

Appendix H

Memo (27 July 2000) – Mine Backfill Drainage: Water Quality Method of Estimation

Memo (3 July 2001) – Paste Backfill Drainage Chemistry for Water Quality Modeling Work

Memo (20 December 2001) – Mine Water Ammonia & Nitrate Concentrations

MEMORANDUM

DATE: 27 July 2000 **FILE NO.:** U419B

TO: Bryan Nethery

FROM: Alexandra Kozak and Tom Higgs

SUBJECT: Mine Backfill Drainage - Water Quality Method of Estimation

cc:

The water quality of the Pogo Project mine backfill drainage has been estimated based on the assumption that the backfill drainage will have the same chemistry as the residual CIP tailings water after cyanide destruction. Testwork conducted at Lakefield Research in the 3rd quarter of 1999 through the 1st quarter of 2000 provides the basis for this chemistry.

In January of this year, Lakefield Research conducted SO₂/Air cyanide destruction testwork on CIP discharge pulp (from a previous Pogo Project testwork program) using sodium metabisulphite and air. The details and results of the cyanide destruction testwork are appended to this memo.

The table below details the expected mine backfill drainage water quality and the basis for its determination.

Parameter	Expected Value in Backfill Drainage to RTP (mg/L)	Basis for Determination
TDS	7170	testwork
Chloride	16	testwork
Sulphate	3900	testwork
Ammonia	30	Note 1
Nitrate	1.0	testwork
Phosphate	1.0	Note 1
Cyanide (total)	2.0	Note 1
Al	1.0	testwork
As	6.1	testwork
Ba	0.3	testwork
B	0.02	testwork
Cd	0.001	testwork
Cu	2	Note 2
Fe	3	Note 2
Pb	0.05	Note 2
Hg	0.003	testwork*
Mn	0.3	testwork
Ni	0.5	Note 2
Se	0.13	testwork*
Ag	0.003	testwork
Zn	0.5	Note 2

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where:

Testwork: Lakefield Research: Destruction or Recovery of Cyanide From Pogo Project Samples submitted by Teck Corporation – Progress Report No. 6 – Table 8: Analysis of CND Feed and Combined Treated Pulp

Testwork*: Lakefield Research: Destruction or Recovery of Cyanide From Pogo Project Samples submitted by Teck Corporation – Progress Report No. 6 – Table 8: Analysis of CND Feed and Combined Treated Pulp
Solution assays following the SO₂/Air cyanide destruction treatment indicate no removal of mercury and selenium. Predicted water quality values for these elements are based on the feed analyses.

Note 1: Predicted values for ammonia, phosphate and total cyanide have been modified based on experience at other operations. Typically long residence time batch test in the laboratory result in lower values for these species than can be expected during normal full scale operation in a continuous slurry treatment systems. In order to reflect this condition during operation, maximum values were estimated for the following parameters:

- Total Ammonia – 30 mg/L (based on experience at other operations and the expected maximum concentration of CN in the raw CIP tailings.)
- Total Phosphate (PO₄) – 1 mg/L as P (based on experience at other operations)
- Total Cyanide (TCN) – 2 mg/L (based on expected worst case performance of a SO₂/Air system for CIP tailings slurry)
- Total Copper (T Cu) – 2 mg/L (see Note 2)
- Total Iron (T Fe) – 3 mg/L (see Note 2)
- Total Zinc (T Zn) – 0.5 mg/L (see Note 2)
- Total Lead (T Pb) – 0.05 mg/L (see Note 2)
- Total Nickel (T Ni) – 0.5 mg/L (see Note 2)

Note 2: Assays for copper, iron, lead, nickel, and zinc are based on the Lakefield testwork results with adjustments for an increased total cyanide level expected during operations. These metals are assumed present in solution as cyanide complexes..

It is important to note that the expected backfill drainage values are conservative since they are based on the assumption that the paste backfill to underground is comprised of 100% CIP tailing following cyanide destruction. Under average operating conditions, the treated solution from CIP tailings will comprise only 50% of the total solution volume in the paste backfill to underground.

An Evaluation of the
**DESTRUCTION OR RECOVERY OF CYANIDE
FROM POGO PROJECT SAMPLES**

submitted by

TECK CORPORATION

Phase 3 Program

LR5241 - Progress Report No. 6

NOTE:

This report refers to the samples as received.

The practice of this Company in issuing reports of this nature is to require the recipient not to publish the report or any part thereof without the written consent of Lakefield Research.

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2.5 CIP Pulp from Test CN124

The barren pulp from CIP Test CN124 was evaluated in a series of CND tests using sodium metabisulphite and air. Test CND-22 was conducted to produce pulp with low cyanide for starting the continuous test (Test CND-23). The tests were conducted using the same conditions as the previous test (a two-stage circuit operated at pH 7.5-8 and at a retention time of approximately 75 minutes per stage). Approximately 80% of the $\text{Na}_2\text{S}_2\text{O}_5$ and 70% of the CuSO_4 were added to the first reactor in order to produce treated pulp for analysis and testing. The results are summarized in the third block of Table 7.

The results indicated that it was possible to reduce the cyanide concentration in the pulp to <1 mg/L using approximately 11.3 g SO_2 , 0.35 g Cu and 2.8 g hydrated lime per g cyanide. The treated pulps were combined and a sample was taken and filtered. The filtrate was analyzed for metals and species of interest. The results are presented in Table 8.

Table 7: SO₂/Air Cyanide Destruction Testwork on Test CN124 CIP Pulp

Test	Reactor 1 (solution analysis)					Reactor 2 (solution analysis)					Reagent Addition (g/g CN _{w,sp})													
	-pH	Ret Time min	CN _T mg/L	CN _{w,sp} * mg/L	Cu mg/L	Fe mg/L	SCN mg/L	S ₂ O ₃ mg/L	-pH	Ret Time min	CN _T mg/L	CN _{w,sp} * mg/L	Cu mg/L	Fe mg/L	SCN mg/L	S ₂ O ₃ mg/L	SO ₂ Equiv.	Cu	Lime	SO ₂ Equiv.	Total Cu	Lime		
Feed	11.2		402	394	50.7	2.2	140	456																
Batch Test																								
CND-22	7.8	300		4.1																	26.2	0.56	17.3	
		360		3.7																	32.6	0.78	20.0	
Continuous Test																								
CND-23	7.8	74		2.9					7.7	70	0.30	1.9									9.6	0.23	2.4	0.8
CND-24	7.8	80		1.8					7.6	76	0.18	1.1	2.16	0.14							8.1	0.24	1.6	0.8
CND-25	7.7	75		1.3					7.6	71	0.82	1.9	1.18	0.14							9.5	0.26	1.8	0.9
Average									7.6	72	0.43	1.6	1.67	0.21							9.1	0.24	1.9	0.8
																					2.3	0.11	0.8	2.8
																						11.3	0.35	2.8
																						0.56	17.3	
																						0.78	20.0	

* By picric acid method

^ Calculated (CN_{w,sp} = CN_T - CN as Fe(CN)₆)

Table 8: Analyses of CND Feed and Combined Treated Pulp

Element	F 1-3 Bulk CN mg/L	Combined CND Pulp mg/L
Ag	1.0	0.003
Al	3.1	< 1.0
As	1.7	6.1
Ba	< 0.30	< 0.30
Be	< 0.05	< 0.05
Ca	210	530
Cd	0.004	< 0.001
Co	0.48	< 0.30
Cr	0.023	0.020
Cu	52	1.0
Fe	3.9	1.2
Mg	< 0.5	15
Mn	< 0.30	< 0.30
Mo	0.60	< 0.5
K	49	42
Na	470	1800
Ni	1.4	0.063
P	< 1.0	< 1.0
Pb	0.004	0.013
Sb	< 0.5	< 0.5
Se	0.13	0.12
Sn	< 0.5	< 0.5
Te	< 1.0	< 1.0
Zn	2.39	0.058
pH	11.2	7.48
Cl	23	16
Alkalinity as CaCO ₃	738	183
Acidity	< 1	< 1
NO ₂ as N	< 0.6	< 0.6
NO ₃ as N	0.8	< 0.5
CN _T	320	0.14
CN _{WAD}	218	0.08
CNO	< 1	240
CNS	173	69
NH ₃ as N	1.0	15.3
SO ₄	340	3900
TDS	2150	7170
Hg	0.003	0.004

Project: 5241

Test: CND-22

Operator: ME, RH

January 11, 2000

Purpose: To conduct a batch cyanide destruction test using Inco's SO₂/Air process to treat the CIP barren pulp from Test CN124 to produce treated pulp for starting continuous test.

Procedure: The feed (1 L) was placed in a 1-L reactor. Mixing was provide with a laboratory agitator. Compressed air was sparged into the pulp. Na₂S₂O₅ solution (40 g/L, at ~1 mL/min) and CuSO₄ (0.5 g/L Cu at ~0.6 mL/min) were pumped to the reactor. The pulp was maintained at approximately pH 7.5-8 (if required) by the addition of lime slurry. Samples were taken during the test and analyzed for residual CN(WAD) using picric acid method. The treatment was carried out until the residual CN(WAD) level was <1 mg/L.

Apparatus: Reactor 1-L volume (10.5 cm I.D.) with 4 baffles.
Lab agitator with a 6 bladed impeller (6.3 cm diameter and 2 cm high)
Other standard laboratory equipment were used as required.

Feed: 1 L of Test CN124 CIP barren pulp (25% sollids). Solution analysis:
CN_T: 402 mg/L CN_{WAD}: ~394 mg/L SCN: 140 mg/L S₂O₃: 456 mg/L
Cu: 50.7 mg/L Fe: 2.9 mg/L pH: 11.5

pH: 7.5-8 with lime slurry

Temperature: Ambient (~18 C°)

Results:

Agitator Speed: 350 rpm

Flowrates (Avg.): Na₂S₂O₅ (40 g/L): 0.99 mL/min Air: 4 L/min
Cu (0.5 g/L): 0.66 mL/min Lime slurry (50 g/kg): 0.39 mL/min
Feed: 0 mL/min

Retention Time: 360 min

<u>Treated Solution:</u>	<u>After 360 min</u>	<u>After 300 min</u>
CN _{WAD} :	3.7 mg/L solution	4.1 mg/L solution
<u>Reagent Added:</u> SO ₂ (equivalent)	32.6 g/g CN _{WAD}	26.2 g/g CN _{WAD}
Lime	20.0 g/g CN _{WAD}	17.3 g/g CN _{WAD}
Cu	0.78 g/g CN _{WAD}	0.56 g/g CN _{WAD}

CN_{WAD} by picric acid method

Batch SO₂/Air Cyanide Destruction Test on Synthetic Combined CIP Pulp

Lapsed Time	pH	EMF	Air Flow-rate	Dis-solved O ₂	Agitation	Na ₂ S ₂ O ₅ Volume in Grad. Cylinder mL	Copper Sulphate in Grad. Cylinder mL	Lime Slurry in Bottle g	CN _T	CN _{picric}	Cu	Fe	Remarks
min		mV	L/min	mg/L	rpm	mL	mL	g	mg/L	mg/L	mg/L	mg/L	
Feed	11.5								402	~394	50.7	2.9	Solution composition
0	11.5	-82	3.7	4.6	350	250	100	1134					
30	9.9	-101	3.7	8.3	350	222	79			216			Sample S1
60	9.3	-63	3.7	7.5	350	182	62						
90	8.2	-23	3.7	4.9	350	152	46			135			S2
120	7.8	-23	3.7	4.2	349	122/250	22/100			95			S3
150	7.8	-29	3.7	3.7	348	216	80			60			S4
180	7.8	-16	3.7	2.2	347	174	60			42			S5
197	7.8	-6	3.7	1.8	350	170/250	50/100						
210	7.8	-2	3.7	1.7	350	238	91			29			S6
240	7.8	0	3.7	1.4	352	211	71			16			S7
270	7.8	3	3.7	1.1	351	185	51			7.1			S8
300	7.8	23	3.7	0.6	351	157/250	32/100	1010		4.1			S9
330	7.9	15	3.7	0.8	350	220	80	1000		3.8			S10
360	7.9	11	3.7	1.0	351	193	60	990		3.7			S11

Feed: 1 L of CIP pulp from Test CN124

Solution volume: 0.91 L

Na₂S₂O₅: 40 g/L at ~1 mL/min. At 2:47 switched to 60 g/L

Cu: 0.5 g/L at 0.6 mL/min. At 2:47 switched to 2 g/L

Lime: 50 g/kg lime slurry

Retention time: As required to achieved ~1 ppm residual CN_{WAD}CN_{picric}: CN_{WAD} by picric acid method.

Impeller: 6 bladed, 6.3 cm dia. x 1.8 cm high

Reactor: 10.5 cm diameter

Vol. of feed pumped: - mL

Purpose: To conduct a continuous cyanide destruction test using Inco's SO₂/Air process to produce treated pulp for environmental testing.

Procedure: This was a continuation of Test CND-22. The treated pulp in reactor R1 and the pulp overflowed from R1 to R2 during Test CND-22 were used for starting Test CND-23. Approximately 80% of the Na₂S₂O₅ and copper were added to R 1. The Na₂S₂O₅ concentration was 50 g/L for R1 and 10 g/L for R2. The copper concentration was 1 g/L for R1 and 0.5 g/L for R2. The feed pulp was pumped to reactor 1 at approximately 10 mL/min. The pulp was maintained at pH 7.5-8 by the addition of lime slurry. Agitation and air flowrates were adjusted as required to try to obtain ~3 mg/L DO. The partially treated pulp flowed by gravity from reactor 1 to reactor 2. The treated pulp from reactor 2 was collected in 1-L plastic containers. Samples were taken during the test and analyzed for residual CN(WAD) using picric acid method. The target residual CN(WAD) was <1 mg/L.

Apparatus: Reactors 1-L volume (10.5 cm I.D.) with 4 baffles. Lab agitators with a 6 bladed impeller (6.3 cm diameter and 2 cm high) Other standard laboratory equipment were used as required.

Feed: Test CN124 CIP barren pulp (25% solids). Solution analysis:
 CN_T: 402 mg/L CN_{WAD}: ~394 mg/ SCN: 140 mg/L S₂O₃: 456 mg/L
 Cu: 50.7 mg/L Fe: 2.9 mg/L pH: 11.5

pH: 7.5-8 with lime slurry **Temperature:** Ambient (~18 C°)

Results:	Reactor 1	Reactor 2	Total
Agitator Speed:	456 rpm	361 rpm	
Flowrates (Avg.):	Feed: 10.3 mL/min Na ₂ S ₂ O ₅ (50 g/L): 1.05 mL/min Cu (1 g/L): 0.86 mL/min Air: 3.5 L/min Lime (50 g/kg): 0.18 mL/min	Na ₂ S ₂ O ₅ (10 g/L): 1.19 mL/min Cu (0.5 g/L): 0.76 mL/min Air: 2.5 L/min	
Retention Time:	74 min.	70 min.	144 min
Treated Pulp: (mg/L solution)	At 240-300 min. CN _{WAD} : 29 CN _T : NA Cu: NA Fe: NA	1.9 0.30 NA 0.36	by picric acid method by LR analytical lab.
Reagent Added: (g/g CN _{WAD})	SO ₂ (equivalent) 9.6 Lime 2.4 Cu 0.23	2.2 0.8 0.10	11.8 3.2 0.33

NA: not analyzed

Continuous SO₂/Air Cyanide Destruction Test on Synthetic Combined CIP Pulp

Lapsed Time	Stage 1										Stage 2					Remarks	
	pH	EMF	Air Flow-rate	Dis-solved O ₂	Mixer	Na ₂ S ₂ O ₅ Vol. in Grad. Cylind.	Lime 5%w/w in Bottle	Cu Vol. in Grad. Cylind.	CN _{picric}	pH	EMF	Dis-solved O ₂	Na ₂ S ₂ O ₅ Vol. in Grad. Cylind.	Cu Vol. in Grad. Cylind.	Air Flow-rate		Mixer
min	mV	L/min	mg/L	rpm	mL	g	mL	mL	mg/L		mg/L	mL	mL	L/min	rpm		
Feed	11.5								~394								
0	7.9	-30	3.0	350	250	990	100					250	100	2.5	330		10 min conditioning
10					240	980	90					238	91				Start feed
30	7.9	30	3.0	363	220	965	71			7.2	90	1.3	210	75	330		
60	7.6	44	3.5	452	188		42/92		3.8	7.2	74	1.2	170	51/100	330		Sample S1
90	7.6	30	3.4	455	156	961	73		26	7.3	66	1	134/254	79	329		S2
120	7.8	46	3.4	453	128/248		49/99		26	7.3	80	1.1	224	61	362		S3
150	7.8	36	3.4	457	214		72		35	7.3	83	1.1	186	38/87	361		S4
180	7.4	33	3.5	455	181		45			7.2	98	0.9	150	64	362		S5
210	7.9	46	3.4	455	153		22/100			7.6	85	1.4	115/240	38/100	362		
240	7.8	64	3.4	457	120		73		24	7.5	107	1.2	211	78	361		S6
270	7.9	57	3.5	456	88/218		46/100			7.9	92	1.8	172	54/100	361		80 mL sample to Lab
300	7.9	60	3.4	456	186		74		34	7.9	98	1.3	138	77	361		S7
330	7.8	68	3.4	456	154	923	48			7.9	99	1.6	101	53	361		Total solid lime to R2 was 1 g

Feed: CIP pulp from Test CN124
 Reactor vol.: J L
 Na₂S₂O₅: 50 g/L solution at ~1 mL/min reactor 1
 10 g/L solution at ~0.6 mL/min reactor 2
 Cu: 1 g/L @ ~1 mL/min to reactor 1
 0.5 g/L @ ~0.6 mL/min to reactor 2
 Lime: 50 g/kg lime slurry to R1, solid lime to R2 if required
 Retention time: ~80 min per reactor
 CN_{picric}: CN_{wad} by picric acid method.

Impeller: 6 bladed, 6.3 cm dia. x 2 cm high
 Reactor: 10.5 cm diameter
 Sample R1: 25 mL
 Sample R2: 50 mL
 O/F collected: Filling R2 900 mL
 0-140 min 1020 mL
 140-240 min 950 mL
 240-305 min 770 mL
 305-330 min 350 mL
 Total Collect 3090 mL

Purpose: To continue treating the CIP barren pulp using Inco's SO₂/Air process.

Procedure: This was a continuation of Test CND-23 (after stopping overnight). The treated pulp in reactors from the previous day were used for starting the test. Approximately 80% of the Na₂S₂O₅ and copper were added to R 1. The Na₂S₂O₅ concentration was 50 g/L for R1 and 10 g/L for R2. The copper concentration was 1 g/L for R1 and 0.5 g/L for R2. The feed pulp was pumped to reactor 1 at approximately 10 mL/min. The pulp was maintained at pH 7.5-8 by the addition of lime slurry. Agitation and air flowrates were adjusted as required to try to obtain ~3 mg/L DO. The partially treated pulp flowed by gravity from reactor 1 to reactor 2. The treated pulp from reactor 2 was collected in 1-L plastic containers. Samples were taken during the test and analyzed for residual CN(WAD) using picric acid method. The target residual CN(WAD) was <1 mg/L.

Apparatus: Reactors 1-L volume (10.5 cm I.D.) with 4 baffles. Lab agitators with a 6 bladed impeller (6.3 cm diameter and 2 cm high) Other standard laboratory equipment were used as required.

Feed: Test CN124 CIP barren pulp (25% solids). Solution analysis:
 CN_T: 402 mg/L CN_{WAD}: ~394 mg/ SCN: 140 mg/L S₂O₃: 456 mg/L
 Cu: 50.7 mg/L Fe: 2.9 mg/L pH: 11.5

pH: 7.5-8 with lime slurry **Temperature:** Ambient (~18 C°)

Results:	Reactor 1	Reactor 2	Total
Agitator Speed:	456 rpm	370 rpm	
Flowrates (Avg.):	Feed: 9.5 mL/min Na ₂ S ₂ O ₅ (50 g/L): 0.81 mL/min Cu (1 g/L): 0.81 mL/min Air: 3.6 L/min Lime (50 g/kg): 0.11 mL/min	Na ₂ S ₂ O ₅ (10 g/L): 1.21 mL/min Cu (0.5 g/L): 0.74 mL/min Air: 2.5 L/min	
Retention Time:	80 min.	76 min.	156 min
Treated Pulp: (mg/L solution)	Sample 7 CN _{WAD} : 18 CN _T : NA Cu: NA Fe: NA	1.1 0.18 2.16 0.14	by picric acid method by LR analytical lab.
Reagent Added: (g/g CN _{WAD})	SO ₂ (equivalent) 8.1 Lime 1.6 Cu 0.24	2.4 0.8 0.11	10.5 2.4 0.35

NA: not analyzed

Project: 5241

Test: CND-25

Operator: RH, ME

January 14, 2000

Purpose: To continue treating the CIP barren pulp using Inco's SO₂/Air process.

Procedure: This was a continuation of Test CND-24 (after stopping overnight). The treated pulp in reactors from the previous day were used for starting the test. The test conditions were the same as in previous tests (CND-23 and CND-24).

The entire volume of the feed was treated through the CND circuit. The content of R1 was then pumped to R2 for treatment.

The treated pulps collected in Tests 23 to 25 were filtered. The filtrates were combined. A sample of the combined filtrate was submitted for chemical analysis. The filter cakes were combined in a plastic bag and stored in a refrigerator. The solution and the combined filter cake were sent to outside laboratory for testing.

Apparatus: Reactors 1-L volume (10.5 cm I.D.) with 4 baffles. Lab agitators with a 6 bladed impeller (6.3 cm diameter and 2 cm high) Other standard laboratory equipment were used as required.

Feed: Test CN124 CIP barren pulp (25% solids). Solution analysis:
CN_T: 402 mg/L CN_{WAD}: ~394 mg/ SCN: 140 mg/L S₂O₃: 456 mg/L
Cu: 50.7 mg/L Fe: 2.9 mg/L pH : 11.5

pH: 7.5-8 with lime slurry **Temperature:** Ambient (~18 C°)

Results:	Reactor 1	Reactor 2	Total
Agitator Speed:	456 rpm	365 rpm	
Flowrates (Avg.):	Feed: 10 mL/min Na ₂ S ₂ O ₃ (50 g/L): 1.0 mL/min Cu (1 g/L): 0.94 mL/min Air: 3.6 L/min Lime (50 g/kg): 0.13 mL/min	Na ₂ S ₂ O ₃ (10 g/L): 1.17 mL/min Cu (0.5 g/L): 0.85 mL/min Air: 2.5 L/min	
Retention Time:	75 min.	71 min.	146 min
Treated Pulp: (mg/L solution)	Sample 11 CN _{WAD} : 13 CN _T : NA Cu: NA Fe: NA	1.9 0.82 1.18 0.14	by picric acid method by LR analytical lab.
Reagent Added: (g/g CN _{WAD})	SO ₂ (equivalent) 9.5 Lime 1.8 Cu 0.26	2.2 0.9 0.12	11.7 2.7 0.38

NA: not analyzed

Continuous SO₂/Air Cyanide Destruction Test on Synthetic Combined CIP Pulp

Lapsed Time	Stage 1										Stage 2					Remarks		
	pH	EMF	Air Flow-rate	Dis-solved O ₂	Mixer	Na ₂ S ₂ O ₅	Lime	Cu	CN _{picric}	Dis-solved O ₂	EMF	pH	Na ₂ S ₂ O ₅	Cu	Air Flow-rate		Mixer	CN _{picric}
min		mV	L/min	mg/L	rpm	Vol. in Cylind. mL	5%w/w in Bottle g	Vol. in Grad. Cylind. mL	mg/L	mg/L		mg/L	Vol. in Grad. Cylind. mL	Vol. in Grad. Cylind. mL	L/min	rpm		
Feed	11.5								~394									
0	8.0	47	3.5	6.6	457	250	864	100		59	8.1	200	100	2.5	373		10 min conditioning	
10						240	862	90				200	90				Start feed	
70	8.0	46	3.5	2.6	457	174		29/200	25	110	7.6	158	35/242	2.5	362		Sample 1	
130	7.8	73	3.6	1.4	456	114/250		175	28	98	7.6	105/250	194	2.5	364		Sample 2	
190	7.8	62	3.6	1.5	456	190		117	28	110	7.4	174	147	2.5	356		Sample 3	
250	7.8	55	3.5	1.8	456	125/200		57/250	31	97	7.9	96/158	97/250	2.5	364		Sample 4	
280	Feed line plugged for ~10 min																	
310	7.7	62	3.6	1.4	457	182		210	25	95	7.8	80/250	200	2.5	367		Sample 5	
370	7.7	87	3.5	1.2	457	126/250		160	30	114	7.8	181	158	2.5	366		Sample 6	
430	7.9	57	3.6	1.5	455	189		96/250	29	112	7.7	120/250	110/250	2.5	362		Sample 7	
490	7.7	78	3.6	1.0	455	118		188	31	107	7.6	172	198	2.5	364		Sample 8	
550	8.0	14	3.6	3.8	455	50/164		126/250	18	123	7.4	94/250	149/250	2.5	362		Sample 9	
610	7.7	49	3.7	2.0	455	100		188	13	111	7.4	176	208	2.5	367		Sample 10	
645	7.6	82	3.7	0.8	455	60	781	143		145		152	159	2.5				
670	Pumping R1 to R2																	
730									13	145	7.6		96	2.5	367		Sample 11	
750										126	7.7	96	26	2.5	367		Sample 12	
										150	7.5	80	9	2.5	367		Solid lime to R2: 2.6 g	

Feed: CIP pulp from Test CN124

Reactor vol.: 1 L

Na₂S₂O₅: 50 g/L solution at ~1 mL/min reactor 1
 10 g/L solution at ~0.6 mL/min reactor 2

Cu: 1 g/L @ ~1 mL/min to reactor 1
 0.5 g/L @ ~0.6 mL/min to reactor 2

Lime: 50 g/kg lime slurry to R1, solid lime to R2 if required
 ~80 min per reactor

Retention time: CN_{wad} by picric acid method.

Impeller: 6 bladed, 6.3 cm dia. x 2 cm high
 Reactor: 10.5 cm diameter
 Sample R1: 25 mL
 Sample R2: 50 mL

Q/F collected:
 0-70 min 840 mL
 70-130 min 845 mL
 130-195 min 860 mL
 195-250 min 750 mL
 250-315 min 785 mL
 315-370 min 790 mL
 370-430 min 765 mL
 430-495 min 870 mL
 495-560 min 730 mL
 560-645 min 850 mL
 645-730 min 960 mL
 730-750 min 940 mL

Total Collect from 0-645 min 8085 mL

Memo

To **Bryan Nethery** File No. **U419B**
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Tel **1-604-664-4542**
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Date **July 3, 2001**

Subject **Derivation of Paste Backfill Drainage Chemistry for Water Quality Modeling Work**

A summary table of the data used to generate the inputs used in the water quality model for paste backfill drainage is attached. Derivation of the proposed backfill drainage chemistry can be described by referencing the individual columns in the table as follows:

- Column 1 is the paste backfill drainage chemistry generated from bench scale SO₂/Air cyanide destruction testwork conducted on Composite 4 by Lakefield in January 2000.
- Column 2 is the backfill drainage chemistry used in the August 2000 Water Management Plan, slightly modified from the bench scale results, based on experience at other operations.
- Column 3 is the maximum measured concentrations for CIP tailings following cyanide destruction using the SO₂/Air process generated during the Pilot Plant studies conducted by Lakefield Research in November, 2000.
- Column 4 provides the proposed CIP Tailings chemistry following cyanide destruction based on the Pilot Plant results, modified as described in Column 5. The proposed backfill drainage chemistry either assumed the maximum value for the Pilot Plant study (Column 3), the Composite 4 results (Column 1) or the estimated metal concentration based on complexation with a residual CN concentration of 2 mg/L following SO₂/Air cyanide destruction.
- Column 6 provides the Tailings Seepage chemistry presented in the August 2000 Water Management Report (Table 4.3, Col. D), which represents the worst case flotation tailings chemistry. As discussed in the August 2000 Water Management Report (pg. 26), the tailings drainage chemistry data was generated from the geochemical modeling conducted by SRK and reported in Appendix D of that report.
- Column 7 provides the maximum concentrations in the recycle water from the flotation circuit of the Pilot Plant study after equilibrium was reached. Even though the measured values were generally lower than the predicted worst case values (Column 6), the Column 6 values are used for blending as per Column 8.
- Column 8 is the estimated paste backfill drainage chemistry based on a blend of Column 4 and Column 6 at design flowrates. This data was used as an input to the water quality modeling work.

Derivation of Paste Backfill Seepage Chemistry for Water Quality Modelling
Table 1

Parameters*	Water Management Report - August 2000				Water Management Report - July 2001											
	Composite 4 Bench Test		Backfill Drainage Chemistry for Modelling		Pilot Plant Study CIP Tails - PPCN1 Max. Concentration		Proposed CIP Backfill Drainage Chemistry for Modelling		Data Source and Rationale for Selection		Reasonable Worst Case Tailings Seepage		Pilot Test Flotation Tails (Recycle Water)		Blended Paste Backfill Drainage Chemistry for Modelling	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Column Flow (gpm)				44												89.8
pH	7.48															11.0*
Total Dissolved Solids (TDS)	7170	7170		24,800												13,682
Chloride (Cl ⁻)	16	16		24												27
Sulphate (SO ₄)	3900	3900		11,800												220
Ammonia (NH ₃)	15.3	30		129												64
Nitrate (NO ₃)	<0.5	1		1												2.39
Phosphate (PO ₄)	<1			1												1.00
Cyanide (CNT)	0.14	2		2												1.01
Arsenic (As)	<0.001	6.1		6.1												5.59
Cadmium (Cd)	1	0.001		0.005												0.01
Copper (Cu)	1.2	2		2												1.00
Iron (Fe)	0.013	3		3												3.00
Lead (Pb)	0.004	0.05		0.05												0.03
Mercury (Hg)	<0.3	0.003		0.004												0.0030
Manganese (Mn)	0.063	0.3		0.862												10.11
Nickel (Ni)	0.12	0.5		0.5												0.37
Selenium (Se)	0.003	0.13		0.75												0.43
Silver (Ag)	0.058	0.003		0.003												0.0024
Zinc (Zn)		0.5		0.5												0.43

* - pH due to cement in paste backfill

* - all concentrations mg/L

British Columbia Technical and
Research Committee on Reclamation
Cyanide Sub-Committee

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For the Environmental Management
Of Cyanide in Mining

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Prepared by:

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Disclaimer

The purpose of this guide is to provide technical information on the use and control of cyanide in the mining industry. This document provides guidance in areas of environmental management, including chemistry, safety, laboratory analyses, toxicity, regulation, treatment and impact assessment, and provides recommendations for future research. Considerable effort has been made to ensure that the information in this guide is both complete and accurate. However neither the Mining Association of British Columbia and the B.C. Technical and Research Committee on Reclamation nor the consultants who prepared this document may be held liable for any action taken by the user based on recommendations contained in this document.

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7.1 Introduction

This chapter provides information on the technological processes currently available to treat cyanide wastes. It describes the main commercial processes used in the mining industry and some of the alternatives currently under development or having site-specific applications.

The discussion commences with a brief outline of the development of cyanide treatment technology and a general review of existing process alternatives. Three major commercial processes are then reviewed in detail: Inco SO_2 -Air, hydrogen peroxide oxidation and natural degradation. These processes are discussed in terms of process chemistry, equipment requirements and general performance data; additional case history information for these processes is provided in Appendix E. The last three sections in this chapter describe biological degradation, alkaline chlorination and cyanide recycle technology, all of which have limited application at present. The review of process alternatives is not exhaustive, since information on available technology is well documented in the literature (Ingles and Scott, 1981, 1987; Zaida *et al.*, 1987; Scott, 1989). The reader should consult these references for details. Rather, the purpose of Chapter 7.0 is to provide the reader with some of the basic tools required to perform independent investigations for specific situations.

The evaluation and selection of an appropriate technology for any given site can be complicated and require an iterative approach, which could include bench tests, pilot tests and examination of data from other installations.

The success or failure of a particular process is often due to a large number of factors that may be site-specific and independent of the process itself. The reader should be especially careful in attempting to apply cost data from one situation to another.

7.2 Historical Perspective

Before the mid-1970s, the only form of cyanide treatment used by the mining industry in Canada was natural degradation of cyanide-bearing wastes that occurred in tailings ponds. Mines with large ponds were sometimes successful in reducing cyanide to acceptable levels during the summer months, but many operations were unable to control cyanide levels during the winter. To date, natural degradation is still the most common treatment method for treating cyanide in gold mill effluent (Scott, 1989), although it is now often supplemented by other treatment processes. With the introduction of federal and provincial environmental regulations in the late 1970s, many new and existing mining operations were required to design and construct additional treatment systems for cyanide-bearing wastes.

Alkaline chlorination was the first chemical process to be used on a commercial scale in Canada to treat mining wastes for cyanide. The first alkaline chlorination treatment system was installed at the Myra Falls operation of Westmin (formerly Western Mines) in 1973 to treat lead and zinc concentrate thickener overflow (Eccles, 1976). Since the production of a lead concentrate has been discontinued at Myra Falls, the treatment system is no longer in use. The last gold mine to use alkaline chlorination was Giant Yellowknife Mines, which converted to the hydrogen peroxide process in 1989.

The next significant development in cyanide treatment after conventional alkaline chlorination was the Inco SO_2 -Air process, introduced in 1982 (Devuyst *et al.*, 1989). The first commercial operation to use this process in Canada was Scottie Gold, which started up in 1982 and shut down only two years later in 1984 (Ingles and Scott, 1987). By 1989, 10 mines were using the process (Scott, 1989).

The third major cyanide treatment method to gain commercial acceptance was hydrogen peroxide

(H₂O₂) oxidation, which was developed by Degussa and Du Pont. The use of hydrogen peroxide for cyanide destruction was originally patented by Du Pont as the "Kastone" process in 1971. Intended for treatment of plating shop wastes, this process involved the use of formaldehyde and elevated temperatures - process conditions not readily applicable to the volume of wastes generated by gold mining operations. The Kastone process was evaluated at the pilot scale by Homestake Mining in 1981. The method proved to be effective but was rejected for full-scale application, in part because of cost (Mudder and Whitlock, 1983).

The high cost of hydrogen peroxide originally precluded its widespread adoption by the mining industry. With the expansion of hydrogen peroxide production capacity in North America and increasing application in the pulp and paper industry, however, pricing has become more competitive (Vickell, 1991). This has, in turn, advanced the application of hydrogen peroxide in cyanide treatment. The first industrial hydrogen peroxide system used in the mining industry was installed by Degussa in 1984 to treat mill tailings at Ok Tedi (Knorre and Griffiths, 1984). The first commercial application in Canada was at Teck Corona, which started up in 1985, using H₂O₂ to treat tailings pond supernatant as a supplement to natural degradation. Twelve mines were using H₂O₂ in Canada in 1989 (Vickell *et al.*, 1989).

7.3 Process Alternatives and Applications

Table 7.1 presents a summary of the existing treatment process alternatives for cyanide-bearing waste streams. General applications for the main group of processes shown on the table are itemized below.

- **Natural degradation** can be universally applied for the treatment of cyanide-bearing wastes, although its effectiveness is limited at low

cyanide concentrations and in treating iron cyanide complexes.

- **Oxidation processes** are capable of treating cyanide-bearing wastes, with some exceptions and limitations: alkaline chlorination cannot effectively remove iron cyanide complexes if encountered in the waste stream; hydrogen peroxide is not generally applicable to treating slurries due to high reagent consumption and, depending on reagent consumption and unit costs, may have limited application for treating barren solutions; ozonation is limited by high capital cost and the need to generate ozone on-site using electricity, which is generally expensive at remote sites.
- **Adsorption and precipitation processes** are generally not able to produce effluent of discharge quality without the use of a supplemental process.
- **Activated carbon adsorption** is generally only applicable in special low strength applications where it is used to polish treated effluent.
- **Biological treatment** is limited to low CN concentration applications where a source of heat is available.
- **Cyanide recycle technology** involving AVR (acidification, volatilization, reneutralization), electrolysis and ion exchange are dependent on cyanide concentrations, solution chemistry and the potential recovery of by-products. AVR is not currently practiced in Canada but was reported to be in use in Tasmania (Scott, 1989). Cyanide recycle technology using ion exchange and AVR may be considered in situations where sodium cyanide consumption is high. Ion exchange processes are still at the developmental stage, however, and resin fouling concerns require site-specific testing to evaluate feasibility.

Table 7.1
Cyanide Treatment Process Alternatives

Treatment Process	Stage	Applications	Comments
Natural Degradation			
Neutralization by CO ₂ Absorption HCN Volatilization Metal Cyanide Complex Dissociation Metal Cyanide Precipitation	C	TPO, B, S	Universal application to treatment of slurries, barren bleed and tailings pond overflow. Application is often limited by site-specific factors associated with TP and regulations (See Section 7.5).
Oxidation Processes			
Alkaline Chlorination	C	S, B, TPO	Displaced by SO ₂ -Air and H ₂ O ₂ due to cost, inability to remove iron cyanide and Cl ₂ residual concerns.
Inco SO ₂ -Air Process	C	S, B, TPO	Universal application - slurry treatment can result in elevated reagent consumption. Not applicable to slurries due to reagent consumption.
Hydrogen Peroxide	C	B, TPO	
Ozonation	D	B	Energy intensive. On-site generation of O ₃ required.
Adsorption/Precipitation			
Hemlo Process (Cuprous Process)	C	B	Not in use. Limited to low CN concentrations. Site-specific.
Cominco Ferrous Sulphide Adsorption	C	B	
Neville Process - Ferrrous Iron Bisulphite	D	B	
Activated Carbon Adsorption	D	TPO	
Biological Treatment			
Biodegradation	C	TPO	Limited to low CN concentrations. May require supplemental heat. Site-specific.
Cyanide Recycle			
Canmet Modified AVR	D	B	May be applicable to reduce cost for NaCN. Safety concerns and capital costs limit application. Site-specific. Site-specific.
Electrolytic Recovery	D	B	
Ion Exchange	D	B	
Resin in Pulp	D	S	
Legend			
C - Commercial stage		S - Mill waste slurry from CIP/CIL or repulped Merrill Crowe	
D - Development stage		B - Barren Bleed from Merrill Crowe process	
		TPO - Tailings pond overflow or reclaimed water	
		TP - Tailings pond	

The selection of a treatment process for a particular application is dependent on the following factors:

- the concentration of cyanide in solution
- the presence or absence of tailings solids
- the form of cyanide in solution, i.e., free, complexed, metals present
- the concentration of iron cyanide in solution
- the volume to be treated
- the presence and type of other contaminants such as thiocyanate, ammonia, arsenic, organic compounds
- the potential for recovery of valuable by-products.

The other major consideration is cost. Treatment costs for any given process and site can be highly variable, depending on location and bulk reagent unit costs.

The following sections review the predominant treatment technologies in use in Canada as well as alternatives that may have site-specific application. For additional information on these alternatives the reader should refer to Ingles and Scott (1987), which provides a state-of-the-art review of cyanide treatment technology. More recently developed processes such as Canmet AVR, Cyanosave CRP ion exchange and Celec electrolytic regeneration are also covered in the proceedings from the "Gold Mining Effluent Treatment Seminar" (1989).

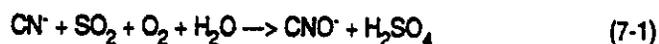
7.4 Inco SO₂-Air Oxidation

7.4.1 Process Description and Chemistry

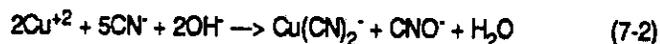
The Inco SO₂-Air process for cyanide treatment employs a combination of sulphur dioxide and air in the presence of a copper catalyst to oxidize both free

cyanide and metal cyanide complexes to cyanate. The optimum pH range is 8 to 10. Retention times of 60 to 90 minutes are required for mill tailings, while lower retention times of 30 to 45 minutes may be applicable for tailings pond overflow. The process is sensitive to the provision of adequate aeration and pH.

The precise reaction mechanisms responsible for the oxidation of cyanide using SO₂ and air have not been delineated. Sulphur dioxide is conventionally used as a reducing agent in a number of chemical and metallurgical processes. The SO₂-Air process can best be described by the overall reaction for free cyanide as outlined below. This reaction requires the presence of a copper catalyst:



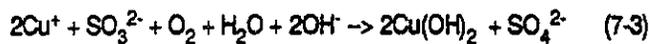
Research conducted by Inco has clearly indicated that SO₂ plus oxygen, in addition to oxidizing cyanide to cyanate, can act as a powerful oxidizing agent for reduced metal ions such as iron and nickel (Devuyt *et al.*, 1982). This research suggests that metal-sulphite complexes are intermediate species in the formation of "activated complexes" containing the SO₅⁻² group, which in turn reacts with cuprous ion to form cupric ion and sulphate. The process is thought to involve the oxidation of Cu(I) to Cu(II) by SO₅⁻² and subsequent oxidation of cyanide by cupric ion. The cupric ion introduced as the copper catalyst will oxidize cyanide ion while chemically being reduced to cuprous ion:



The resulting cuprous ion is complexed with remaining cyanide, and so it stays in solution until most of the cyanide ion has been destroyed.

Based on the stoichiometry of this reaction the theoretical dosage is 2.47 kg SO₂/kg CN⁻ oxidized. In practice the dosages are generally higher due to demand exerted by other reduced components in the waste stream, such as metals and thiocyanate. The

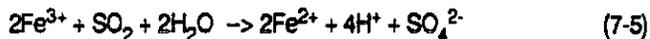
ratio reported by Inco is 2 to 8 kg SO₂/kg CN⁻ (Devuyst *et al.*, 1989). In addition to SO₂ consumption, the process produces acid, which consumes alkalinity. Based on Equation 7-1, the theoretical consumption of alkalinity is 3.85 kg CaCO₃/kg of CN⁻ oxidized; or, expressed as CaO, the ratio is 2.15 kg CaO/kg CN⁻ destroyed. However, a number of other reactions will increase both SO₂ consumption and lime consumption above the theoretical amounts. Examples are the oxidation of sulphite in the presence of cuprous ion to form cupric hydroxide:



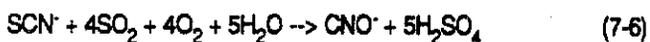
the precipitation of other metals such as zinc as their respective hydroxides:



and the reduction of ferric iron in solution to ferrous iron:



In addition, thiocyanate can theoretically be oxidized to cyanate by the SO₂-Air process according to the following proposed reaction:



Based on the stoichiometry of this reaction, the theoretical SO₂ dosage is 1.1 g SO₂/g SCN⁻ oxidized. The kinetics of this reaction are considerably slower than those of the cyanide oxidation reaction, however, and complete thiocyanate oxidation is not usually achieved. Process evaluation studies conducted for Environment Canada at the McBean Mine (Zaida *et al.*, 1988) and Carolin Mines (Carviro Consultants, 1988) indicated that thiocyanate oxidation was in the range of 15% to 25% when the process was used to treat barren bleed. The presence of nickel was reported to catalyze the oxidation of thiocyanate, thereby increasing SO₂ consumption.

Ferrocyanide complex present in solution can also be precipitated by cupric ion to form an insoluble complex:

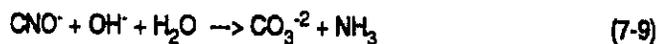


The cupric ferrocyanide is insoluble and will therefore precipitate with the solids in a tailings pond or thickener. It has been reported that cupric ferrocyanide is not stable in the presence of free CN⁻ ion, however, and will, in fact, react to release ferrocyanide and cuprocyanide complexes (Zaida *et al.*, 1988). Another point to consider is that CN⁻ ion may also liberate copper by solubilizing insoluble cuprous cyanide, via:



Metal ions released after the breakdown of metal cyanide complexes such as Cu(CN)₃⁻² and Zn(CN)₄⁻² will precipitate as their hydroxides, although several cases have been reported where dissolved copper concentrations following removal of cyanide via oxidation did not correspond to theoretical copper solubilities based on copper hydroxide (see Section 2.6). Possible explanations for the presence of elevated copper include complexation with thiocyanate, organic ligands and ammonia. Adverse kinetics and lack of carbonate may also be involved (Higgs, 1990).

The products of the SO₂-Air oxidation process include cyanate and metal ions as well as intermediate sulphur compounds. The effluent from a cyanide destruction circuit using the SO₂-Air process may also contain some sulphite residual, which would be expected to subsequently oxidize in the receiving environment or the tailings pond. A portion of the cyanate generated by the process may hydrolyze to ammonia and CO₂ (see Section 2.2.2.6) as follows:



The degree of hydrolysis that actually takes place during treatment is limited by both pH and retention time.

7.4.2 SO₂-Air Process Equipment

A process flow diagram for the SO₂-Air treatment of mill tailings, based on a two-stage design, is shown in Figure 7.1. The process flow diagram for SO₂-Air treatment of either barren bleed or tailings pond overflow would be similar.

The SO₂-Air process can be carried out in a variety of aerated reactors, including flotation cells and mixed tanks with air spargers. Proper design and location of tank inlets and outlets is essential to control short-circuiting problems. Flotation cells operating in series are commonly used to treat pulp because of the need to maintain the solids in suspension and transfer oxygen. For clear solutions such as tailings pond overflow, single reactors are recommended. A single tank arrangement allows precipitated copper to contact and react with any free cyanide present in the feed. However, it can be advantageous to operate reactors in series when treating high strength streams. This can reduce short-circuiting problems and, with a recycle loop from treated discharge to the feed side of the system, provide some benefit in terms of copper recycle at the same time. The process vendor (Inco) should be consulted for design recommendations for each application.

The following ancillary equipment is required for reagent handling and control:

- Sulphur dioxide can be added as liquid/gaseous SO₂ or as a solution of sodium bisulphite (Na₂SO₃) or sodium metabisulphite (Na₂S₂O₅) (Scott, 1989). A dissolution tank complete with a mixer and metering pump is required for solution feeding. Stainless steel piping is used for SO₂ gas delivery because of the corrosion problems associated with carbon steel pipe if any moisture gains access. The delivery system should include pressure regulation and a flow control valve to set dosage. SO₂ can also be fed directly as a liquid if consumption rates so warrant, but this can entail flow control problems. Flashing of the

liquid to vapour at the control valve can lead to inconsistent feed rates, and external frosting may inhibit adjustment. All items in the delivery system should be rated for gas/liquid SO₂ service. Liquid SO₂ is generally delivered to site in 1 tonne cylinders or in bulk tank trucks. Sodium bisulphite and metabisulphite are generally supplied in 25 kg bags or may be available in bulk containers. Chemical suppliers and the process vendor should be consulted before designing a system that uses SO₂.

- Copper, if required, is added to the process using copper sulphate solution. The necessary equipment includes a dissolution tank, a mixer and a metering pump, as well as plastic pipe and corrosion resistant pumps for solution delivery. Granular copper sulphate is sold as pentahydrate CuSO₄•5H₂O, normally in 25 kg bags.
- Lime slurry is commonly used to maintain pH. Dry lime feeders may be considered in some cases, but they generally exhibit poor dosage control at low feeding rates. Lime slurry can be provided from a ring main recirculating through a stock tank. Lime is fed off the main by means of air-operated or solenoid valves that pulse-feed slurry to the reactor.
- The pH control system requires industrial quality pH electrodes (spares are recommended), a pH meter and a controller, and also commonly includes isolated switches for high and low alarms. The controller adjusts pulse frequency or length, or both, according to the pH set point.

All reagent dosing systems should include flowmeters and alarms in addition to dosage control equipment. There are two alternatives for SO₂ dosage control. The first is measurement of Oxidation-Reduction Potential (ORP), either by establishing a given site-specific set point for automatic control or by using a

hand-held instrument to monitor the process. In the absence of ORP measuring equipment, a titration method for sulphite residual measurement may be a convenient means of process monitoring.

After the oxidation step clarification is required to remove precipitated solids. Retention in the tailings pond fulfills this requirement for tailings pulp or barren solution, while an independent unit process is needed for treatment of tailings pond overflow. Clarification can be provided by settling ponds or clarifiers (circular, reactor or lamella). Equipment selection will ultimately depend on site conditions and desired effluent specifications.

7.4.3 SO₂-Air Treatment Performance

Treatment performance data from pilot scale studies conducted by Inco on selected barren solutions and tailings slurries are summarized in Tables 7.2 and

7.3, respectively (Devuyst *et al.*, 1989).

The results demonstrate that TCN can be reduced to <0.5 mg/L in low nickel effluents and to about 1.0 mg/L in high nickel effluents. Reagent requirements for these tests were in the range of 3.2 to 6.8 kg SO₂/kg CN destroyed for barren solution and 4.4 to 6.7 kg SO₂/kg CN for tailings slurry.

Copper was added to all the slurry samples at a ratio of 0.4 to 0.91 kg Cu/kg CN, but in most cases with the exception of Barren Sample D, it was not required to treat barren solution.

Performance data generated by Inco from seven mines using the SO₂-Air process are given in Table 7.4.

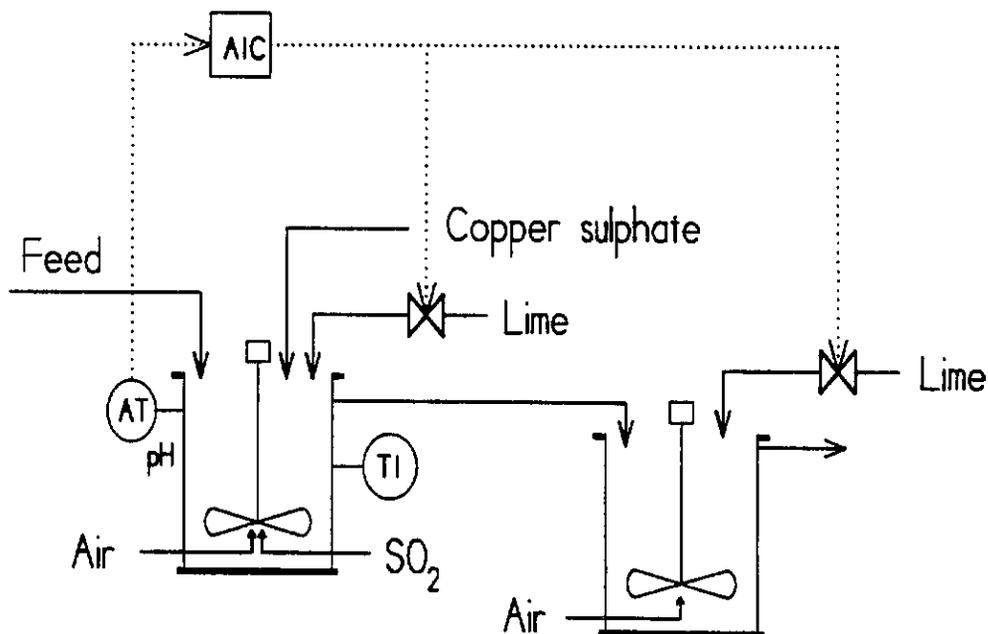


Figure 7.1
SO₂-Air Process Flow Diagram

Table 7.2
Selected Gold Mill Barren Solution Results Using SO₂-Air Process

STREAM	RETENTION TIME (min)	REAGENT	pH	ASSAYS (mg/L or wt %)*						REAGENTS ADDED (g/g TCN)		
				TCN	SCN	Cu	Ni	Fe	Zn	SO ₂	LIME	Cu ⁺⁺
FEED A STAGE 1	-	-	-	1680	820	210	0.6	2.0	758	-	-	-
	97	Na ₂ SO ₃	9.3	0.13	767	0.54	0.1	0.1	3.2	3.20	0	0
FEED B STAGE 1	-	-	12.6	420	1584	137	1.6	19	71	-	-	-
	26	SO ₂	9.0	-	-	13	0.2	5.2	0.4	5.44	8.16	0
STAGE 2	26	SO ₂	9.0	0.11	1408	1.4	0.2	0.2	0.2	1.36	2.04	0
	-	-	-	-	-	-	-	-	-	-	-	-
FEED C STAGE 1	-	-	9.5	500	270	55	53	66	53	-	-	-
	22	SO ₂	9.0	3.0	220	13	3.2	0.2	-	3.40	4.39	0
STAGE 2	22	SO ₂	9.5	1.2	216	0.4	0.8	0.2	0.4	0.85	2.19	0
	-	-	-	27	-	6.60	6.15	8.53	5.99	-	-	-
FEED D STAGE 1	-	-	11.8	2180	1820	235	2.0	325	210	-	-	-
	60	Na ₂ S ₂ O ₅	9.0	0.43	-	4.4	0.2	0.1	3.8	5.00	4.50	0.25

Reference: Devuyst *et al.* (1989)

Table 7.3
Selected Gold Mill Tailings Slurry Results Using SO₂-Air Process

STREAM	RETENTION TIME (min)	SO ₂ REAGENT	pH	ASSAYS (mg/L or wt %)						REAGENTS ADDED (g/g TCN)		
				TCN	SCN	Cu	Ni	Fe	Zn	SO ₂	LIME	Cu ⁺⁺
FEED E STAGE 1	-	-	-	1480	1380	138	1.7	252	214	-	-	-
	130	Na ₂ S ₂ O ₅	8.0	0.65	1300	3.0	0.1	0.1	0.7	4.4	4.4	0.46
FEED F STAGE 1	-	-	-	40	87	1.3	1.6	12.5	<.1	-	-	-
	15	Na ₂ S ₂ O ₅	8.0	0.07	81	0.1	<.1	0.4	<.1	4.8	7.3	0.91
FEED G STAGE 1	-	-	10.7	200	129	47	-	7	55	-	-	-
	17	H ₂ SO ₃	8.0	6.6	91	16	-	<1	<.1	6.7	11.8	0.40
STAGE 2	17	-	8.5	0.2	92	0.3	-	<1	<.1	0	0	0

Feed E - 30 % Solids

Feed F - 24 % Solids

Feed G - 24 % Solids

Reference: Devuyst *et al.* (1989)

Table 7.4 shows SO_2/TCN ratios in the range of 4 to 8, which is comparable to the results obtained from the pilot studies (Devuyst *et al.*, 1989). It should be noted, however, that these data represent optimized operating conditions and may not reflect the process upsets that some of these operations have experienced.

Using a hypothetical design case, Devuyst generated an operating cost estimate for the SO_2 -Air process of \$2.24/tonne mill feed (1989 dollars). In this example, the equivalent cost per kg CN destroyed is

approximately \$3.80/kg CN. Performance data generated during full-scale evaluation programs conducted by Environment Canada yielded reagent consumption ratios for the McBean and Carolin Mines of 3.6 kg and 5.4 kg SO_2 equivalent/kg TCN respectively. Additional case history information on the performance of these treatment systems is provided in Appendix E.

Table 7.4
Cyanide Removal Results at Commercial Operations Using the Inco SO_2 -Air Process

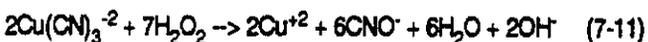
Company	Type of Effluent	Stream	Monthly Average Assays (mg/L)				Reagents (kg/kg TCN)		
			pH	TCN	Cu	Fe	SO_2	Cu^{++}	Lime
Equity Silver		CIL Tails	Feed	11.0	150	35	2.0		
		Effluent	8.0	1-6	2-5	0.2	5.4	0.27	0
Mount Skukum	Repulp Tails	Feed	11.0	100	5.0	15			
		Effluent	8.2	0.9	1.0	0.2	4.0	0.25	0
McBean	Barren Bleed	Feed	11.5	370	30	20			
		Effluent	9.0	0.2	0.7	<0.2	4.0	0	4.0
Lynngold	Pitwater	Feed	8.7	100	10.0	2.0			
		Effluent	9.5	0.6	0.1	0.1	6.0	0.1	8.0
Colosseum California	CIP Tails	Feed	10.6	375	129	2.2			
		Effluent	8.7	0.4	1.5	0.2	5.6	0.11	2.9
Ketz River	CIP Tails	Feed	9.8	150	8.0	<0.1			
		Effluent	8.4	5.0	15	<0.1	6.0	0.3	0
Skyline	Repulp Tails	Feed	10.5	450	300	10			
		Effluent	8.1	<1	0.8	0.3	6.0	0	-
Kurtz	Electroplating Wastewater	Feed	9.5	150	90	2.8			
		Effluent	8.5	0.2	1.2	<0.2	8.0	-	-

Reference: Devuyst *et al.* (1989)

7.5 Hydrogen Peroxide Oxidation

7.5.1 Process Description and Chemistry

In the presence of a copper catalyst, hydrogen peroxide (H_2O_2) will oxidize cyanide and metal cyanide complexes. The overall reactions for the oxidation of cyanide ion and tricyanocuprate ($Cu(CN)_3^{-2}$) with hydrogen peroxide are as follows:

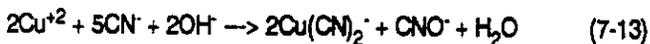


Cupric ion released by the above reaction reacts with hydroxide ion and precipitates as copper hydroxide:

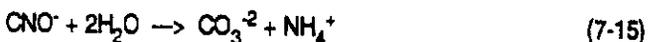


The precipitation of hydroxides consumes alkalinity, and lime must be added to control pH.

As with the SO_2 - Air process, the addition of cupric ion as a catalyst in Equation 7-10 will oxidize free cyanide ion to yield copper cyanide complex and cyanate. Cupric ion will also precipitate ferrocyanide as cupric ferrocyanide:

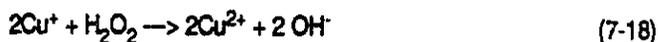
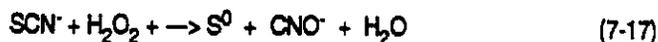


Cyanate formed by the oxidation of cyanide in turn hydrolyzes to ammonia and carbon dioxide:



The process has an optimum pH range of 9.5 to 10.0. The reaction rate accelerates dramatically with temperature and with increasing cyanide concentration. Increasing the H_2O_2 dosage also reduces reaction time. Based on Equation 7-10, the stoichiometric ratio for hydrogen peroxide oxidation of cyanide is 1.3:1.

In practice, the consumption of hydrogen peroxide is considerably higher than the stoichiometric ratio due to the oxidation of reduced metals and other species in solution. For example, the ratio increases to 1.5:1 for the cuprocyanide complex reaction described in Equation 7-11, since cuprous ion oxidation consumes more H_2O_2 . Other reduced species that increase H_2O_2 consumption during oxidation include sulphide, thiocyanate and sulphite:



Some hydrogen peroxide is also lost through decomposition. Any residual H_2O_2 in the discharge will decompose to yield water and oxygen in a reaction catalyzed by metals and suspended material:



7.5.2 Hydrogen Peroxide Process Equipment

A process flow diagram for hydrogen peroxide treatment of tailings pond overflow is provided in Figure 7.2.

All storage and feeding equipment used for handling hydrogen peroxide must be specially designed and fabricated and must be free of contamination. Hydrogen peroxide is stored as a 40% to 70% solution in Class I passivated aluminum storage tanks or in plastic drums. The aluminum tanks are carefully fabricated to prevent heavy metals from being imbedded in the interior surface. Piping is generally stainless steel or aluminum. All aluminum piping must be welded, while stainless steel piping can consist of Schedule 40 or 80 threaded fittings. Detailed design recommendations for storage and handling of hydrogen peroxide are given in Du Port (1990). Additional safety information is provided in Section 3.8.3.

Conventional stirred tank reactors are adequate as long as the design minimizes short-circuiting. Multiple reactors can significantly reduce short-circuiting problems, which is especially important in the treatment of high strength wastes. Retention times are in the range of 45 minutes to 2 hours for clear solutions. Degussa recommends that design parameters such as retention time, H_2O_2 dosages and reactor configuration be based on bench and pilot scale data generated for each application (Vickell *et al.*, 1989).

Equipment for pH control, lime addition and copper sulphate addition is the same as that discussed in Section 7.4.2.

A clarification step is required to remove precipitated metals after cyanide treatment. This is often coupled with the need to remove arsenic or antimony using ferric sulphate and lime co-precipitation. The use of

reactor clarifiers or lamella clarifiers with sludge recycle is common in the treatment of tailings pond overflow. These types of system are recommended to reduce problems with metals when treating low strength wastes.

7.5.3 Performance of the Hydrogen Peroxide Process

The first large-scale peroxide installation was designed by Degussa and installed at the Ok Tedi Mine in Papua New Guinea (Knorre and Griffiths, 1984). Pilot testing at this mine generated a consumption rate of $0.7 \text{ kg } H_2O_2 / m^3$ of mill tailings at 45% solids with an initial TCN concentration in the range of 110 to 300 mg/L. The TCN concentration in the treated effluent was reported to be from 1 to 10 mg/L.

Degussa presented treatment performance data for

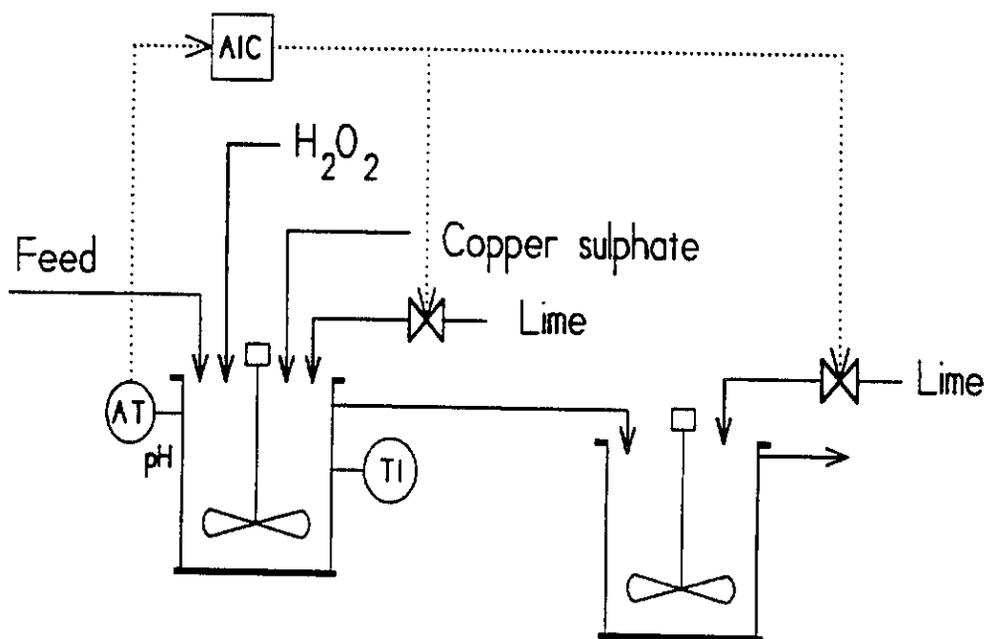


Figure 7.2
Hydrogen Peroxide Treatment Process Flow Diagram

two different waste streams - tailings pond overflow and barren bleed solution (Vickell *et al.*, 1989). The process design for tailings pond overflow treatment involved two stirred tank reactors operating in series, followed by clarification in a settling pond. Lime slurry and H_2O_2 were dosed to the first tank. Total operating costs were estimated at $\$0.30/m^3$, equivalent to $\$8.27/kg$ TCN destroyed. Cyanide concentration was reduced from 40 to <1.0 mg/L, while dissolved copper dropped from 40 to <0.5 mg/L.

The barren bleed stream in the second case study contained elevated levels of ferrocyanide. The process design in this case included four stirred tanks operating in series. Lime, copper sulphate and H_2O_2 were fed to the first reactor to oxidize cyanide, while sulphuric acid (with copper sulphate also available) was fed to the third tank to reduce pH and precipitate ferrocyanide. Plant performance data indicated that cyanide concentrations dropped from 730 to 10 mg/L, while copper dropped from 400 to 8 mg/L. The treated effluent was then discharged to a tailings pond for further treatment. Total operating costs were estimated at $\$6.68/m^3$ of barren solution, equivalent to $\$9.15/kg$ of CN^- removed.

Given the current unit cost of reagents (1991) and the high reagent consumption rates involved in the process, hydrogen peroxide oxidation may have limited application in treating concentrated barren solution and slurries.

7.6 Natural Degradation

7.6.1 Natural Degradation Mechanisms

Natural degradation can be defined as the removal of cyanide and metal cyanide complexes by natural physical/chemical means through prolonged exposure to natural elements. The major cyanide removal mechanisms responsible for natural degradation are the following:

- pH depression due to CO_2 absorption

- volatilization of hydrogen cyanide gas (HCN)
- dissociation of metal complexes with release of cyanide ion
- photolysis of iron cyanide
- precipitation of metal complexes.

In a review carried out for Environment Canada, IEC concluded that neutralization and volatilization appear to be the primary mechanisms responsible for cyanide removal in tailings ponds (IEC Ltd., 1979). The review suggested that biodegradation and photolysis are not likely to be significant factors in a tailings ponds environment because of potential limitations in supernatant clarity and temperature, and that dissociation of the metal complexes could be the rate-controlling step in the process. Test data were presented on air stripping of cyanide solutions at neutral pH, which indicated that neutralization was rapid but stripping of HCN was slow and not particularly sensitive to increases in air to liquid ratios. However, reductions in the liquid surface to depth ratio demonstrated significant increases in the stripping rate. This factor has major implications in the design of tailings pond systems for natural degradation.

Environment Canada's Wastewater Technology Centre (WTC) has conducted a series of field and bench scale research projects to develop a better understanding of the natural degradation process. The first of these studies involved an evaluation of the tailings pond system at Dome Mines at South Porcupine, Ontario (Schmidt *et al.*, 1981), where the concentration of cyanide in a barren bleed pond effluent was tracked before and after spring melt and disappearance of the ice cover. The study results showed that cyanide concentration decreased from 68.7 to 0.008 mg/L over a 15-week period from April 30 to August 6, 1980. The first active mechanism to occur after spring melt was pH depression due to absorption of carbon dioxide from the air and precipitation of calcium carbonate. The study

concluded that dissociation of the metal cyanide complexes and volatilization of HCN were responsible for most of the treatment. It also found a small increase in cyanate concentration, indicating that some direct hydrolysis or photodecomposition of cyanide was taking place. A plot of the concentrations generated during this study is provided in Figure 7.3.

The chemistry involved in the natural degradation process and the factors that affect the rate of degradation are discussed in the following section.

7.6.2 Chemistry and Rate of Natural Degradation Process

7.6.2.1 Form of Cyanide

Cyanide must be present as HCN to volatilize from solution; therefore the form that cyanide takes in solution is important. As discussed in Section 2.2.1, "free cyanide" in solution represents the total of cyanide ion (CN^-) and molecular hydrogen cyanide (HCN). The fraction of "free cyanide" present in solution as molecular HCN is dependent on pH. The partition of "free cyanide" into molecular HCN and CN^- ion as a function of pH is illustrated in Figure 2.1. At pH 9.36 the concentrations of HCN and CN^- ion are equal. Thus, pH should be below 9.0 to ensure that a substantial percentage of "free cyanide" is present as HCN.

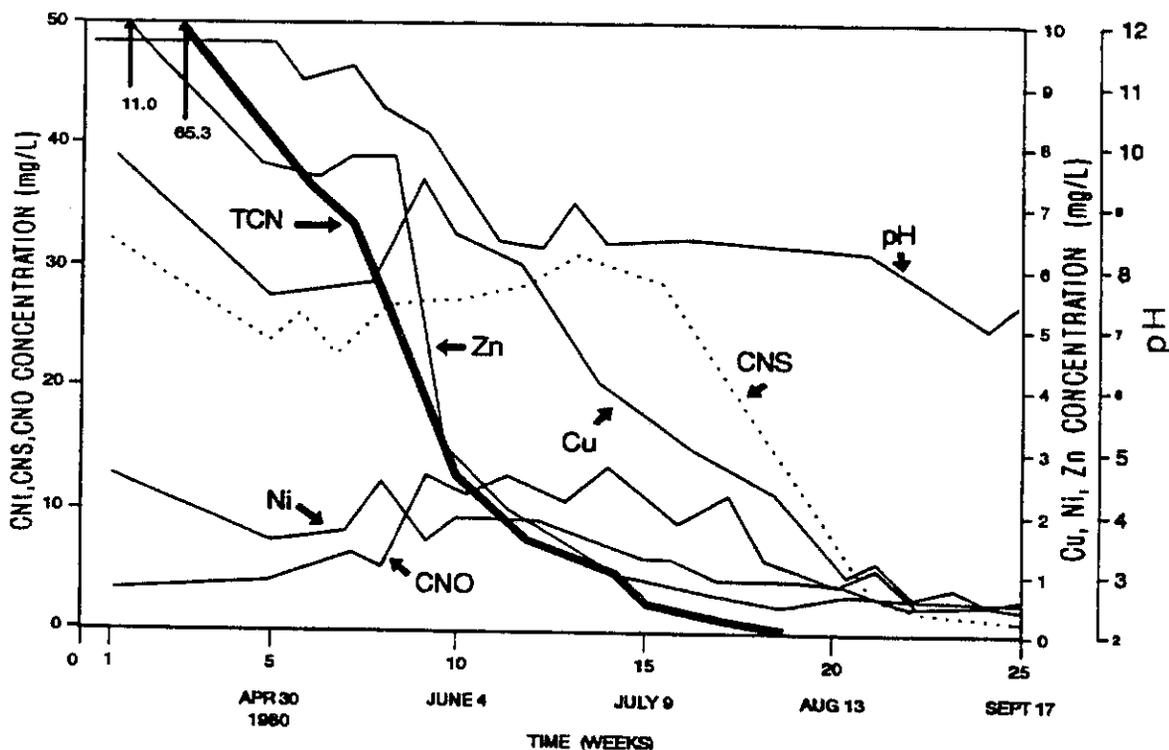
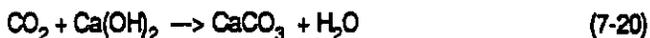


Figure 7.3
Concentration Trends in Shallow Barren Bleed Holding Pond at Dome Mines

7.6.2.2 pH Depression

The cyanidation process uses high pH conditions (i.e., pH >10.5) to reduce the loss of cyanide during milling. Mill tailings are therefore characterized by high pH and a low percentage of HCN.

In tailings ponds systems where lime has been used in the mill for pH control, the pH of the pond supernatant will drop as carbon dioxide is absorbed from the air, as follows:



In this reaction, alkalinity in the form of calcium hydroxide reacts with absorbed carbon dioxide to form insoluble calcium carbonate, which precipitates from solution. Hydroxide ions (OH)⁻ are consumed by the reaction, which in turn lowers pH.

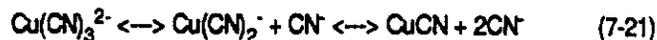
The rate of CO₂ absorption is influenced directly by the degree of contact between the air and the solution. In a stagnant pond system this rate is enhanced by providing a high ratio of surface area to pond volume or by mechanically mixing and aerating the pond. Depression of pH by CO₂ absorption can only occur under ice-free conditions in stagnant ponds. Pond pH typically increases during winter months due to the alkalinity of the tailings and depresses rapidly after spring melt.

7.6.2.3 Volatilization

Once pH has dropped, volatilization can take place. The volatilization rate is enhanced by providing good contact between air and the solution, identical to the circumstances that enhance pH depression. Mechanical aeration and mixing can also be used to enhance volatilization; however, limitations to the use of aeration would be expected at low cyanide concentrations because of the high solubility of HCN and reduced driving force. As discussed below, the actual rate of volatilization can be expressed as a mass transfer coefficient.

7.6.2.4 Dissociation of Metallo-Cyanide Complexes

Dissociation Mechanism - Cyanide forms a variety of metal complexes of varying stability, as discussed in Section 2.2.2.3. These metal cyanide complexes equilibrate with cyanide ion CN⁻ in solution, for example with copper:



Depending on the pH of the solution, the cyanide ion released from the complex can then combine with hydrogen ion to form molecular HCN, which volatilizes from solution. As CN⁻ ion is lost from solution due to volatilization of HCN, the Cu(CN)₃²⁻ complex will release additional CN⁻ ion in an attempt to maintain the equilibrium. Naturally, dissociation is affected by pH, as this influences the form of free cyanide. Tricyanocuprate is stable in the presence of sufficient CN⁻ ion.

Dissociation Rate - Dissociation rates for the metallo-cyanide complexes normally encountered in gold mill effluents are provided in Table 7.5. These data were generated from experiments conducted by the Wastewater Technology Centre using synthetic samples containing mixtures of metal cyanide complexes. The experimental work yielded volatilization mass transfer coefficients for HCN of 0.0294 and 0.04175 cm/h at pH 7 and temperatures of 4° and 20°C, respectively, when cyanide was fully complexed with metals (Simovic and Snodgrass, 1989).

The half life of these complexes can be calculated using the rates reported in Table 7.5. For example, at 20°C and pH 7, Zn(CN)₄²⁻ has a dissociation rate, k₁, of 0.049 h⁻¹. Therefore the half life, t_{1/2}, under these conditions is equal to ln2/0.049, or 14 hours. Similarly, the calculation for Fe(CN)₆³⁻ at 4°C and pH yields a half life, t_{1/2}, of 2.5 years.

Table 7.5
Dissociation Rates (h^{-1}) for Metallo-cyanide Complexes

COMPLEX	pH 7 4°C	pH 7 20°C	pH 10.5 4°C	pH 10.5 20°C
$Cu(CN)_3^{-2}$	0.0018	0.0055	0.000071	0.00022
$Zn(CN)_4^{-2}$	0.023	0.049	0.001	0.0022
$Ni(CN)_4^{-2}$	0.00042	0.00097	0.000051	0.00012
$Fe(CN)_6^{-2}$	0.000031	0.00009	0.000003	0.0000097
HCN Volatilization Coefficient (cm/h)	0.0294	0.04175		

Reference: Simovic and Snodgrass (1989)

The data in Table 7.5 can be used to evaluate the relative dissociation rates of the individual complexes but may not apply directly to a pond system because actual volatilization rate will vary with HCN concentration. In addition, iron cyanide complex would be expected to precipitate as copper or zinc ferrocyanide instead of being removed by dissociation and volatilization.

At neutral pH, the rate of metal cyanide complex dissociation is assumed to be the rate-limiting step in the natural degradation process. Under higher pH conditions, however, where a significant portion of the "free cyanide" is present as CN^- ion, the rate of HCN volatilization may control (Higgs, 1989). Ideally, the pond supernatant pH should be below 8.5 to maximize the percentage of HCN present.

Case history information from natural degradation studies conducted at the Lupin mine is provided in Appendix E.

7.7 Biological Degradation

The application of biological degradation is limited to site-specific situations where heat is available and treatment is required for other contaminants such as thiocyanate and ammonia, as well as cyanide.

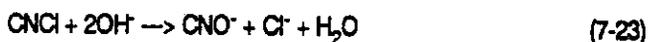
Homestake Mining Company in Lead, South Dakota, treats tailings pond decant and mine water in a two-step biological treatment process using rotating biological contactors (RBC) (Scott, 1989). The first step converts cyanide and thiocyanate to ammonia and sulphate by oxidation and hydrolysis. Metals are removed by adsorption into the biological film. This film periodically sloughs off and is removed in the clarification stage. In the second step of the process, ammonia is oxidized to nitrate by biological nitrification. The effluent is then clarified using ferric chloride coagulant in a clarifier, followed by sand filtration. Phosphoric acid is added to provide phosphorous as a nutrient for the biological system, while soda ash is added to provide alkalinity, which assists the nitrification process. A particular advantage at this site is ambient temperature: untreated water is between 10° to 18°C year-round. The Homestake system removes cyanide, thiocyanate and ammonia and was designed to produce a "non-toxic" effluent.



7.8 Alkaline Chlorination

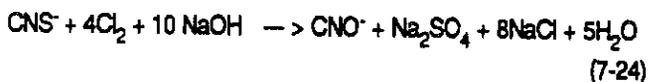
7.8.1 Chemistry of Alkaline Chlorination

The alkaline chlorination process involves the destruction of cyanide using hypochlorite ion at pH values in the range of 10 to 11. Hypochlorite may be supplied in the form of either chlorine gas, calcium hypochlorite or sodium hypochlorite. Lime or caustic is required to maintain pH in the alkaline range. The process involves two steps: the formation of cyanogen chloride by the reaction of cyanide ion and chlorine, and the hydrolysis of cyanogen chloride to cyanate:

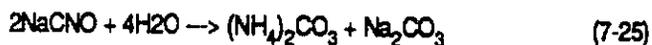


The overall reaction rate is sensitive to pH, with the optimum pH level being 10.5 to 11.0; poisonous CNCl gas forms when the pH is below 8. The theoretical chlorine requirement for oxidation of free cyanide to cyanate is 2.72 kg Cl₂/kg CN. An additional 3.34 kg of Ca(OH)₂/kg CN is added to control pH. The cyanate produced by the process is stable in water unless additional chlorine and retention time are provided. Chlorine will also oxidize other components of the waste stream, such as thiocyanate, ammonia and thiosulphate.

Thiocyanate readily reacts with chlorine to form cyanate :

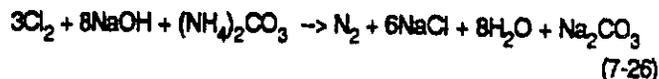


In the presence of excess chlorine, cyanate can be oxidized to form ammonium carbonate :

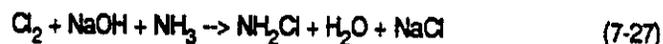


This reaction requires 1.5 hours and is favoured at low pH (Ingles and Scott, 1981; Brodie, 1982). Once hydrolysis is complete, the ammonium carbonate

formed by the above reaction is rapidly oxidized to nitrogen gas and bicarbonate:



The overall reaction requires a total of 6.82 kg Cl₂/kg CN destroyed and 8.35 kg Ca(OH)₂/kg CN destroyed. Where the dosage is too low for complete ammonia destruction, the formation of monochloramine would be expected when the pH is above 9:



Chloramines will persist in waste streams and therefore impart toxicity to the receiving environment. In addition, chlorine oxidizes ferrocyanide to ferricyanide, which can remain in solution and present a disposal problem.

One of the main attractions of alkaline chlorination is its rapid reaction rate.

7.8.2 Application of Alkaline Chlorination

No active mining operations in Canada are currently using the alkaline chlorination process. It has been supplanted by the SO₂-Air and hydrogen peroxide processes because of the following disadvantages:

- higher capital costs
- inability to remove iron cyanide
- increased reagent costs due to thiocyanate oxidation
- concerns with discharges containing residual chlorine and chlorinated by-products.

The advantages of the process are favourable kinetics and the ability to remove thiocyanate, cyanate and ammonia, if required. Its inability to remove iron cyanide is not a major limitation, since

concentrations of ferrocyanide are usually low and the toxicity of ferrocyanide is also relatively low (see Section 5.4).

While it is questionable whether the alkaline chlorination process will find application for conventional treatment of high strength wastes, it may be considered for emergency situations and for treating low strength wastes on a batch basis, especially if some form of dechlorination is available. Case history information on the alkaline chlorination process is provided in Appendix E.

7.9 Cyanide Recycle Technology

Several processes have been developed to recover and recycle cyanide. The basic processes are AVR (acidification, volatilization, reneutralization) and ion exchange with AVR and electrolytic recovery.

7.9.1 AVR (Acidification, Volatilization, Reneutralization)

In the AVR process, developed by Canmet, barren solution is acidified to pH 2 to 3 using sulphuric acid and passed countercurrent to a stream of air in a series of packed towers. HCN is volatile and is stripped from solution. Low pH is essential to dissociate the metal complexes and convert cyanide ion to HCN. HCN in the gas stream is absorbed in a tower, and the recovered cyanide solution is recycled to the cyanidation circuit. The process can generate a dischargeable effluent consisting of clear stripped solution (McNamara, 1989), but it also produces a sludge containing cuprous cyanide, copper ferrocyanide, zincocyanide, nickelocyanide and gypsum (Ingles and Scott, 1987), which must either be treated or discharged to the tailings pond.

Costs associated with AVR are controlled by the gasification step. In additional development work, Canmet has modified the AVR process by using direct liming, which reduces some of these costs (McNamara, 1989).

The AVR process was used by Hudson Bay Mining and Smelting at Flin Flon, Manitoba, from 1935 to 1978 and has been used by others on a batch basis. General acceptance will probably be slow due to the perceived hazard of handling HCN gas, the marginal economics and overall complexity. The attractiveness of the process will hinge on cyanide consumption rates at a given site and future unit costs of sodium cyanide.

7.9.2 Ion Exchange

Two processes of interest use ion exchange resin for cyanide recovery and recycle.

The RTA process, patented by Resource Technology Associates, has been tested on a pilot scale. It involves the adsorption of metal-cyanide complexes from barren solutions on a weak-base anion exchange resin and concentration of the cyanide by eluting with a calcium hydroxide solution, followed by resin regeneration and cyanide recovery via AVR (Scott, 1989).

The Cyanosave process uses a metal-binding resin marketed under the name Vitrokele™. Vitrokele™ beads are contacted with pulp in a series of tanks. The Vitrokele™ resin moves countercurrent to the pulp, and the loaded Vitrokele™ is eluted, regenerated and returned to the adsorption step. Both cyanide and metals are recovered (Kidby *et al.*, 1989).

The major limitations of ion exchange processes appear to be resin poisoning and costs. Further development work involving pilot and full-scale testing will be required before these processes gain acceptance.

MEMORANDUM

DATE: December 20, 2001 **FILE NO.:** U419B
TO: Rick Zimmer
FROM: Bryan Nethery / Tom Higgs
SUBJECT: Mine Water Ammonia and Nitrate Concentrations

Cc: Bryan Nethery, Karl Hanneman, Eric Konigsmann, Mike Davies

The purpose of this memo is to provide the basis for selection of the mine water quality data for ammonia and nitrate to be used in the water quality modeling work, originally presented in the Pogo August 2000 Water Management Plan and currently being updated.

In order to estimate the ammonia and nitrate levels in mine drainage from Pogo, actual data from operating gold mines was assembled and reviewed. We were able to obtain data from four mines on ammonia levels, of which two had data on nitrates. This information is as follows:

Ammonia Values(ppm)

Mine	Mean	SD	Mean + 1SD	TPD	Backfill	Exp. Type	Net Inflow (gpm)
Eskay Creek Mine	0.75	0.38	1.13	500	Quarry sand	Cart. Emul.	500
Snip Mine	3.3	4.2	7.5	400	Hydraulic	Bag Anfo	400
Williams Mine	11.3	4.0	15.3	7000	Quarry rock	Bag Anfo	200
Golden Giant Mine	21.2	11.0	32.2	3000	Paste	Bulk Anfo	Dry

Nitrate Values(ppm)

Mine	Mean	SD	Mean + 1SD
Eskay Creek Mine	1.2	0.7	1.9
Williams Mine	41.6	10.4	52.0

As can be seen from the above data, there is a high degree of variability from mine to mine. Site specific factors have a big impact on the drainage from these mines. The Eskay Creek Mine and the Snip Mine are at the low end of the range. In the case of Eskay Creek, this is attributed to the use of cartridge emulsion explosives and a relatively high degree of inflow into the mine. The Snip Mine, however, used bagged ANFO for its explosive product and the data includes a period of time in which very poor practices were followed whereby unused explosives were merely dumped onto the ground rather than returning bag remnants to the magazine for later re-use. This resulted in high ammonia/nitrate levels in the mine water for a period of time. In discussions with environmental staff at the Snip Mine, it was reported that once management effort was focused on this practice, there was a resultant increase in effluent quality almost immediately.

The Williams Mine is a much larger operation and uses a combination of bagged (by far the largest proportion) and bulk ANFO. (It is also experimenting with emulsion products at this time.) The Golden Giant mine, which is closest to Pogo in size and operating characteristic (ie uses paste fill) has historically used bulk ANFO but is now considering switching to emulsion for operational reasons. It must be pointed out however, that GG is essentially a dry mine in that the only water pumped out of the mine is first introduced from drilling and mining operations.. This explains the higher values for the GG effluent.

Ammonia and nitrate in mine water is mainly due to the incomplete detonation of explosives. This can be from failure of explosives to detonate or, from poor handling/spillage of unused material. Therefore the key to controlling ammonia and nitrate is to ensure that best management practices are followed in the use and care of explosives. The biggest factor in this regard is to ensure that excess explosives are not merely dumped onto the ground rather than returned to the magazine for later use. Further, as ANFO is much more soluble in water than emulsion based products, switching explosives can often reduce ammonia levels. In addition, cartridge type as opposed to bagged and bulk explosives are less apt to be spilled and are more easily cleaned up if necessary. This probably is best seen in comparing Eskay Creek with Snip. The Pogo Mine will utilize best management practices (BMP), including cartridge and emulsion explosives, if necessary, to control the release of ammonia and nitrates. At this time it is planned to use ANFO, however as noted above, there are a number of factors to be considered in the use of an explosive product. More specialty products can be introduced if considered necessary for the operation.

From a review of the data it is noted that is impossible to predict exactly what the ammonia/nitrate level will be in the effluent. Therefore, the approach taken was to use estimates that are reasonable considering the Pogo site and the experience of other operators.

We therefore propose to use an estimate of 10 ppm for ammonia, and also 10 ppm for nitrate in the Pogo mine effluent since under the chemical conditions found in the mine, the two compounds will be found in stoichiometric proportion.