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# FARO DOWN VALLEY TAILINGS

# RESEARCH PROGRAM

# REPORT: TAILINGS REPROCESSING

# EXECUTIVE SUMMARY

By

G. W. McDonald - Curragh Resources Limited

14-33

Canada

Yukon
Government

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# EXECUTIVE SUMMARY

June 1, 1993
G. W. McDonald
Vice President, Metallurgy

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## INTRODUCTION

The Faro Down Valley Tailing Ponds (see map and section) contains a residual quantity of minerals that have a total value of more than a billion dollars, however, only a portion of these minerals may be recoverable through research. A research proposal for the development of an economical reprocessing method for the recovery of this resource, which would create jobs and eliminate an environmental liability, was approved for co-funding by the Government of the Yukon, Department of Economic Development (Canada/Yukon Economic Development Agreement). This ambitious and diligent research program involved Canmet (Mineral Sciences Laboratories), Lakefield Research, Normet and Curragh Inc.

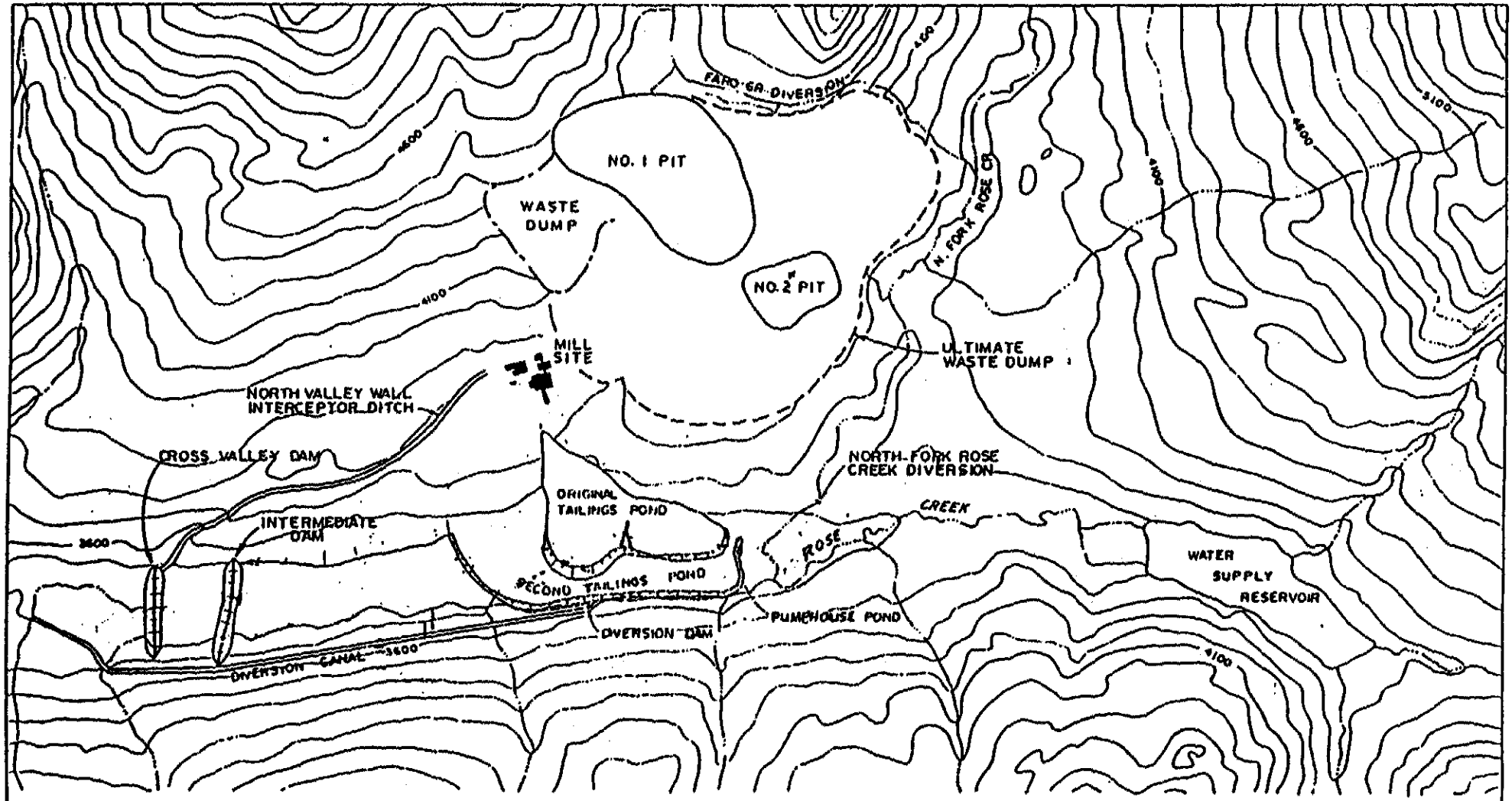
The Laboratory test results from the initial research programs are very encouraging with the production of a marketable bulk concentrate of 50% lead plus zinc metal content at a zinc metal recovery of 58 percent. There is considerable confidence in the Faro Down Valley Tailings reprocessing approach because of the metallurgical results attained, the implementation of proven new technology equipment, the use of current reagents and the availability of the Faro Mill (low capital requirement) when the known, economic ore reserves are depleted.

## CONCLUSION

The research programs run at Canmet (Mineral Sciences Laboratories), Lakefield Research and Normet on Faro Down Valley Tailing composites indicate a technical success with the production of a marketable bulk sulphide concentrate at a respectable recovery of 58%.

| Testwork Composite | Product | Assay | | Recovery | |
|---|---|---|---|---|---|
| | | Pb% | Zn% | Pb% | Zn% |
| pH >7 | Final Bulk Conc | 10.2 | 37.4 | 25.4 | 58.2 |
| | Rghr Bulk Conc | 2.88 | 6.1 | 59.4 | 78.6 |
| | Calc. Headgrade | 0.70 | 1.12 | 100.0 | 100.0 |
| pH <7 | Final Bulk Conc | 5.13 | 31.2 | 15.8 | 57.9 |
| | Rghr Bulk Conc | 1.73 | 3.81 | 61.4 | 81.2 |
| | Calc. Headgrade | 0.62 | 1.03 | 100.0 | 100.0 |

The research programs of each laboratory were scoped to develop a reprocessing flowsheet for the Down Valley Tailings. Although the Canmet and Normet laboratories' preliminary testwork did not attain the same metallurgical results as Lakefield Research, their on-going testwork has reported similar overall metallurgical results.




CURRAGH RESOURCES

FARO MINE LAYOUT

DATE

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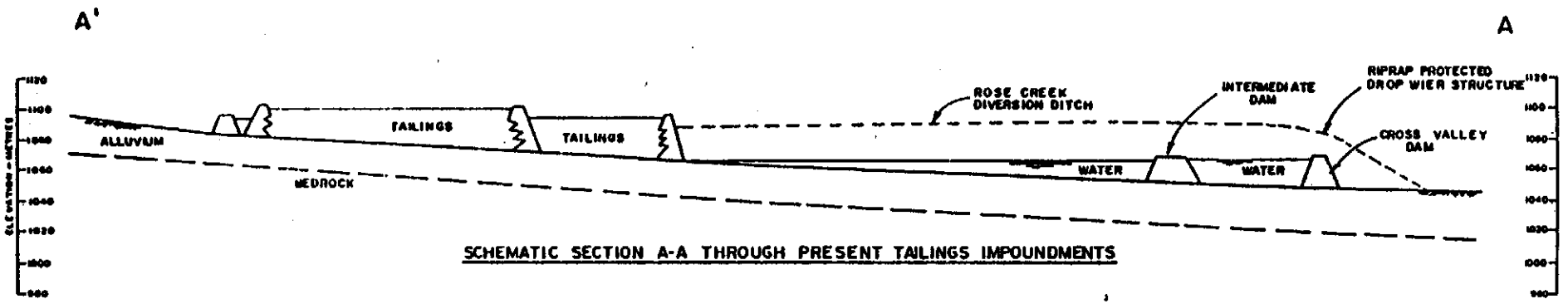



SCHEMATIC SECTION A-A THROUGH PRESENT TAILINGS IMPOUNDMENTS

| | |
|---|---|
| CURRAGH RESOURCES | DATE |
| FARO ABANDONMENT PLAN EVALUATION | PROJ NO |
| LONG SECTION THROUGH EXISTING IMPOUNDMENTS | APPROVED |
| STEFFEN ROBERTSON & KIRSTEN, Consulting Engineers | NO 1.2 |

The research testwork must continue as there is more information needed for the final reprocessing flowsheet. Larger volume laboratory bench testwork is needed to determine the high intensity conditioner equipment design criteria, bulk rougher concentrate regrind requirements and bulk cleaner concentrate grades and recoveries. This research work will require more Down Valley tailings.

## PURPOSE OF THE RESEARCH

All of the flotation tailings from the Faro mill, from start up in July 1969 through to August 1992, have been impounded in the Rose Creek Valley area. Subsequent tailings are pumped to the mined-out Faro Open Pit. There are 51,926,452 tonnes of tailings assaying 0.8% Pb, 1.3% Zn, 0.12% Cu, 20 g/t Ag placed in this Down Valley area behind water/solids impervious dams. Research is required to develop a process for the recovery of any of the metals in the Down Valley Tailings pond which at present are <u>not</u> recoverable but worth over a billion dollars.

A major factor in the design, cost estimating and implementation of the Faro Decommissioning plan is this large quantity of acid mine drainage tailings. Many decommissioning scenarios have been discussed, plans developed to a preliminary engineering status and costs estimated. These decommissioning scenarios varied from complete water flooding of the entire Down Valley Tailing Impoundment area by the construction of a high Cross Valley Dam (at an estimation capital cost of +$60 million) to placing a composite dry cover over the exposed tailing with permanent water cover of the remaining tailings behind the structurally modified existing Cross Valley Dam (at an estimated capital cost of $24 million).

It is apparent that these estimated decommissioning costs are excessive so a further search and/or development of new technology is imperative. Since sufficient space would be available in the mined-out Faro Pit for final deposition of the reprocessed Down Valley tailing, the question is "Can the tailings be reprocessed, economically?". There will be many positive spin offs of a successful reprocessing approach: site jobs for many operating years, a more complete usage of the natural resource and an integral part of a better decommissioning plan for Faro (all processed tailing would be water flooded thereby eliminating acid mine drainage).

## RESEARCH PROPOSAL AND MDA YUKON FUNDING

In 1990-91, Denhurst Limited in Australia developed a laboratory flowsheet for the recovery of a bulk, mineral sulphide concentrate from the impounded tailings at their Woodlawn Mine. This successful laboratory program culminated in the design, construction and commissioning of a production tailings reprocessing mill in 1991. Their process flowsheet was kept secret, however, they were willing to give a Faro Down Valley tailings sample a preliminary evaluation. Their laboratory test (1992) produced better metallurgical results than previous testwork run on a similar sample.

Discussions were held with Ms. L. Walton, MDA Co-ordinator (Government of the Yukon, Department of Economic Development), Mr. M.C. Campbell, Manager (Canmet, Resource Utilization Laboratories), Mr. S. Bulatovic, Consulting Metallurgist (Lakefield Research) and Mr. I. Pattison, Executive Director (Denhurst Limited) re: Reprocessing Faro Down Valley tailing to produce a bulk, mineral sulphide concentrate (at least 50% lead and zinc metal) - program, schedule and cost.

Subsequently each party prepared a research proposal that had a very limited overlap of the testwork. Curragh Inc. would co-ordinate the program and be responsible for the project report. The program must be complete by March 31, 1993. The cost estimate for the proposed research is as follows:

| Sub Contractor | Type of Work | Original Budget |
|---|---|---|
| Canmet | Laboratory Flotation<br>Mineralogy | $120,000 |
| Curragh Inc. | Sample Acquisition<br>Sample Analysis<br>Project Management | $ 45,000 |
| Lakefield Research | Laboratory Flotation | $ 20,000 |
| Denhurst Limited<br>(Normet Pty Ltd) | Laboratory Flotation | $ 40,000 |
| TOTAL | | $225,000 |

The co-funded program cost was distributed as follows:

| Co-Funders | Original Budget |
|---|---|
| Curragh Inc. | $ 80,000 |
| MDA | $145,000 |
| TOTAL | $225,000 |

The research program commenced on schedule on October 28, 1992.

## RESEARCH PROGRAM

The research program was divided into two phases. Phase One, was sample acquisition and sample analysis. Phase Two, was the laboratory testwork with metallurgical balance results.

## PHASE ONE

### 1.0 Sample Acquisition

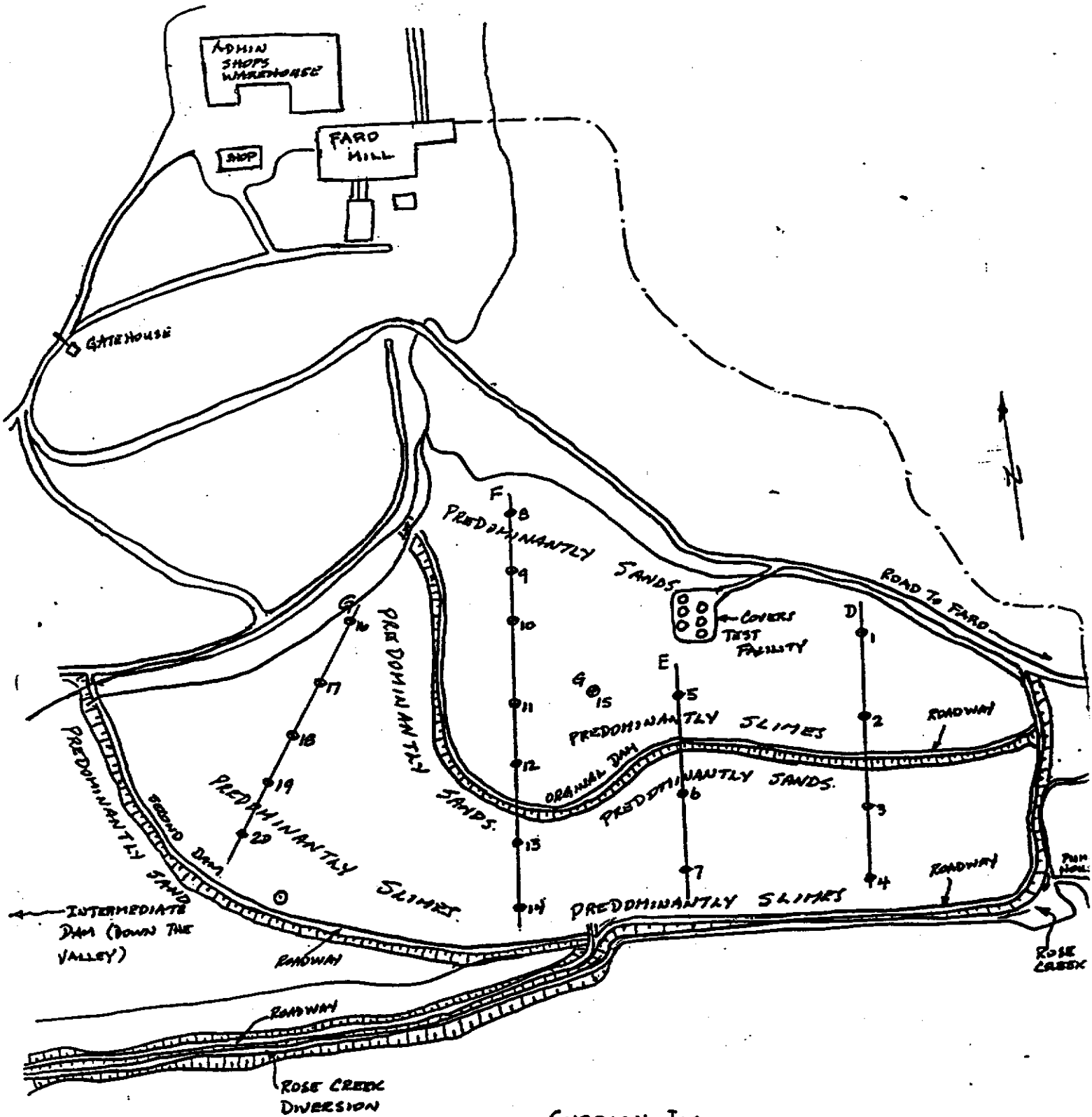
The geological department of Curragh Inc. reviewed available historical data (pre-1983) and site maps to best identify the spigot points of the mill flotation tailing within the two upper tailing pond areas. They recommended four section lines (letters) and the collar location of twenty drill holes (numbers) so the drill hole, core samples should best represent the stored tailing. The tailing drill hole locations are shown in figure no. 1.

A vibro core drill was selected as the preferred equipment to drill the tailing ponds. It was light weight and readily mobile; it had a special "shoe" attachment that will lock the core in the rods (NQ rods with no core barrel - 2 3/8" ) on retrieval so no sample is lost. No air, water, etc. is added to the drilling face thereby preventing sample mixing or dilution during the drilling program. Ace Drilling from Surrey, B.C. was the closest available vibro core driller and they did a good job.

The drilling program was designed to recover all core from the tailing pond's surface to the valley floor or an impregnable subsurface. The drill hole, core sample was composited in one meter increments which were numbered from the surface downward in consecutive order. Each drill hole core, sample composite was subjected to the following procedure:

a) weighed (wet weight) and recorded (254 core composites)
b) paste pH read and recorded (254 core composites)
c) observed degree of moisture content and recorded
d) screen analysis (200 and 325 mesh screen) and size distribution recorded (762 screen fractions)
e) each sample composite was cut into four, one kilogram portions for metallurgical testwork, identified as I, II, III, and IV.
f) chemical analysis (lead, zinc, copper, iron) run on each screen fraction and a metal balance recorded (4064 chemical analyses).

The mean metal content of the drill hole, core increments was 0.72% lead, 1.26% zinc, 0.12% copper and 29.9% iron. A condensed copy of each reporting sheet is shown in figure no. 2.




CURRAGH INC

FARO DOWN VALLEY AREA

- ORIGINAL POND
- SECOND POND
- INTERMEDIATE POND

VIBRO CORE DRILL HOLE ROW LETTER AND HOLE NO.

Figure No. 1

# FARO DOWN VALLEY TAILING
# SAMPLING PROGRAM (1992)

- VIBRO CORE DRILLING
- METER SAMPLE INCREMENT LENGTH

DATE: _____

| ROW LETTER | HOLE NO. | INCREM. NO. | TOTAL WEIGHT kg | PASTE pH | TESTWORK COMPOSITES | | | | | SCREEN & ANALYSIS 0.5 kg | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | I | II | III | IV | EXTRA | | |
| | | | | | 1 kg | 1 kg | 1 kg | 1 kg | kg | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

| | DEGREE OF MOISTURE CONTENT | | | | WATER CLAIRITY | |
|---|---|---|---|---|---|---|
| SAMPLE # | LOW 1 | MODER 2 | VERY 3 | EXTREME 4 | CLEAR 1 | MUDDY 2 |
| | | | | | | |
| | | | | | | |

## SCREEN DISTRIBUTION AND METAL ANALYSIS

| ROW NO. | INCRE. NO. | SCREEN | | | ASSAYS | | | | DISTRIBUTION | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SIZE | WT. | % WT. | Pb % | Zn % | Cu % | Fe % | Pb % | Zn % | Cu % | Fe % |
| | | + 200 | | | | | | | | | | |
| | | + 325 | | | | | | | | | | |
| | | - 325 | | | | | | | | | | |
| TOTAL | | | | | | | | | | | | |

## INCREMENT METAL ANALYSIS

| ROW LETTER | HOLE NO. | INCREM. NO. | ANALYSIS | | | |
|---|---|---|---|---|---|---|
| | | | Pb % | Zn % | Cu % | Fe % |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

Figure No. 2

## 2.0 Laboratory Testwork Composites

Individual drill hole, core sample increments, sealed in plastic bags and identified with Roman Numerals, were gathered into "testwork composite" lots and shipped to designated research laboratories. In turn, they were instructed to keep the sample and subsequent composite factions: sealed, moist and in cold storage when not in use. The following "weight of samples" were shipped to:

| | |
|---|---|
| Lakefield Research | - 50 kilograms |
| Denhurst Ltd. (Normet) | - 75 kilograms |
| Canmet | - 250 kilograms |

## PHASE TWO

## 1.0 Laboratory Research Programs

### a) Lakefield Research

The laboratory testwork program was quite focused - prefloat conditioning and reagents. The individual drill hole, core sample increments were composited into two testwork composites. One testwork composite contained increments with paste pH's $<7$ and the other testwork composite contained increments with paste pH's $>7$. The testwork program evaluated flotation responses following prefloat conditioning (conventional conditioning, a short grind or high intensity conditioning, a Lakefield specialization). This program also evaluated reagents (pH modifiers, pyrite depressants and collectors) to produce a high recovery, bulk rougher concentrate. At optimum bulk rougher concentrate recovery conditions, several cleaner flotation tests were run to determine concentrate upgrade.

### (b) Denhurst Limited (Normet)

The laboratory testwork program was quite focused - Denhurst flowsheet evaluation and modified flowsheet evaluation. The drill hole, core sample increments were combined to make one testwork composite and then subjected to the Denhurst established pre-float conditioning and reagent scheme to produce a bulk concentrate (special emphasis on the zinc content). This work was followed with several flotation tests in which the slurry was oxygenated during prefloat conditioning and another series of flotation tests in which the prefloat conditioning step was eliminated.

### (c) Canmet

The scope of this laboratory testwork program was a broad baseline - mineralogy, bulk rougher prefloat conditioning, bulk concentrate cleaning and reagent evaluations.

Mineralogy via an optical microscope, an electron microscope and an image analyzer was done on testwork composites from the entire Down Valley drilling program. These composites were assembled at three specific pH levels (< 5, 5 to 7, >7). Each composite was screened on four sizes and prepared for instrument assisted mineral identification, mineral liberation count and mineral particle size analysis.

A second mineralogical program was done to provide information on the surface characteristics that may affect reprocessing. This mineralogical work was done on a Laser Ionization Mass Spectrometer on individual grains of sphalerite and pyrite/marcasite.

The metallurgical program started with a broad baseline search/development approach. The testwork composite, a mix of all the drill hole, core sample increments, was subjected to eleven prefloat and flotation activities/conditions at two levels for the recovery of a bulk sulphide rougher concentrate. The flotation test results were analyzed by a fractional statistical model to determine which activities/conditions provide the highest bulk sulphide rougher concentrate grade and recovery. In turn, the most favourable activities/conditions were run at 3 levels; then another statistical analysis of the test results was done to advance the development of the Down Valley tailings reprocessing flowsheet. Several bulk sulphide cleaner flotation tests as well as some comparative flotation tests were run on Lakefield and Normet testwork procedures/conditions.

## 2.0 Laboratory Research Results

### (a) Lakefield Research

The laboratory flotation test results were very encouraging, a marketable grade bulk sulphide concentrate (31 - 37% Zn, 5 - 10% Pb) was produced at respectable metal recoveries of 58 percent.

The two Down Valley Tailings testwork composites (pH <7, pH >7) were subjected to similar laboratory development tests:

(i) Preflotation Conditioning
- standard conditioner (single and multi stage)
- high intensity conditioner (single and multi stage)
- grinding (varying time duration)

(ii) Reagent Balance
- types of pyrite depressants
- sphalerite activation
- galena/sphalerite collectors
- pH modifiers

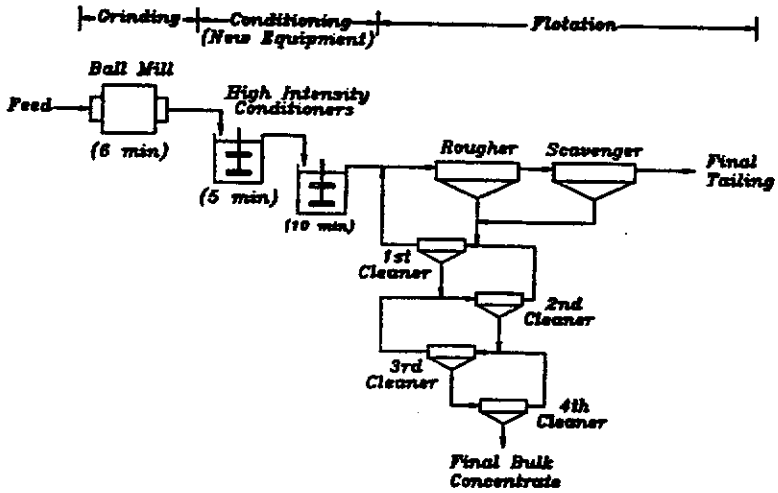
The laboratory program on each testwork composite did develop a reprocessing flowsheet and conventional reagent scheme. The following metallurgical balances were calculated from laboratory batch flotation tests which do not include the metal that would be recovered in the final concentrate by recycling the cleaner tailing, as occurs in the mill operation. Therefore, the mill will have slightly higher metal recoveries.

| Testwork Composite | Product | Assay | | Recovery | |
|---|---|---|---|---|---|
| | | Pb% | Zn% | Pb% | Zn% |
| pH >7 | Final Bulk Conc | 10.2 | 37.4 | 25.4 | 58.2 |
| | Rghr Bulk Conc | 2.88 | 6.1 | 59.4 | 78.6 |
| | Calc. Headgrade | 0.70 | 1.12 | 100.0 | 100.0 |
| pH <7 | Final Bulk Conc | 5.13 | 31.2 | 15.8 | 57.9 |
| | Rghr Bulk Conc | 1.73 | 3.81 | 61.4 | 81.2 |
| | Calc. Headgrade | 0.62 | 1.03 | 100.0 | 100.0 |

A Release Analysis Plot (see figure 3) of the laboratory batch flotation test results (roughing and four stages of cleaning) on Testwork Composites pH < 7 and pH >7, illustrates the family of Bulk Concentrates grades and recoveries. The overlap of metallurgical performances for the composites indicates an upside potential for higher overall recoveries in a mill operation.

The laboratory developed, reagent scheme is very conventional; it uses lime for the pH modifier, copper sulphate for the sphalerite activator, xanthate and M2030 for the galena/sphalerite collectors and MIBC for the frother.

The laboratory developed flowsheet is as follows:



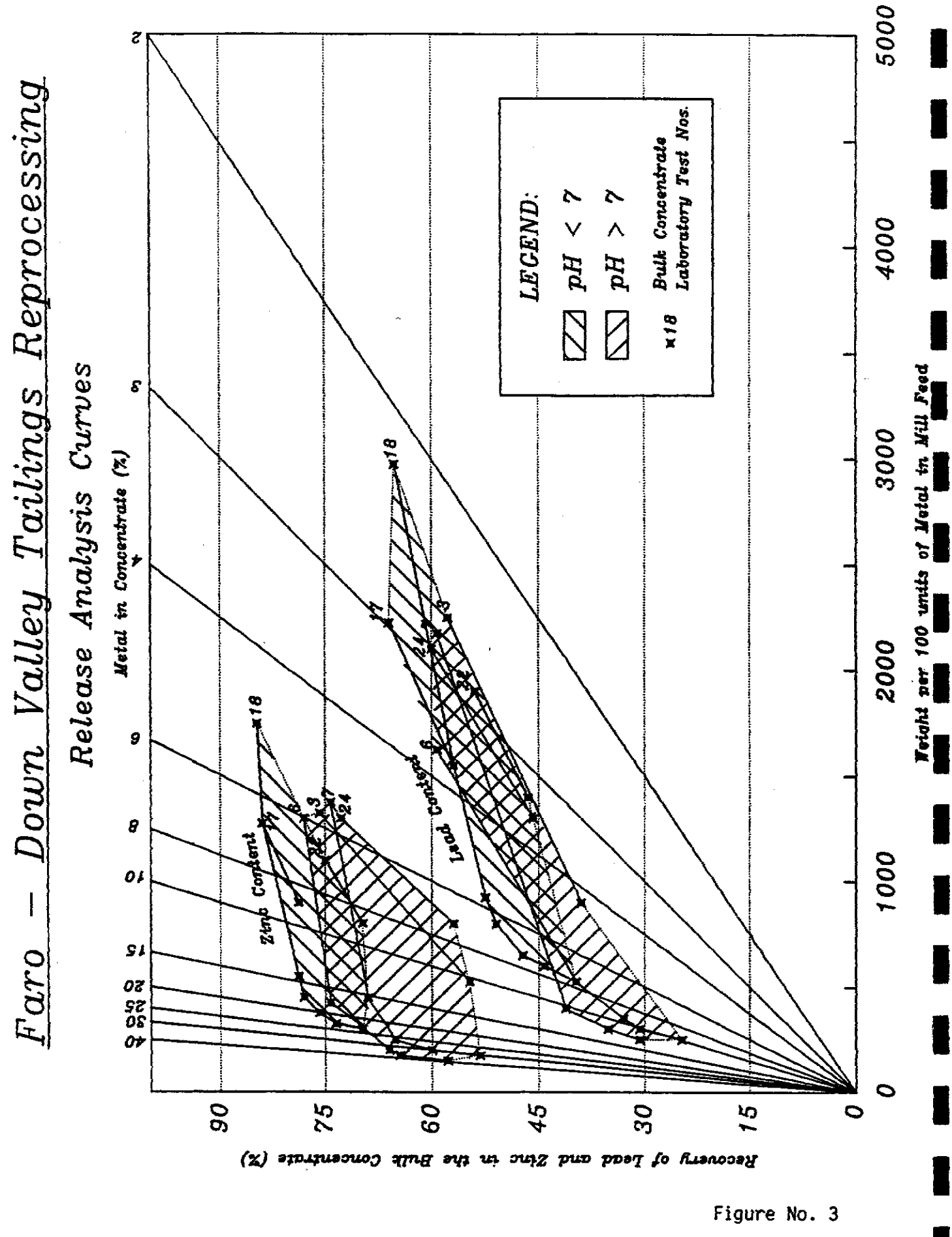

Faro – Down Valley Tailings Reprocessing
Release Analysis Curves
Metal in Concentrate (%)
2
5
6
8
10
15
20
25
30
40
Zinc Content
Lead Content
18
17
24
3
LEGEND:
pH < 7
pH > 7
×18 Bulk Concentrate Laboratory Test Nos.
0
1000
2000
3000
4000
5000
Weight per 100 units of Metal in Mill Feed
90
75
60
45
30
15
Recovery of Lead and Zinc in the Bulk Concentrate (%)

Figure No. 3

(b) **Normet**

The laboratory flotation test results confirm and improve upon the metallurgical response reported on preliminary Down Valley tailings flotation testwork done in 1992 by Denhurst. The Normet testwork was done on a Testwork Composite comprising samples from twelve drill holes that give a good cross-section of the Down Valley tailings area.

Nine of twelve laboratory flotation tests were run on a flowsheet which included bulk sulphide roughing and three stages of cleaning. The laboratory testwork evaluated the following flowsheet configurations:

(i) Prefloat Conditioning - without oxygenation
- with oxygenation*

(ii) No Prefloat Conditioning

* oxygenation (Oxygen gas is bubbled into the slurry during conditioning to ensure replacement of the oxygen that was consumed through chemical reaction with the mineral surfaces and the flotation reagents.)

The metallurgical balances for batch flotation tests on different flowsheet configurations, are as follows:

| Conditioning | Products | Assays | | Recover | |
|---|---|---|---|---|---|
| | | Pb% | Zn% | Pb% | Zn% |
| Pre Float - No Oxygenation | Final Bulk Conc | 2.5 | 35.7 | 4.6 | 37.5 |
| | Rougher Bulk Conc | 3.3 | 17.5 | 22.0 | 66.7 |
| | Calc. Headgrade | 0.63 | 1.09 | 100.0 | 100.0 |
| Pre Float - With Oxygenation | Final Bulk Conc | n.a. | 33.6 | n.a. | 42.2 |
| | Rougher Bulk Conc | n.a. | 12.8 | n.a. | 65.0 |
| | Calc. Headgrade | n.a. | 1.14 | n.a. | 100.0 |
| No Pre Float | Final Bulk Conc | 3.5 | 44.8 | 4.6 | 34.5 |
| | Rougher Bulk Conc | 4.1 | 20.5 | 21.5 | 62.0 |
| | Calc. Headgrade | 0.68 | 1.17 | 100.0 | 100.0 |

The design and operation of the Denhurst/Normet high intensity conditioner is not much different than a conventional conditioner re: comparative metallurgical balance, in the previous table, with and without prefloat conditioning. However, the Lakefield design of high intensity conditioner, which will be installed in the Faro mill as part of the Grum ore, process flowsheet modifications and is currently used in other milling operations, provides very vigorous mixing. This cleans the surface of the mineral particles and forces those particles to collide with reagents thereby improving the overall mineral recoveries into the bulk sulphide concentrate.

(c) **Canmet**

The Canmet research program was very thorough and started with an investigation of the physical nature of the flotation feed:

> What will be reprocessed?
> How is the mineral worth distributed in the feed?
> Are there any physical detriments to flotation recovery (liberation, coatings, etc.)?

These questions are best answered in a detailed mineralogical study of the reprocessing feed (Down Valley tailings). This approach is very common when developing or evaluating process flowsheets.

A mineralogical investigation was initiated to determine mineral occurrence, identification, distribution and the degree of liberation, as well as the occurrence of secondary minerals suggesting mineral remobilization. This work involved an optical microscope, an election microscope, an image analyzer and an X-ray diffraction analyzer and was done on three Testwork Composites (pH < 5, pH 5-7, pH 7). This mineralogical report prepared by Dr. W. Petruk.

The mineralogical report stated that in the < 75 micron size fraction the sphalerite and chalcopyrite are 40% totally liberated and 60% are 75% liberated. In all screens size fractions the galena showed random liberation. In the > 75 micron size fraction considerable locking of sphalerite, galena and chalcopyrite with pyrite and quartz was observed. Some goethite and iron sulphate was associated with pyrite and some was present as free grains. Pyrite, marcasite and pyrrhotite were observed as liberated and locked particles. Regrinding will be an integral part of the final reprocessing flowsheet in order to upgrade the bulk sulphide concentrate.

The second mineralogical investigation was initiated to look at the surface chemistry of <u>selected</u> sphalerite and pyrite/marcasite particles (grains) to obtain a semi-quantitative analysis in any coatings that have developed on the surface of these particles. This mineralogical report prepared by Dr. L.J. Cabri.

This mineralogical investigation was done on a very special analyzer called the Laser Ionization Mass Spectrometer (located in California) which was equipped with a laser microprobe. This analyzer determines the composition of the very surface of the particle and by consecutive shots of the laser microprobe on the same spot, gradually penetrating the surface a few angstroms at a time, thereby peeling away the coating while compiling data on the composition of each successive layer through to the original particle mass. This information will be useful in determining if the coating(s) can be removed and if it will be detrimental to the subsequent reprocessing procedure or if the coating(s) have to be removed at all.

The analysis showed that most sphalerite particles have copper coatings (Cu S) a result of previous processing. Selected, liberated sphalerite particles from Testwork Composites pH<5 and pH5-7 showed erratic occurrences of lead in their coatings while the liberated sphalerite particles from Testwork Composite pH>7 showed a dominance of lead in their coatings. Lead and copper coatings on sphalerite should not be detrimental to subsequent reprocessing. No coatings on pyrite/marcasite were mentioned but should be further investigated in samples of bulk sulphide concentrate.

The broad research approach employed on Canmet has developed a lot of data (factorial metallurgical tests - fractional analysis modelling, etc.) and generally is directing the researcher to the flowsheet developed in the Lakefield testwork. This is a good response as it shows that the work done at Lakefield and Normet (Denhurst), on very specific scopes, was indeed correct. The nature of the metallurgical research work at Canmet has been time and sample consuming but they have diligently and expeditiously carried on the testwork. The laboratory metallurgical testwork was done on a Testwork Composite comprising all the drillhole, core samples.

The following eleven prescreening variables at two levels were run to produce a rougher bulk sulphide concentrate only:

| | Variable | High Level | Low Level |
|---|---|---|---|
| A. | Agitation Intensity | 1800 rpm | 700 rpm |
| B. | Agitation Time | 20 min. | 5 min. |
| C. | Slurry Density | 40% | 35% |
| D. | Aeration Time | 10 min. | 5 min. |
| E. | Alkalinity Agent* | lime | soda ash |
| F. | Lime/Soda Rate | 3000 g/t | 750 g/t |
| G. | Copper Sulphate | 300 g/t | 150 g/t |
| H. | Sulphur Dioxide | 600 g/t | 250 g/t |
| I. | Sodium Cyanide | 100 g/t | 50 g/t |
| K. | Collector Type** | 3418A | 5AX |
| I. | Collector Level | 35 g/t | 20 g/t |

* Lime

** Dithiophosphinate (3418A)

The statistical results from the prescreening testwork, in respect to zinc recovery has reduced the number of significant variables to the following:

- Agitator Intensity
- Agitator Time
- Aeration Time
- Level of Soda Ash or Lime
- Level of Sulphur Dioxide

Subsequently each variable was tested at three levels. The statistical analysis is not complete at this time.

In the meantime testwork has been initiated to investigate the following unit functions at the reprocessing flowsheet development:

- Regrinding (at varying pH's) followed by Low Intensity Conditioning
- Different Sphalerite Collectors
- Varying pH's for the Bulk Rougher float
- Some initial Bulk Rougher Concentrate Cleaning

The initial results are encouraging.

A mineralogical examination of two bulk rougher concentrates (one-high recovery and one-low recovery) and two bulk rougher tailings, showed that sphalerite coarser than 53 microns after 5 minutes agitation, did not float whereas 36% of the sphalerite floated after a 20 minute agitation.

## RECOMMENDED ON-GOING RESEARCH PROGRAM

The objectives of the on-going research program are:

a) develop the reprocessing flowsheet
b) finalize the reagent scheme
c) prepare equipment design criteria.

The laboratory flotation tests will be run on 20 kilogram tailings samples (current test work used 2 kilogram samples). The higher sample weight per test will produce a higher weight of bulk rougher concentrate which is necessary for regrind testwork, bulk concentrate cleaner testwork and to confirm the reagent scheme. Separate laboratory testwork will be required to optimize the high intensity conditioner(s) equipment design criteria. Locked-cycle laboratory testwork will confirm the reprocessing flowsheet metallurgical performance.

rbw:flr