APPLICATION OF THE SART PROCESS TO HEAP LEACHING OF GOLD-COPPER ORES AT MARICUNGA, CHILE

KEVAN J. R. FORD AND ROBERT D. HENDERSON — KINROSS GOLD CORPORATION, AND DR. CHRIS A. FLEMING — SGS

ABSTRACT

Kinross Gold Corporation's Maricunga mine in Chile presents an ideal opportunity to apply the SART process to a heap leach operation. Given increasing levels of cyanide complexed copper in current pregnant solutions from Maricunga heaps (over 300 ppm Cu), there is a need to reduce these levels and decrease cyanide consumption and cost. Additionally, a means of disposing of this copper is required, preferably as a saleable product. The well published SART process applied to gold-copper cyanide solutions was selected as it allows rapid precipitation of cyanide soluble copper as a relatively pure copper sulphide. The process also allows effective recovery and recycle of cyanide back to the heap leach operation.

This paper reviews the SART process chemistry and presents a summary of SART bench-scale and pilot plant testwork completed by Kinross. Key design parameters and engineering aspects of the proposed plant at Maricunga are discussed. SART plant operating costs and net revenue analysis are included and illustrate the compelling economics of installing a SART process plant.

INTRODUCTION

MARICUNGA OPERATION

Compañia Minera Maricunga (CMM), fully owned by Kinross Gold Corporation, operates the Maricunga mine (formerly Refugio) which is located 120 km due east of the city of Copiapó at an elevation of 4,200m above sea level in the Andes mountains of northern Chile. Figure 1 shows a map of the location of the Refugio mine relative to other gold and copper mines in the region.

The Maricunga mine produces 45,000 - 52,000 t/day of gold bearing ores from the Verde Open pit, with ore gold grades ranging from 0.6 - 1.0 g/t and copper levels of 0.05% - 0.1%. The operations flowsheet is schematically given in Figure 2. Blasted ore is trucked from the pit to a primary crusher and conveyed to a 2 stage crushing plant, which produces ore with a P80 of 10 - 12mm for stacking on permanent heaps in 10m lifts. To date, approximately 80Mt of ore have been placed on the heap leach pads. Cyanide solution is pumped onto the heap through polypropylene pipes with drip emitters and make-up cyanide (sodium cyanide) is added to recycled barren and low grade preg solutions.

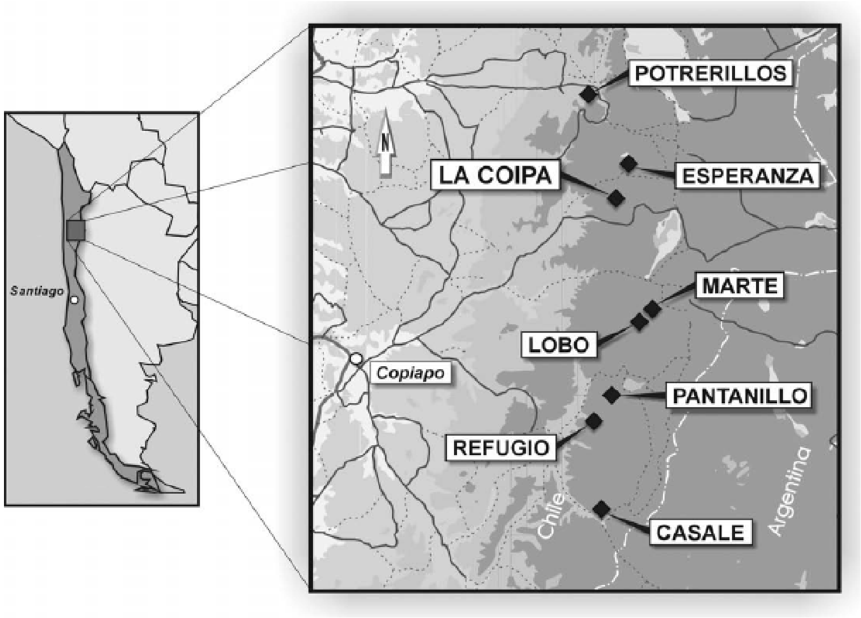

Figure 1 Regional Location of Maricunga Mine (Refugio) In N. Chile

Typical solution application rates are 1.5 - 2.0 m³/t ore. Preg solution flowrates from the base of the heaps average 2,000 - 2,400 m³/hr and contain about 0.3 - 0.4 ppm Au, 300 - 350 ppm total CN and 300 ppm Cu.

Preg solutions are collected in a lined preg solution pond, and fed to an adsorption, desorption refining (ADR) plant using activated carbon for gold recovery. Cyanide is added to limit the adsorption of copper onto carbon, and a cold cyanide strip of the carbon is performed to remove copper. The cold strip Cu-CN solution is fed back to the heaps. The ADR plant consists of 5 carbon adsorption tanks, with Zadra pressure elution of carbon coupled with gold electrowinning. Overall gold recovery from ore to gold dore at Maricunga is 65 - 70 %.

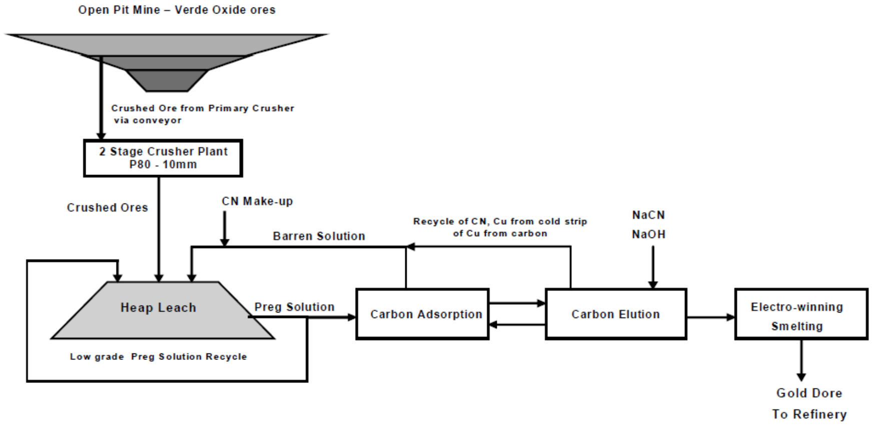

Figure 2 Maricunga Operation Flowsheet

Table 1 Solubility of Cu Minerals in NaCN Solution (Hedley and Tabachnick, 1958)

COPPER MINERAL	FORMULA	% COPPER DISSOLVED IN NaCN SOLUTION
Azurite	$2Cu(CO)_3.Cu(OH)_2$	94.5
Malachite	$2CuCO_3\ (OH)_2$	90.2
Chalcocite	Cu_2S	90.2
Covellite	CuS	95.6
Native Copper	Cu	90.0
Cuprite	Cu2O	85.5
Bornite	$FeS.2Cu_2S$	70.0
Enargite	Cu_3AsS_4	65.8
Tetrahedrite	$(Cu.Fe.Ag.Zn)\ 12Sb_4S_{13}$	21.9
Chrysocolla	$CuSiO_3.(nH_2O)$	11.8
Chalcopyrite	$CuFeS_2$	5.6

CYANIDE SOLUBLE COPPER

In the Maricunga region, gold mineralization occurs with copper minerals, some of which leach readily in the cyanide solution that is applied to extract the gold. Table 1 indicates typical cyanide solubility of copper minerals in 0.1% NaCN solutions (Hedley and Tabachnick, 1958). The percent cyanide-soluble copper in the ore therefore depends on the type and amount of each copper mineral present. Gold-copper ores may be classified according to their degree of oxidation as either oxide, mixed or sulphide ore. The extent of oxidation of a block of ore strongly affects the amount and chemistry of the copper minerals present, and hence the fraction of copper that will be cyanide soluble. Ores in which the oxidation weathering processes have been pronounced with high removal of sulphur and copper units from the original sulphides result in low levels of residual copper and sulphur. This residual copper may be in the form of oxide and/or hydrolyzed copper minerals such as cuprite, malachite or azurite. Although such copper minerals exhibit high cyanide solubility >85%, cyanide solubility of residual copper in Maricunga oxide ores has been shown to be low, of the order of 18 - 32%.

Oxidation of sulphides by weathering of the ore at surface or along fracture planes, results in the formation of acid, which in turn dissolves the copper in the copper minerals that have been oxidized. This leached copper remobilizes to flow by gravity down through the ore body, to eventually reprecipitate out in a "mixed" ore zone. In this zone, the copper may cement out on pyrite or reprecipitate as a chalcocite (Cu_2S) "blanket". Chalcocite is a copper-rich sulphide mineral of lower S/Cu molar ratio, with a significantly enhanced cyanide solubility of > 90%.

In fresh sulphide ores with no oxidation, sulphur has not been leached out, leaving primary, unaltered sulphides such as chalcopyrite, bornite and possibly tetrahedrite, along with pyrite. These copper minerals show variable, but generally low levels of copper CN solubility, from 5% up to 70%. Chalcopyrite is only sparingly soluble in strong cyanide solution, and not at all in weak cyanide solution that is typical of heap operations.

The level of copper (as copper cyanide) in Maricunga heap leach solutions has shown a steady increase since operations restarted in May 2005. Figure 3 shows the rise in copper in preg leach solutions from 50 ppm Cu to over 300 ppm Cu by June 2007. This copper concentration represents a build up of solubilized copper and cyanide inventory in the heap leach system, due to recycle of cyanide leach solution back to the heaps after the ADR plant. Currently, no bleed stream for copper exists at Maricunga to reduce the copper levels.

As more copper continues to leach out of existing ores in the heaps as well as from fresh ore added in each lift, copper concentrations are expected to continue to rise with resulting increase in cyanide consumption and operating cost.

CYANIDE CONSUMPTION AT MARICUNGA

Cyanide solubilized copper from Maricunga ores will lock up and consume cyanide, with stochiometry depending on the pH and cyanide concentration present in the leach solution. Formation

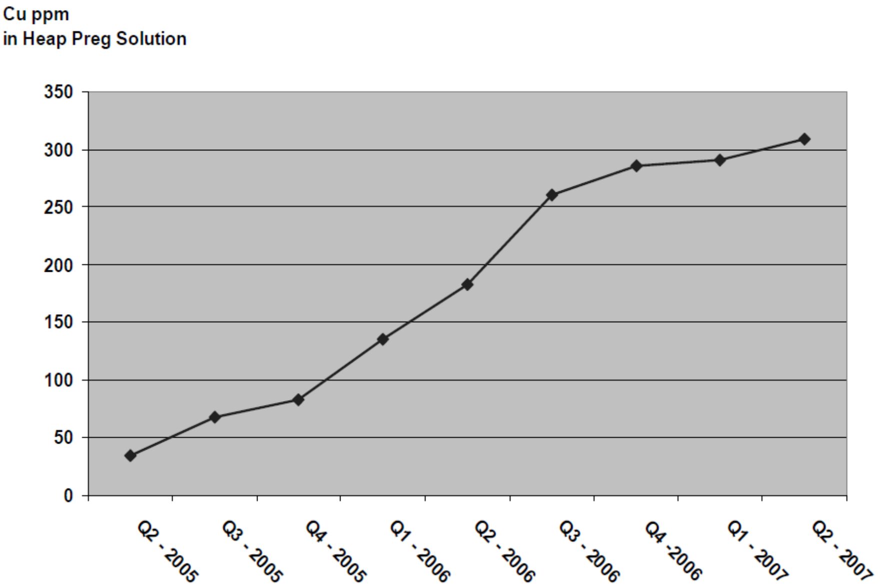

Figure 3 Cyanide Soluble Copper in Maricunga Preg Leach Solution

of $[Cu(CN)_2]$- is favored at low pH's and low cyanide concentrations, whereas $[Cu(CN)_4]^{3-}$ is formed at pH's above 10 and cyanide strengths above 200ppm. $[Cu(CN)_3]^{2-}$ is the most stable form of copper cyanide. A solid precipitate of CuCN is produced at pH's below 3.

Table 2 NaCN Consumption per kg Cu Present in Cu-CN Reaction Species

REACTION	EQUATION	kg NaCN CONSUMED PER 1 kg OF Cu
1	$Cu^+ + CN^- = CuCN$	0.8
2	$Cu^+ + 2CN^- = [Cu(CN)_2]^-$	1.5
3	$[Cu(CN)_2]^- + Cn^- = [Cu(CN)_3]^{2-}$	2.3
4	$[Cu(CN)_3]^{2-} + Cn^- = [Cu(CN)_4]^{3-}$	3.1

The associated NaCN consumption may be estimated from the Cu-CN species present, as shown in Table 2. Using reaction 3 as the basis, since this represents the most stable form of Cu-CN, the stoichiometric consumption of sodium cyanide is approximately 2.3 kg for every kg of cyanide soluble copper extracted. Therefore, if the ore has 40 g/t of cyanide-soluble copper, then the minimum quantity of cyanide required for copper leaching is 0.1 kg NaCN/t. If the quantity of copper extracted increases to 300 g/t then the cyanide requirement increases to 0.7 kg NaCN/t. Viewed another way, since the 3 moles of cyanide that are complexed with each mole of copper in the leach solution are effectively "inactive" as far as gold leaching is concerned, the Maricunga heap leach solution is now carrying the equivalent of 0.7 g/L NaCN excess cyanide over and above that needed for effective gold leaching.

Heap leach cyanide consumptions for each Maricunga ore category, from operations data and various Kinross testwork programs (SNC Lavalin, 2003 and McClelland, 2007), are summarized below in Table 3.

For Verde oxide and sulphide ores, the lower total cyanide consumption of 0.3 - 0.4 kg NaCN/t ore results from relatively low levels of cyanide soluble copper. Based on reaction 3 above, the NaCN consumption due to cyanide soluble copper extracted may be estimated as 0.07- 0.09 kg/t ore. This consumption due to copper therefore represents approximately 22 - 35% of total cyanide consumption.

Table 3 Copper Grade And Cyanide Consumption For Maricunga Ores

MARICUNGA ORE	ORE Cu GRADE ppm	CN SOL Cu EXTRACTED ppm	CYANIDE CONSUMPTION kg NaCN/t ORE
Verde Oxide	100	28	0.2 - 0.3
Verde Mixed	120	36	0.3 - 0.4
Verde Sulphide	135	37	0.3 - 0.4
Pancho Oxide	150	11 - 38	0.4 - 0.7
Pancho Mixed	1000	502 - 664	1.5 - 2.0
Pancho Sulphide	800	48 - 286	1.0 - 1.3

Future Maricunga production will come from Pancho ores, for which testwork data has shown significantly elevated copper and cyanide soluble copper levels, particularly for the mixed and sulphide ores. Pancho mixed ore is projected to consume higher amounts of cyanide owing to the presence of chalcocite. Based on reaction 3 above, the % of total CN consumption due to cyanide soluble copper in the Pancho mixed ores is expected to be over 50%. Compared to the Verde ores, cyanide consumption and cost in the future processing of Pancho ores at Maricunga is expected to more than double, with an associated sharp rise in copper levels in heap leach preg solutions. Allowing copper to continue to build in the heap leach solutions is seen as not an option.

A study was initiated to find an economic and environmentally acceptable means to remove cyanide soluble copper from Maricunga heap leach solutions and recover the associated cyanide. A number of alternative processes were briefly considered, such as AVR and the Hannah process, but given their greater complexity they were rejected. A distinguishing feature of the SART Process (relative to the alternatives of AVR and Hannah) is that the free cyanide strength in the final treated solution is essentially the same as the total cyanide strength in the feed to SART. By contrast, in the AVR and Hannah processes, a small volume of concentrated cyanide solution is produced for recycling. There is no need to produce concentrated cyanide recycle solutions for heap leach operations, since all of the solution flow is generally recycled to the heap. Therefore, out of the available technologies, the well- published and much simpler SART process was selected.

THE SART PROCESS

PROCESS FLOWSHEET

The SART process was developed into a technically feasible process by SGS Lakefield Research and Teck Corporation in 1997 (MacPhail, Fleming and Sarbutt 1998), with full-scale commercial application at Newcrest's Telfer Mine in W. Australia (Barter 2001). The process involves releasing the cyanide associated with the copper cyanide complex, allowing it to be recycled back to the leach process as free cyanide, with recovery of the copper as a valuable, high-grade Cu_2S by-product (~70% Cu).

The SART name is derived from an acronym describing the unit operations in the process flowsheet, as follows:

- Sulphidization
- Acidification
- Recycling of precipitate/s
- Thickening of precipitate/s

The SART process flowsheet is shown schematically below in Figure 4.

PROCESS CHEMISTRY

SART, as originally developed (Fleming, 1998, 2005), involves adding chemical sulphide ions, such as sodium hydrosulphide (NaSH), to an acidified CN solution (pH 10 to pH 5 or below) to precipitate copper, silver and zinc (if present) as metal sulphides, and convert cyanide to HCN, under weakly acidic conditions. Other cyanide-solubilized base metals like Ni and Co would also be precipitated. HCN is a very soluble gas, and remains in solution until the Cu_2S, Ag_2S or ZnS are removed by thickening and filtration. Importantly, gold does not precipitate to any significant extent during the SART process, and

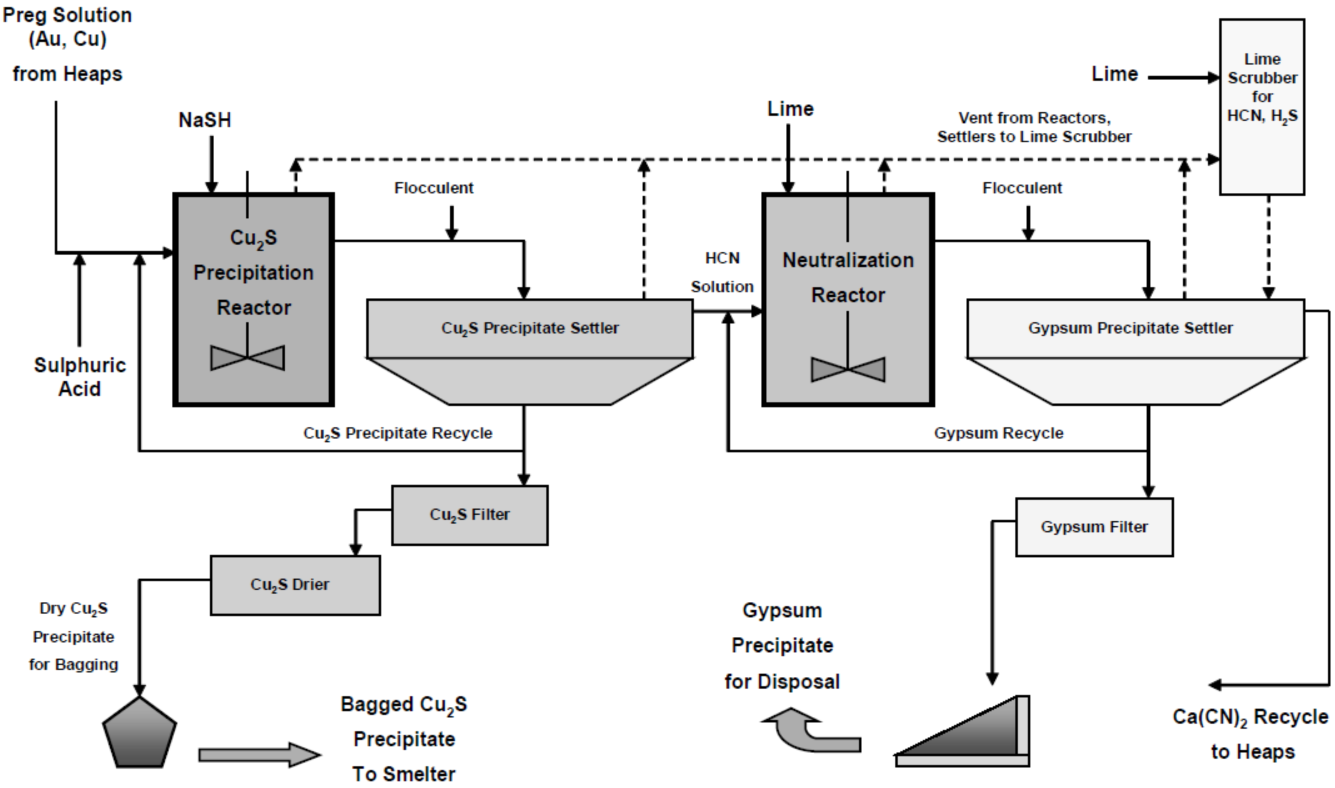

Figure 4 SART Process Plant Flowsheet

remains in solution to be recovered on activated carbon. The HCN solution is then neutralized with lime or caustic soda, prior to recycling to leach. The overall chemical reactions applied to Cu, Zn and Ag cyanide complexes are:

$$2Cu(CN)_3^{2-} + S^{2-} + 6H^+ \rightarrow Cu_2S + 6HCN$$

$$2Ag(CN)_2^- + S^{2-} + 4H^+ \rightarrow Ag_2S + 4HCN$$

$$Zn(CN)_4^{2-} + S^{2-} + 4H^+ \rightarrow ZnS + 4HCN$$

These reactions are all fast and irreversible, due to the fact that cyanide is inert when present in solution in the form of HCN gas. The reactions take place in a first stage (primary) precipitation reactor, from which sulphide precipitates are fed to a thickener. A portion of the thickened slurry of sulphide precipitate is recyled back to the reactor to develop a suitable precipitate particle size and achieve sufficient bed depth in the thickener. A precipitate slurry of 10 - 15% solids may then be drawn off the thickener underflow and washed, filtered and dried. The Cu_2S precipitate (with Zn, Ni and other metal sulphides) is then sold to a smelter as a valuable co-product.

A second reactor is used to neutralize the aqueous HCN in the thickener overflow from pH 5 back to pH 10. Lime or caustic soda may be used to produce $Ca(CN)_2$ or NaCN for recycle to the heap or tank leaching circuit. The neutralization reactions are:

$$2HCN + Ca(OH)_2 \rightarrow Ca(CN)_2 + H_2O$$
$$2HCN + NaOH \rightarrow NaCN + H_2O$$

All four process units (2 reactors and 2 thickeners) are sealed and have vents to a lime scrubber system to capture any evolved HCN or H_2S gases.

By acidifying with sulphuric acid in the primary reactor, the SART process leads to the formation of a gypsum- type precipitate when neutralization of HCN in the neutralization reactor is performed with lime. This gypsum precipitate needs to be removed from the neutralized cyanide solution prior to recovery of gold on carbon and recycle of barren cyanide solution to the leach circuit. To achieve this, a gypsum thickener is included in the circuit with the option of recycling the gypsum thickener underflow to enhance precipitation rates and settling / consolidation in the thickener.

The SART process may be applied to pregnant gold solutions prior to carbon adsorption or on barren solutions after carbon adsorption. Applying the process before carbon adsorption has the distinct advantage of potentially eliminating copper adsorption on carbon in the gold recovery plant, which improves the performance of the carbon for gold adsorption, and obviates the need for a cold cyanide strip of carbon to remove copper ahead of gold elution and electro-winning.

For a heap leach operation, the inherent separation of leach solution from ore solids that occurs in the heap suits the SART process, as clear solutions are fed directly to the primary precipitation reactor. For mill plants, the leach slurry may be washed via CCD with the overflow pregnant solution feeding a SART plant prior to carbon adsorption. When the leach slurry feeds a CIP plant, the CIP tails (barren) may be washed in a CCD circuit or recovered from a tailings dam, and then fed to a SART plant.

SART AT MARICUNGA

MARICUNGA FLOWSHEET WITH SART

To recover copper from Maricunga heap leach solution and release the cyanide for recycle, a portion of the preg solution (bleed stream) from the heaps will be fed to the SART plant. Figure 5 shows the position of the proposed SART plant in the Maricunga flowsheet.

The SART plant will be fed by high grade preg gold solution from the heaps, prior to carbon adsorption, rather than barren solution after the ADR plant. This will significantly lower the copper concentration and increase the cyanide to copper ratio in the feed to the carbon columns. This will in turn tend to complex the copper as the $Cu(CN)_4^{3-}$) species, which does not adsorb readily on carbon, so the loading of copper onto carbon at Maricunga is expected to decrease significantly once the SART plant is installed. Currently, cyanide is added to the preg solutionprior to carbon adsorption to control copper loading on the carbon, and it is expected that this practice will be discontinued. In addition, copper that does load onto carbon is currently coldstripped using cyanide at Maricunga, to mitigate the risk of copper reporting to gold dore. With SART in place, it is expected that the copper loading on carbon in the ADR plant will be sufficiently low that no cold strip of carbon will be required.

Of note is that gold in the preg feed solution is largely unaffected by the SART process. A very small amount of gold (<0.5%) reports to the copper sulphide precipitate, for which credit will be given by a copper smelter. The neutralized low copper, gold cyanide solution exiting from the SART plant will be fed to the existing carbon adsorption plant for gold recovery.

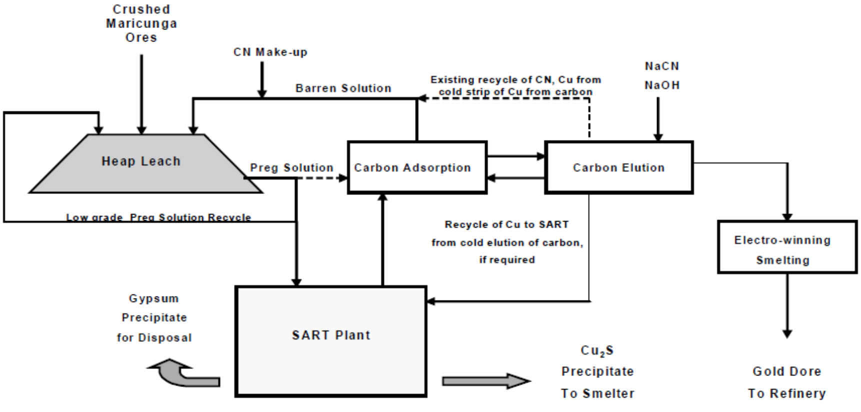

Figure 5 Maricunga Flowsheet with SART

SART TESTWORK

To evaluate the SART process and define the parameters for engineering of a plant at Maricunga, Kinross has completed significant amounts of testwork on a bench-scale and pilot plant level (at SGS Lakefield Research in Santiago). Both preg and solutions from the mine, as well as CN-Cu solutions generated from leaching Pancho ore, were used as feed solutions for the testwork.

BENCH-SCALE TESTWORK

Bench-scale testwork applied the SART process to each CN-Cu solution, under the following conditions:

- Sealed batch tests on 1 Liter solutions at 20°C
- Both preg solution (with Au - no carbon pre-adsorption) and barren solution (v. low Au – after carbon pre-adsorption) were used
- All solutions saturated with gypsum to simulate heap leach conditions
- H_2SO_4 acid used to reduce pH to pH 3-5
- NaOH used to re-neutralize the HCN generated back to free CN. (Lime was used in the pilot plant and will be used in the commercial plant, but NaOH was used in the lab tests for convenience).
- NaSH added at 80 - 120% of stochiometric (Cu basis)
- Tests run for 20 min, with Cu_2S precipitation reaction times observed to be fast

Effect of pH in Cu Precipitation Reactor

The effect of pH in the Cu_2S precipitation reactor was investigated, with the following results summarized in Table 4:

Table 4 Effect of pH on the SART Process

FEED SOLUTION	FEED Cu ppm	FEED NaCn (F) ppm	NaSH ADDITION % OF STOCHIOMETRIC	pH in Cu PRECIPITATION REACTOR	% Cu RECOVERY TO Cu_2S PRECIPITATE
Preg Solution 0.3 mg/L Au	290	265	100	5	86.2
	290	265	120	5	96.6
	290	265	100	4	89.7
	290	265	100	3	93.1
Barren Solution < 0.1 mg/L Au	220	147	100	5	81.8
	220	147	120	5	95.5
	220	147	100	4	90.9
	220	147	100	3	96.4

Main conclusions on the effect of pH were:

- At 100% NaSH addition, a lower pH increases the recovery of Cu from solutions.
- However, at pH 5 with 120% NaSH addition rates, high % Cu recoveries to Cu_2S are achieved. In order to decrease acid costs pH 5 was selected for further testwork.
- The presence of gold (in preg solutions) across the range of pH's tested does not affect the SART Cu precipitation process.

NaSH Addition Rate

Further bench-scale tests were completed at pH 5 to assess the effect of NaSH addition rate (% of stochiometric required for precipitation of Cu) on Cu recovery and Free CN recovery, as shown in Table 5.

Table 5 Effect Of NaSH Addition In The SART

FEED SOLUTION	FEED Cu ppm	FEED NaCn (F) ppm	NaSH ADDITION % OF STOCHIOMETRIC	% Cu RECOVERY TO Cu_2S PRECIPITATE	FINAL SOLUTION Cu ppm	FINAL SOLUTION NaCN (F) ppm
Preg Solution 0.3 mg/L Au	288	238	80	58.3	120	368
	288	238	90	75.7	70	453
	288	238	100	86.1	40	538
	288	238	120	96.5	10	570
Barren Solution < 0.1 mg/L Au	248	174	80	63.7	90	260
	248	174	90	75.8	60	326
	248	174	100	83.9	40	376
	248	174	120	96	10	410

From these tests the following was concluded:

- Copper recovery is directly proportional to NaSH addition rates, as shown below in Figure 6. High Cu recovery of 96.0% or above may be achieved provided sufficient sulphide ions exist at pH 5 to complex the Cu and precipitate Cu_2S. Over 100% stochiometric addition rates of NaSH (based on Cu present) are required, as sulphide ions are consumed by other metal cations like Zn, Ag, Ni and Fe plus other complexation reactions in solution that consume S ions and complexes in SART plant feed solutions. If excess S is added, the formation of thiocyanate SCN will occur and reduce the free CN available for gold leaching. Therefore, it is important to provide sufficient S ions in the SART process to recover Cu and other valuable metals, but not enough to generate thiocyanate or other S species, which would reduce the recovery of free cyanide and could retard the gold leaching on recycle of CN solutions back to the heap leach.
- Low final solution Cu levels down to 10 ppm are possible via the SART process.
- Free CN recovery from Cu-CN and other WAD CN solution complexes is significant via the SART process. NaCN (Free) concentrations in final solutions more than doubled at NaSH addition rates of 100% and 120% of stochiometric.

H_2SO_4 and NaOH Consumption

For Maricunga solutions, H_2SO_4 and NaOH reagent consumptions in the SART process are given in Table 6. The data shows:

- No effect of Au in solution on acid and NaOH consumptions
- A slight increase in acid consumption with increasing NaSH addition (due to liberation of increasing amounts of WAD-CN), with the average at 0.46 kg/m^3.
- Relatively steady NaOH consumption rates to neutralize HCN to NaCN in the SART process, with an average consumption of 375 g/m^3.
- These acid and base consumptions are close to the theoretical consumptions, based on the assumption that every molecule of CN in the feed will be converted to HCN (ie 0.5 moles sulphuric acid per mole cyanide….or 1 kg H_2SO_4 for 1 kg NaCN), and each mole of HCN will consume one mole of NaOH (or half a mole of lime) in being neutralized back to free cyanide, i.e. ~0.8 kg NaOH or $Ca(OH)_2$ for 1 kg of NaCN equivalent).

Temperature of SART Feed Solution

SART process tests with feed solutions at 4°C and at 20°C at a 90% NaSH addition rate were completed. These tests, shown in Table 7, gave identical Cu recovery, similar Free CN recovery and almost the same reagent consumptions, and showed that temperature of the feed solution does not affect the SART process with respect to Cu and CN recovery and reagent consumptions.

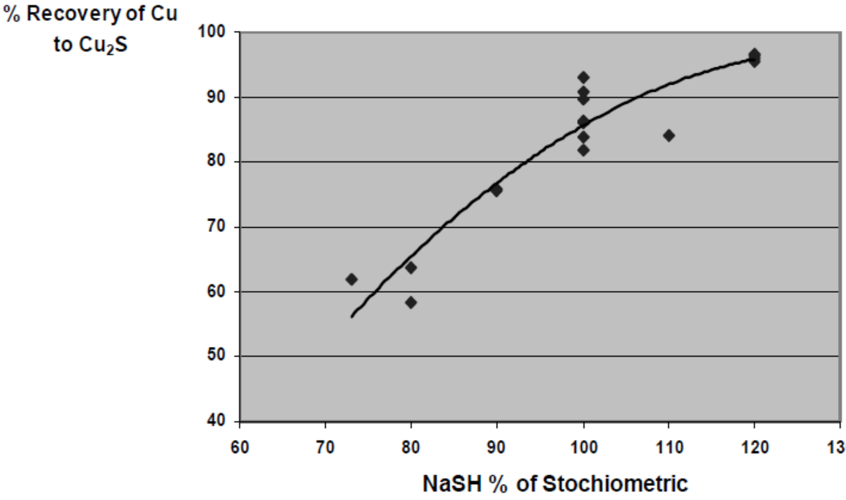

Figure 6 SART Cu Recovery As A Function Of % NaSH Addition Rate

Table 6 SART Process H_2SO_4 and NaOH Consumption

FEED SOLUTION	NaSH ADDITION % OF STOCHIOMETRIC	H_2SO_4 CONSUMPTION kg/m^3	NaOH CONSUMPTION kg/m^3
Preg Solution 0.3 mg/L Au	80	0.44	370
	90	0.45	375
	100	0.47	372
	120	0.51	378
Barren Solution < 0.1 mg/L Au	80	0.38	378
	90	0.4	370
	100	0.47	368
	120	0.52	375

Table 7 Effect of SART Feed Solution Temperature

FEED SOLUTION TEMPERATURE °C	FEED NaCN (FREE) ppm	FINAL SOLUTION NaCN (FREE) ppm	% Cu RECOVERY TO Cu_2S	H_2SO_4 CONSUMPTION kg/m^3	NaOH CONSUMPTION kg/m^3
20	174	356	75.8	0.4	0.37
4	174	372	75.8	0.39	0.37

PILOT PLANT TESTWORK

Four continuous pilot plant runs were completed, using the SART process parameters established from the bench-scale testwork. Figure 7 below shows the setup of Pilot Plant rig. The Pilot Plant testwork run conditions and equipment used were as follows:

- Closed, continuous feed pilot plant fed at 5 – 6 L/hr over 2 to 7 days
- % NaSH addition rate at 100% of stochiometric (Cu basis)
- Cu_2S precipitation reactor (5 L with agitator) controlled at pH 5 with sulphuric acid
- Cu_2S Thickener - 30 L with conical bottom
- Neutralization Reactor (30 L with agitator) run at pH 10 – 11, with neutralization by lime slurry.
- HCN Scrubbers (5% NaOH solution) connected to reactors and thickener

Pilot Plant Testwork Results

From the pilot plant runs, steady SART process conditions were established over a period ranging from 2 to 7 days. A summary of the pilot testwork results is presented in Table 8.

The testwork results showed Cu recovery to Cu_2S of up to 88%, given that NaSH addition rates were set at 100% of stochiometric requirement based on Cu present. This Cu recovery is consistent with the bench-scale testwork results, presented earlier.

A significant increase in Free CN in neutralized solutions was achieved, with approximately 76% recovery of CN from the WAD CN in the feed solution. Overall CN accountability averaged 90%, with small losses of CN as HCN to the scrubber system and due to natural degradation.

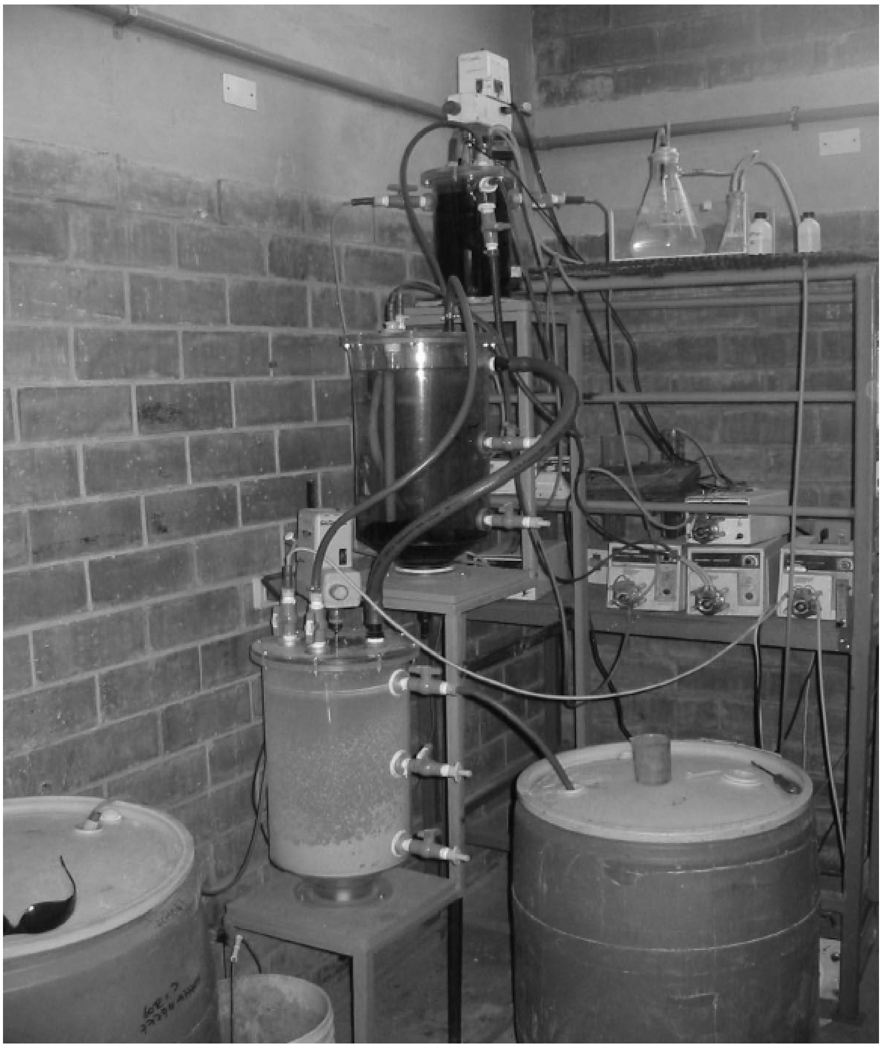

Figure 7 SART Pilot Plant Test Rig

Reagent consumptions ranges were shown to be consistent with the bench-scale work, as follows:

- Acid consumption (pH 5) 0.39 – 0.59 kg/m^3
- $Ca(OH)_2$ consumption 0.33 – 0.56 kg/m^3
- Flocculent addition 2.2 – 4 g/m^3

The acid and lime addition rates were quite variable owing to changes made in the pilot plant operating parameters to optimize the process. However, based on the NaCN equivalent concentration in the feed to the pilot plant of about 600ppm, the range of acid and lime consumptions agree well with what would be expected theoretically Based on the stoichiometry of the SART reactions, the theoretical consumptions would be about 0.6 kg/m^3 acid and 0.5 kg/m^3 lime.

Table 8 Summary of Pilot Plant Testwork Results

FEED SOLUTION (AVERAGE)			NEUTRALIZATION TANK OVER-FLOW		NaSH ADDITION %	FREE CN RECOVERY	Cu RECOVERY TO Cu_2S
Cu ppm	TOTAL NaCN ppm	NaCN (FREE)	FREE NaCN ppm	Cu ppm	%	%	%
250	631	115	507	35	100	76	79 - 88

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A significant increase in Free CN in neutralized solutions was achieved, with approximately 76% recovery of CN from the WAD CN in the feed solution. Overall CN accountability averaged 90%, with small losses of CN as HCN to the scrubber system and due to natural degradation. Reagent consumptions ranges were shown to be consistent with the bench-scale work, as follows:

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SART Process Precipitates

The SART pilot plant generated both Cu_2S and gypsum precipitates from Maricunga preg solutions, which had the following average compositions, given in Table 9.

The composition of the SART precipitates indicates the following:

- The SART Cu_2S precipitates are relatively pure, with high Cu grades of over 62%. Pure Cu_2S would analyze 79.9% Cu and 20.1% S.
- Zinc is also recovered from its CN complex, and precipitated as ZnS
- The Fe content in the feed solution was low and the $Fe(CN)^6$ complex is very stable at pH 5. Therefore iron will not be present in Maricunga precipitates.
- Some gold appears to be captured and dragged down within the Cu_2S precipitate. But this gold represents only 0.36% of the total gold that passed through the SART reactor system.
- The composition of the gypsum precipitate shows that it is likely comprised of both calcium carbonate and calcium sulphate. The supply of carbonate is probably from the lime added in neutralization.

Table 9 Composition of SART Process Precipitates

PRECIPITATE	Cu %	S %	Zn %	Ca %	Au g/t	NaCN (total) %	CO_3 %	CO_4 %
Cu_2S	62 - 73	16 - 21	0.7 - 1.1	0.08	3 - 7	0.2 - 0.4	3.4	-
Gypsum	0.18	4.6	0.03	20 - 26	0.1	0.13	32.3	13.8

For design of the SART precipitates thickeners, settling and filtration testwork was completed and showed:

- Cu_2S precipitates were fine, but settled readily leaving clear supernatant solutions both in the pilot plant settler vessel and in a settling cylinder. A clear overflow solution also resulted from settling out of gypsum
- Precipitate settling testwork gave a low settling rate for Cu_2S at 1.4 – 3.0 m/hr, but a higher rate for the coarser particles of gypsum at 5.0 – 10.0 m/hr.
- Precipitates produced from the pilot testwork were fine (Cu_2S 64% -8 micron, gypsum 64% -13 microns. Settled Cu_2S pulps approached a solids density of 5%, but earlier studies at SGS Lakefield (MacPhail et al, 1998) indicated that settled densities of 15% are achievable. By recycling the underflow to the copper precipitation reactor, the recycled precipitate 'seeds' the reactor and increases the precipitate crystal size and the underflow density in the settler. The Maricunga pilot plant tests were not run for long enough to gauge the full benefit of seeding on crystal size, and the impact on settling rates in the thickener and thickener underflow densities.
- Following water washing of precipitates to remove CN, both precipitates filtered easily, but only to 50 – 55% moisture. Thermal drying of the Cu_2S is planned to reduce moisture to 10%, which is required by a Cu smelter. The gypsum precipitate is planned to be air-dried on disposal.

SART PLANT ENGINEERING

PLANT DESIGN BASIS

Key process parameters were defined from the SART testwork, and applied in the design basis for basic engineering of a SART plant for Maricunga. The capacity of the SART plant was established at 750m^3/hr, which represents about one third of the preg solution flowrate from the heap leach operation. The SART plant capacity was set by process/economic simulation of the heap leach – ADR plant – SART plant operation, in which a target equilibrium concentration of approximately 450ppm cyanide soluble copper in the heap solution system was determined. This was calculated using inputs from the future schedule of ore supply from Pancho and Verde, and removal of copper via the bleed stream to the SART plant. Cyanide balances were also included and operating costs / net revenues used to determine the optimum SART plant capacity.

A summary of the main SART plant engineering design parameters is given below in Table 10.

PLANT ENGINEERING ASPECTS

Aspects considered in the engineering of the proposed SART plant for installation at Maricunga were:

- On-off plant operation with turn-down throughput capacity depending on copper levels in the pregnant solution
- Pregnant solution bypass of the plant to ADR, if required
- A safe to operate, well- instrumented plant
- Automated operation of the SART process and services to minimize manual operator input
- Adequate measurement and control of all sealed freeboard gas zones to allow measurement, control and removal of HCN and H_2S emissions
- Separate and safe storage areas for reagents, H_2SO_4, lime, NaOH, NaSH, flocculent and propane gas.
- Stainless steel Cu_2S precipitator, settler and neutralization reactors with one full standby reactor unit
- Mild steel gypsum thickener
- Easy access by operators from control room across the plant on a single level walkway
- Completely enclosed plant with heated, ventilated building to protect against wind and cold.
- Right through road passage for truck delivery of consumables and dispatch of bagged Cu_2S precipitate
- Side-door Bob-cat access for removal of gypsum and transport of spares, consumables, etc.

SART PLANT ECONOMICS

OPERATING COSTS

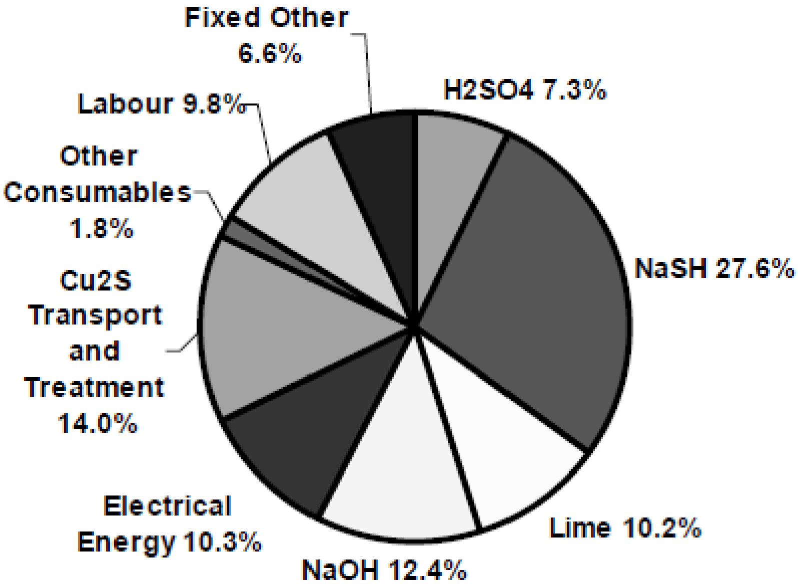
Using the given testwork parameters, design basis and local costs, the operating cost of the Maricunga SART Plant was estimated. The estimated operating cost structure comprises mainly variable costs (83.6%), with fixed costs only at 16.4%. The relative breakdown of a typical operating cost profile is presented in Figure 8.

From Figure 8 the SART process operating cost is dominated by the cost of NaSH reagent (28%), with acid at about 7%. Labor and electrical energy represent about 10% each. Clearly, in SART process economics, a supply of cheap but usable sulphide source will improve the economics. The other

Table 10 SART Plant Engineering Design Parameters

DESIGN AREA	DESIGN PARAMETER	UNITS	VALUE
PLS SOLUTION	PLS solution capacity	m^3/hr	750
	Cu concentration (equilibrium)	mg/L	454
	NaCN total	mg/L	935
	NaCN Free	mg/L	130
Cu_2S PRECIPITATION	Residence time	min	10
	Cu recovery (min - max)	%	80 - 95
	Free CN recovery	%	79
	pH		5.0
	NaSH addition range % of stochiometric	%	95 - 120
Cu_2S THICKENING	Underflow % solids	%	15
	Recirculation rate	%	95
	Settling rate	$m^2/t/d$	1.5 - 3.0
Cu_2S FILTRATION	Final moisture	%	50
Cu_2S DRYING	Final moisture	%	10
GYPSUM PRECIPITATION	pH		10 - 11
GYPSUM THICKENING	Underflow % solids	%	20
GYPSUM FILTRATION	Final moisture	%	20
OFF-GAS SCRUBBER	pH		10 - 11
	HCN volatilization	%	5

Figure 8 SART Plant Operating Costs Distribution



significant cost is that of the estimated transport and smelting/ refining charges applied to the Cu_2S precipitate, if sold to the local Enami copper smelter at Paipote near Copiapo, Chile.

PROJECT NET RETURN

The project returns of a SART plant project may be evaluated on a unit per lb Cu recovered basis. This Cu recovered is that in the Cu_2S precipitate dispatched to a Cu smelter, for which Cu revenue net of treatment and refining charges with penalties are applied. To illustrate the net returns of the SART plant at Maricunga, the following economic case is presented in Table 11.

Clearly, from the analysis in Table 11, net revenue is estimated to be > 50% of total revenue, i.e. total costs are likely to be less than 50% of revenue, on a unit basis. The plant capital cost is paid from net revenue, giving an estimated simple payback of approximately 2 years.

As noted in Table 11, no additional credit is assumed from the net cost of detoxification of CN solutions and disposal of Cu units in a bleed stream, which would be the alternative and "conventional" approach to managing the build up of copper in the heap leach solution should a SART plant not be installed at Maricunga. Each pound of copper in the feed to a detox plant would carry 2 to 3 lbs of cyanide as NaCN, and the cost of destroying this cyanide with SO_2/air for example, would be at least $1.00/lb Cu. If this credit is applied, and a more bullish price of copper is assumed (say $2/lb), the net revenue doubles to $3/lb copper recovered, and the incremental capital payback of a SART plant versus the alternative cyanide destruction plant accelerates to less than 1 year.

Table 11 SART Plant Net Revenue and Project Payback Analysis

PARAMETER	US$/lb Cu	NOTES
Cu REVENUE	1.25	Assumed Cu price, with no metal credits for contained gold, silver or penalties for impurity elements in the Cu_2S precipitate
NaCN CREDIT	1.51	$Cu(CN)_3$ complexation and 90% CN recovery via SART
CN DETOX CREDIT		Not applied, but would apply if SART was not installed and would be > US$1.00/lb Cu
REVENUE TOTAL	2.76	
SART PLANT OPERATING COST	1	Approximate assumed cost
TRANSPORT AND TREATMENT	0.3	Truck transport and smelter and refining charges
NET REVNUE	1.46	Net revenue > 50% of total revenue
PLANT CAPITAL	US$18M	Estimated capital, mid 2007
ESTIMATE PAYBACK	2 Years	750 m^3/hr 380 ppm Cu recovered

CONCLUSIONS

Increasing level of cyanide soluble copper in the existing Maricunga heap leach operation requires an effective process to remove copper and reduce costs. The future Pancho ore with greater amounts of cyanide soluble copper minerals will significantly add to pregnant solution copper levels. Unless a bleed stream process to remove copper is put in place, cyanide reagent costs will increase markedly.

Heap leaching at Maricunga presents a unique opportunity to apply the SART process given existing separation of pregnant solutions from leached solids. Additionally, the recycle of neutralized cyanide solution to the heap leach operation is likely to present no water balance problems.

Significant testwork has shown that the SART process is effective when applied to CN-Cu leach solutions from Maricunga ores. Sound engineering of a SART plant for Maricunga, based on careful design and supported from testwork, has been completed.

Application of SART at Maricunga could reduce operating costs and enable economic heap leach processing of high copper content gold ores. SART plant unit economics per unit of copper show that credits from cyanide savings and copper sales should significantly exceed operating costs. Payback of the plant capital is projected to be less than two years.

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CONTACT INFORMATION

Email us at minerals@sgs.com
WWW.SGS.COM/MINERALS