

The present case studies also give a good indication of the accuracy of SAGDesign testing and the usefulness of these techniques to solve routine and difficult grinding design challenges.

RECOMMENDATIONS

We recommend contacting any of the SAGDesign Consulting Group members listed above, for new grinding mill design, or throughput forecasting projects. The program we offer is suitable for any mining company and it is fair to say that the SAGDesign testing program is becoming better known and more popular with each passing month.

Future work will focus on expanding the comparisons between SAGDesign testing and other previously conventional methods because so far all the work done to date suggests that this is a powerful tool to give clients the grinding equipment they need to run successful and profitable mining operations.

REFERENCES

Starkey, J, and Dobby, G, 1996. Application of the Minnovex SAG Power Index at Five Canadian SAG Plants. *Proceedings of the International Conference on Autogenous and Semi-Autogenous Grinding Technology*.

Starkey, JH, Hindstrom, S, and Nadasdy, G, 2006. SAGDesign Testing – What It Is and Why It Works. *Proceedings of the International Conference on Autogenous and Semi-Autogenous Grinding Technology*.

Starkey, J, and Meadows, D, 2007. Comparison of Ore Hardness Measurements for Grinding Mill Design for the Tenke Project. *Proceedings of the 39th Annual Meeting of the Canadian Mineral Processors.*

ACKNOWLEDGEMENTS

Thanks are extended to Freeport McMoRan for permission to publish the Climax Moly design data.

Thanks are also given to our many clients who have favoured us with their grinding mill design assignments.

LIST OF HEADINGS

CAPTIONS

Table captions

Table 1. Climax SAGDesign testing - summary of results

Table 2. Climax mill sizing for hardest ore

Table 3. Pre-feasibility SAGDesign testing - summary of results

Table 4. Pre-feasibility study mill sizing

Table 5. Existing mills SAGDesign testing - summary of results

Table 6. Existing mills calculated throughput for various options

Figure captions

Figure 1. Relationship between SPI energy and SAGDesign revolutions

Figure 2. Climax Molybdenum ore hardness vs depth

Figure 3. Climax pinion energy variability – SAG mill and total

Figure 4. PFS project pinion energy variability – SAG mill and total

Figure 5. Existing mills pinion energy variability – SAG mill and total

TABLE 1

Climax SAGDesign testing - summary of results

Ore type	Avg	SAG test		Bond Wi	Pinion kWh/t to P80		
	Depth	Revs	gms	kWh/t	10M	100M	Total
Preliminary samples							
Crushed rock #1		988	6944	13.05	7.3	7.49	14.78
Crushed rock #2		1126	7229	11.84	8.09	6.8	14.88
Crushed rock #3		1090	6988	12.28	8.01	7.05	15.06
Crushed rock #4		850	7835	12.72	5.78	7.3	13.08
Design avg 2 & 3		**1108**	**7109**	**12.06**	**8.05**	**6.92**	**14.97**
Final design samples	**m**						
Split DD Core #1	285	691	7227	14.23	4.97	8.17	13.13
Split DD Core #2	375	872	7308	14.06	6.22	8.07	14.29
Split DD Core #3	625	691	7312	12.69	4.93	7.28	12.21
Split DD Core #4	825	878	6900	11.79	6.52	6.77	13.28
Split DD Core #5	1315	1241	7306	14.68	8.85	8.43	17.27
Split DD Core #6	355	802	7520	11.26	5.61	6.46	12.07
Split DD Core #7	675	813	6942	10.92	6.01	6.27	12.27
Split DD Core #8	915	1091	7137	12.1	7.91	6.94	14.85
Split DD Core #9	1245	837	7239	12.09	6.01	7.34	12.95
Split DD Core#10	475	1124	7524	12.79	7.86	7.27	15.2
Design avg. (80th %) 8 & 10		**1108**	**7330**	**12.44**	**7.88**	**7.14**	**15.02**
Hardest ore #5		**1241**	**7306**	**14.68**	**8.85**	**8.43**	**17.27**

TABLE 2

Climax mill sizing for hardest ore

Option	Dia Ft.	EGL Ft.	D80 µ	Drive	HP	kW	Load	Steel	% Crit.
Preliminary sizing - based on 4 samples									
SAG Mill	36	15	1700	Vari	16 000	11 931	26	12	80
Ball Mill	22	31	150	Synchr.	11 000	8203	35	35	75
TOTAL INSTALLED POWER					27 000	20 134			
Final sizing, no pebble crusher - hardest ore - 10 samples									
SAG Mill	36	15.5	1,700	Wrap	17 000	12 677	26	12	80
Ball Mill	22	34	150	Synchr.	12 000	8949	35	35	75
TOTAL INSTALLED POWER					29 000	21 626			
Final sizing with pebble crusher - hardest ore									
Pebble Cr	10	Cone	~ 15 mm	Fixed	1000	746	MP 1000 (Prelim. Estimate)		
SAG Mill	34	14.3	1,700	Wrap	13 500	10 067	26	12	80
Ball Mill	22	34	150	Synchr.	12 000	8949	35	35	75
TOTAL INSTALLED POWER					26 500	19 761			
Purchase Order									
Pebble Crushers		Cone	~ 15 mm	Fixed	1000	746	2 only - 500 HP each		
SAG Mill	**34**	**17**	**1,700**	**Wrap**	**15 000**	**11 186**			
Ball Mill	**22**	**35.5**	**150**	**Synchr.**	**12 000**	**8949**			
TOTAL INSTALLED POWER					**28 000**	**20 880**			

TABLE 3
Pre-feasibility SAGDesign testing - summary of results

TOMS Test No.	SAGDesign Test Revs No.	SAGDesign Test Wt ore grams	Calc SAG Pinion W kWh/t	SG Solids g/cc	SAGDesign Bond BM Wi kWh/t	SAGDesign Bond Closing Screen	Calc BM Pinion W kWh/t	TOTAL Pinion W kWh/t
			to 1.7 mm				*to 70 µ*	
1	3041	8746	19.24	3.02	17.82	105 µ	16.98	**36.21**
2	2771	8696	17.59	3.04	18.53	105 µ	17.65	**35.25**
3	2549	8973	15.86	3.03	22.28	105 µ	21.23	**37.09**
4	2736	8540	17.58	3.06	18.93	105 µ	18.03	**35.61**
5	2910	8697	18.47	3.18	19.50	105 µ	18.58	**37.05**
6	2656	8601	16.98	3.00	18.61	105 µ	17.73	**34.71**

TABLE 4
Pre-feasibility study mill sizing

Option	Mills	Diam. Feet	EGL Feet	Motor HP	Motor MW	Drive Type	Speed %Crit. Design	Speed %Crit. Normal	Mill Ld %Vol. Steel	Mill Ld %Vol. Chg	Fd F80 mm	T_{80}/P_{80} µm
1	SAG	42	19.4	32000	23.9	V/S	80	75	11	26	152	1,700
	Ball	22	34	12000	8.9	Fixed	75	75	35	35	1.7	70
	Ball	22	34	12000	8.9	Fixed	75	75	35	35	1.7	70
	Total Power			56000	41.8							
2	SAG	40	20	29000	21.6	V/S	80	75	11	26	152	4,000
	Ball	22	37	13000	9.7	Fixed	75	75	35	35	4	70
	Ball	22	37	13000	9.7	Fixed	75	75	35	35	4	70
	Total Power			55000	41.0							
3	*Peb Crusher*			*1000*	*0.75*	*Fixed*	** MP-1000 in-circuit*		*SH cone crusher*		*65*	
	SAG	38	18.4	24000	17.9	V/S	80	75	11	26	152	3,000
	Ball	22	36	13000	9.7	Fixed	75	75	35	35	3	70
	Ball	22	36	13000	9.7	Fixed	75	75	35	35	3	70
	Total Power			51000	37.3							

TABLE 5
Existing mills SAGDesign testing - summary of results

DML Test No.	SAGDesign Test Revs No.	SAGDesign Test Wt ore grams	Calc Pinion W kWh/t	SG Solids g/cc	Plant Fd F80 mm	SAG Ground Ore Bond Wi kWh/t	SAG Ground Ore Closing Screen	Design Product P80	Calc BM Pinion W kWh/t	TOTAL Pinion W kWh/t
			to 1.7 mm						*to 30µ*	*to 30µ*
1	2221	10982	12.20	4.47	152 mm	10.99	75 µ	30 µ	20.41	**32.61**
2	2054	10615	11.51	4.36	152 mm	10.45	75 µ	30 µ	19.41	**30.92**
3	2720	11355	14.65	4.52	152 mm	11.43	75 µ	30 µ	21.23	**35.88**
4	2165	11138	11.79	4.55	152 mm	12.55	75 µ	30 µ	23.31	**35.10**

TABLE 6

Existing mills calculated throughput for various options

PROCESS OPTION	Ball Mill OPTION	FEED F80	PEBBLE CRUSH	SAG Mill HP	BM 1 HP	BM 2 HP	BM 3 HP	T80	t/h	t/d	REMARKS
Existing SAG Mill				**22' x 6.5'**							
Mill Sizing	1	152 mm	No	**2000 HP**	2500	800		1700	102	2274	SAG Limited
	2	152 mm	No	2000	2500	800		2610	107	2393	Ball Mill Limited
	3	152 mm	No	2000	2500	1000		4270	113	2513	T80 too coarse
Fine Feed	1	102 mm	No	2000	2500	800		1520	111	2486	Possibility
	2	102 mm	No	2000	2500	1000		2155	117	2610	Best at present
	3	102 mm	No	2000	2500	1000	800	7630	133	2977	T80 too coarse
Pebble Crusher	1	152 mm	Yes	2000	2500	800		826	118	2639	Expense not justifed
Not recommended	2	152 mm	Yes	2000	2500	1000		1047	124	2772	Expense not justifed
	3	152 mm	Yes	2000	2500	1000	800	2185	142	3161	Need third ball mill
											SAG HP D' x EGL'
New SAG Mill	1	152 mm	No	2000	2500	800		362	134	3000	3500 **24 x 9**
	2	152 mm	No	2000	2500	1000		555	134	3000	3200 **24 x 8**
	3	152 mm	No	2000	2500	1000	800	6130	134	3000	2500 22 x 7.5

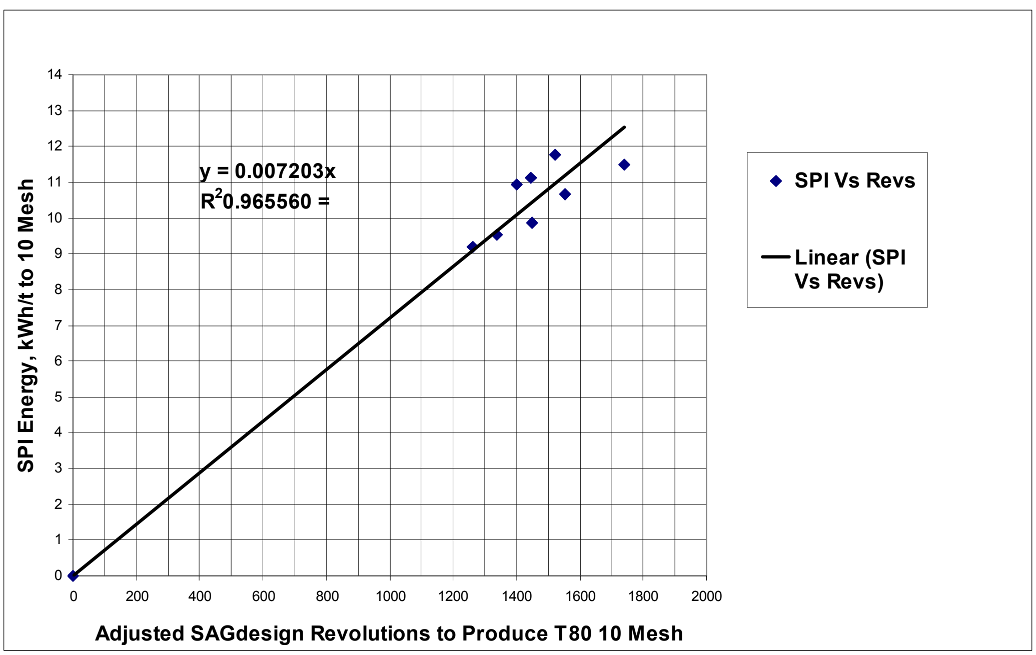

FIG 1 - Relationship between SPI energy and SAGDesign revolutions

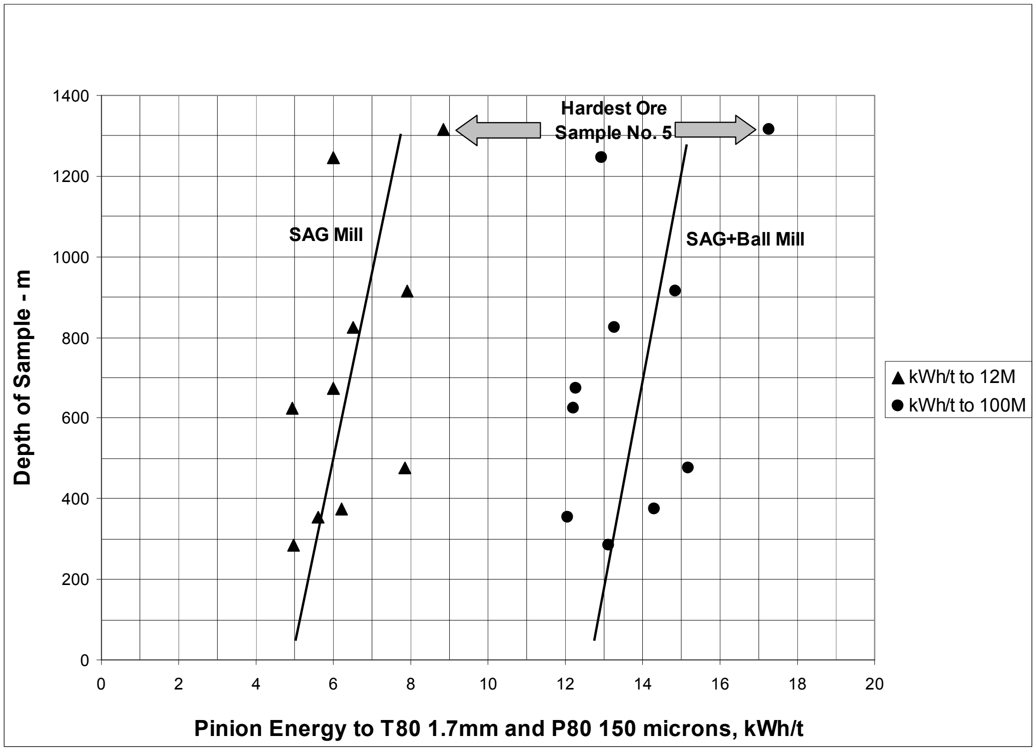

FIG 2 - Climax Molybdenum ore hardness vs depth

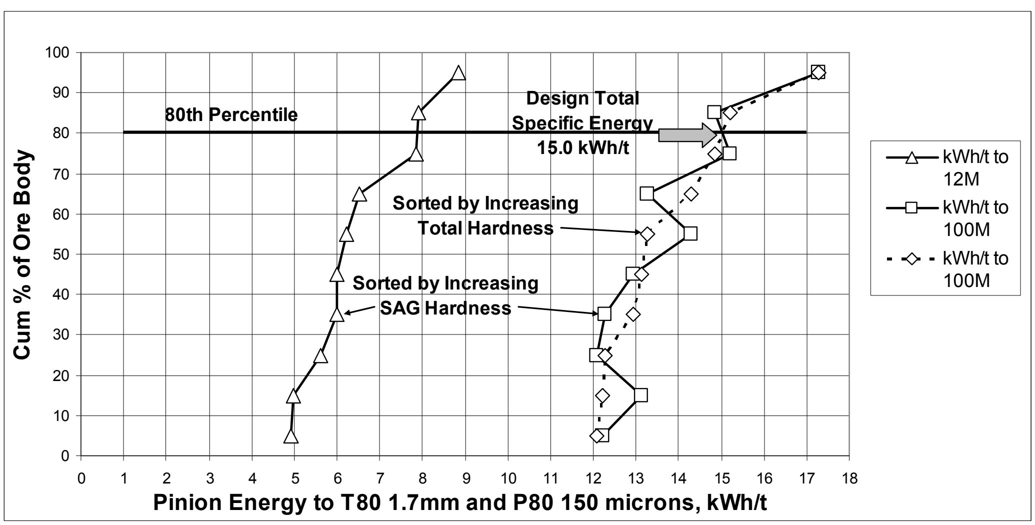

FIG 3 - Climax pinion energy variability – SAG mill and total

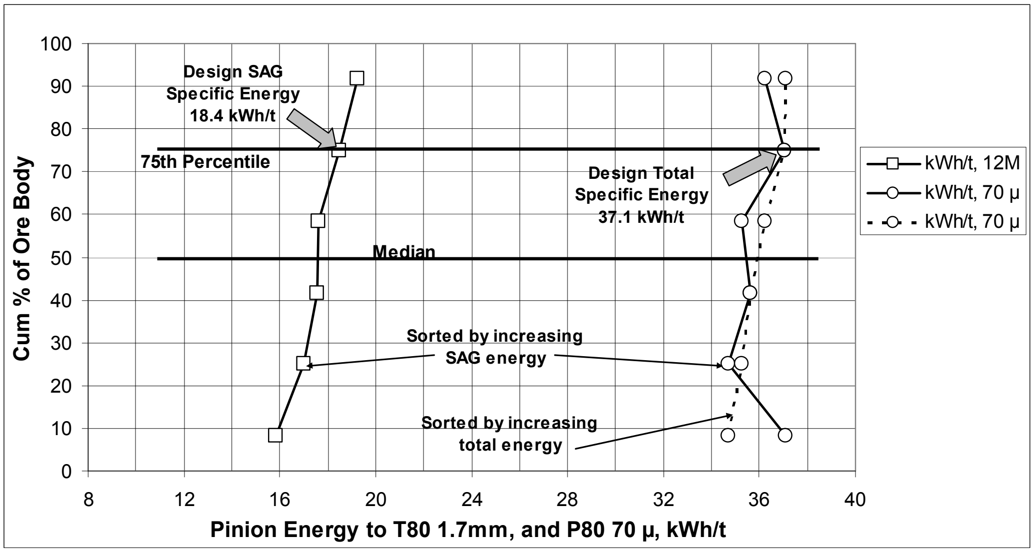

FIG 4 - PFS project pinion energy variability – SAG mill and total

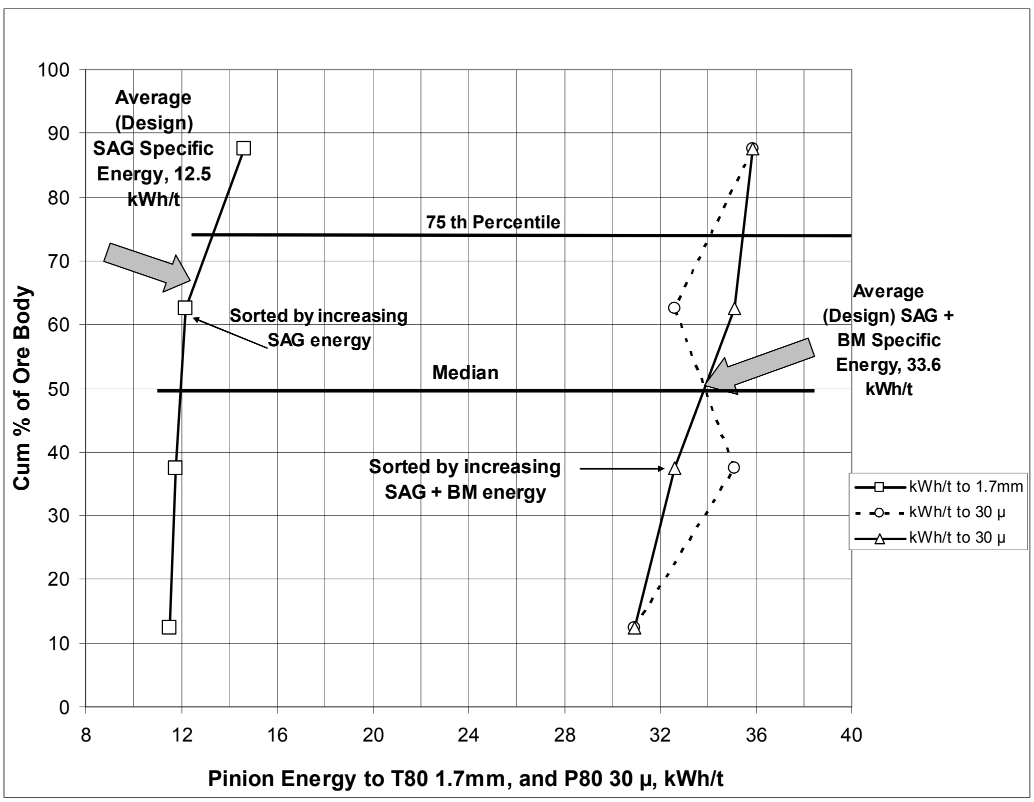

FIG 5 - Existing mills pinion energy variability – SAG mill and total