

Royal Canadian Mint

CONTINUOUS IMPROVEMENT PROGRAM REFINERY OPERATION - TECHNICAL REVIEW

REPORT

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Giffels Associates Limited

TABLE OF CONTENTS

DEFINITIONS	A
1. EXECUTIVE SUMMARY	1
1.1 The Undertaking.....	1
1.2 Approach.....	1
1.2.1 Thorough Process Review	1
1.2.2 Independent Testing.....	2
1.2.3 loss estimation	2
1.3 Findings	2
1.3.1 Process Review.....	2
1.3.2 Batch Balance Test	3
1.3.3 Sampling and Assaying	3
1.3.4 Loss Estimates	3
1.4 Conclusion.....	5
2. INTRODUCTION	6
3. PROCESSES.....	7
3.1 Pre-melt and Casting	7
3.1.1 Process description	7
3.1.2 Procedures	10
3.1.3 Potential Losses	10
3.1.4 Observations	11
3.1.5 Recommendations.....	11
3.2 Sampling and Assay	12
3.2.1 Process Description.....	12
3.2.2 Potential Losses	16
3.2.3 Assay Sampling Methods for by-Products	17
3.2.4 Observations	18
3.2.5 Recommendations.....	18
3.3 Chlorination/Anode Casting and Processing	19
3.3.1 Process description	19
3.3.2 Procedures	22
3.3.3 Potential Losses	22
3.3.4 Observations	24
3.3.5 Recommendations.....	26
3.4 Gold Electrowinning & Gemstone Recovery.....	28
3.4.1 Process Description	28
3.4.2 Procedures	31
3.4.3 Potential Losses	31
3.4.4 Observations	33
3.4.5 Recommendations.....	34
3.5 Hydromet Slag Recovery.....	35
3.5.1 Process description	35
3.5.2 Procedures	37
3.5.3 Potential Losses	37

TABLE OF CONTENTS (CONT'D)

3.5.4	Review and Comparison to De-gold Process.....	38
3.5.5	Observations	38
3.5.6	Recommendations	38
3.6	Fine Gold Casting and Processing.....	39
3.6.1	Process description	39
3.6.2	Procedures	41
3.6.3	Potential Losses	41
3.6.4	Kilo Bar Furnace	41
3.6.5	Observations	42
3.6.6	Recommendations	42
3.7	Testing.....	43
3.7.1	Mass Balance Testing.....	43
3.7.2	Third Party Sampling and Assay	50
3.7.3	ACC Site Visit	55
3.8	Process Exhaust	57
3.8.1	System Description	57
3.8.2	Procedure	63
3.8.3	Potential Losses	63
3.8.4	Stack Sampling	63
3.8.5	Dust Collector Efficiency	64
3.8.6	Lower Cottrell Electrostatic Precipitator Efficiency.....	64
3.8.7	Process Exhaust System Observations	64
3.8.8	Gold Recovery from Refinery Exhaust.....	64
3.8.9	Recommendations	65
3.9	Transactions.....	66
3.9.1	Existing Processes	66
3.9.2	Procedures	68
3.9.3	Analysis of Product Giveaway Factors	69
3.9.4	Potential Losses	69
3.10	General.....	71
3.10.1	Review of Deloitte & Touche Report.....	71
3.10.2	general revirw of Health & Safety.....	72
3.10.3	Environmental review	73
3.10.4	Maintenance.....	77
4.	PROCESS FLOW DRAWINGS	79
5.	CALCULATION OF LOSSES AND GAINS	80
5.1	General.....	80
5.2	Loss Factors	82
5.3	Calculation of Losses	87
5.4	Recommendations	90
6.	RECENT IMPROVEMENTS	91
7.	CONCLUSION.....	95
7.1	Thorough Process Review	95

TABLE OF CONTENTS (CONT'D)

7.2	Findings	96
8.	REFERENCES	99

TABLE OF FIGURES

Figure 3.1 - Gold Receiving, Premelt and Casting.....	9
Figure 3.2 – Sampling and Assay	14
Figure 3.3 - Chlorination and Anode Casting.....	21
Figure 3.4 - Electrorefining and Gemstone Recovery.....	30
Figure 3.5 - Hydromet Slag Process.....	36
Figure 3.6 - Fine Gold Casting and Processing	40
Figure 3.7 - Mass Balance Test Process	46
Figure 3.8 – Slag Testing Comparison	54
Figure 3.9 – Exhaust Flow	62

LIST OF TABLES

Table 3.1 – Estimated Sample Error for Standard Sampling Methods	17
Table 3.2 – Summary of Test Results.....	52
Table 3.3 – Summary of Slag Test Results	53
Table 5.1 – Summary of Gold Refining Potential Losses	83
Table 5.2 – Loss Balance Model.....	87
Table 5.3 – Estimate of RCM Refinery Loss Limits	89
Table 5.4 – Estimated Losses to External Refiners.....	90

APPENDICES

Appendix A – Independent Tests
Appendix B – Chlorination Test Results
Appendix C – Slag Test Report
Appendix D – Gold Refining Process Flow Sheet
Appendix E – Certificates of Analysis
Appendix F – Refinery Process Exhaust Flow Sheet
Appendix G – Summary of Gold Refining Potential Losses and Tests

DEFINITIONS

Assay	The process of determining the exact precious metal content for the purpose of valuation of customer <i>Doré</i> and jewellery, <i>by-products</i> and <i>fine gold</i> products.
By-products	Materials resulting from the refining of gold which hold small quantities of gold and other precious metals. These may be processed internally at RCM or by to External Refiners. These include: <i>sweeps</i> , <i>Cottrell</i> dust; <i>Cottrell</i> sludge, chlorination Slag, <i>silver chloride cake</i> , depleted Hydromet liquor, depleted electrolysis liquor, etc.
Button Samples	A button shaped sample taken by a spoon from molten metal for assay.
Cottrell (ESP)	An Electrostatic Precipitator (ESP) used to collect particulate from process exhaust hoods. The most valuable particulates are copper and silver chlorides; and gold vapour from the chlorination process.
De-Gold	A process to reduce the gold content of Chlorination Slag from a range of 3.0% - 4.0% to a lower content using one of two methods: Mechanical Milling - Slag which is mechanically milled is manually <i>de-golded</i> . This reduces gold content to between 1.5% to 2.0%. Hydromet – Slag, which is granulated, is in effect de-golded by re-melting and letting the gold sink to the bottom of the melt. The Slag is then poured off the top and the gold button, remaining at the bottom, is returned to Chlorination. This would reduce the gold content to 0.1% to 0.2%. The molten slag is then poured into a salt tank to produce slurry for the start of the <i>Hydromet</i> process. <i>By-products</i> resulting from the <i>Hydromet</i> would have minor quantities of gold retained.
Doré	Gold ingots from the mines. It is typically alloyed with copper and silver and contains 50% to 80% gold.
Electrorefining (Electrolysis)	The process of increasing the purity of gold or silver by means of an electrochemical cell. The cell uses a less pure metal anode to create a more pure metal cathode. The process takes place in an acid bath (electrolyte).
Fine Gold	Metallic gold of 99.99% (4.9s) or 99.999 (5.9s) purity.
Gain	The RCM achieves a <i>gain</i> in their gold <i>pool</i> account as a result of settlement negotiations completed on every incoming <i>Doré</i> or jewellery lot that it receives. This “gain” occurs by RCM retaining a percentage of the precious metal as a refining fee. A <i>gain</i> also occurs when RCM truncates their measured assay values providing a small, but calculable <i>gain</i> on every transaction.
Giveaway	The RCM purposely specifies a slightly higher assay and weight for commercial gold products so that the buyer is assured of getting the amount and purity requested. This “over-specification” is considered to be part of the cost of being in the gold refining business and is an <i>unrecoverable loss</i> .

HSSE High Speed Silver Electrolysis is a proprietary process to continuously producing 99.9% purity silver in series of electrolytic cells. Feedstock is silver grains containing less than 10% copper. The silver electrolyte is continuously regenerated in an associated treatment train.

Loss **Apparent** - When RCM undertakes a transaction for these dilute forms of *by-products* and negotiation occurs, then the difference between the settlement amount and the *apparent loss* becomes an *unrecoverable loss*. There is an inherent risk in sending *by-products* for outside processing given the value of the precious metals. Unless the risks are mitigated the loss may shift from *apparent loss* to *unrecoverable loss*.

By-products which have not been processed at the time of inventory reconciliation are valued for the purpose of the inventory at an assumed assay value.

Unrecoverable - The RCM achieves an *unrecoverable loss* in their gold *pool* account at the completion of the biannual or quarterly accounting reconciliation when certain amounts of gold could not be accounted for. On the other hand, when gold is tied up in a dilute form in *by-products*, it remains as an *apparent loss* until a transaction and/or negotiation occur. In other words, as an *apparent loss*, the gold is not physically lost, but is measurable given the right sampling and *assaying* method, and it can be recovered through proper processing. When RCM completes internal processing of the *by-products*, further gold recovery is achieved and *apparent loss* is reduced. For example, the internal processing of *by-products* such as Chlorination Slag will recover the bulk of the entrained gold and silver thus reducing the *apparent loss*. The remainder of the gold contained in dilute form in the Slag *by-products* is sent to External Refiners.

When *by-products* are sent to External Refiners the gold and other precious metals are recovered and the total amount of metal recovered is subject to the external refiner percentage retention. The external refiner keeps the retention and it becomes an *unrecoverable loss* to RCM. The by-product retention is negotiated with each refiner and the historical average for the past three year period is 2.58%

Gold can become embedded into the fabric of the refinery building or process equipment and is only recoverable after demolition. This is considered to be an *unrecoverable loss*. The gold will be recovered eventually as a windfall in the year of the demolition. Unrecoverable losses will always occur in a refinery operation.

Gold which escapes from the exhaust stack to atmosphere or discharged to the municipal sewer system is an *unrecoverable loss*.

Pin Sample	A sample taken by means of an evacuated glass tube which is submerged into the molten metal. When the tube is submerged, the end of the glass tube melts and the melted metal is sucked into the tube.
Pintube	A vacuum sealed glass tube used to produce the pin sample.
Pool	Gold and silver enter the RCM in batches tagged to individual customers. Once settlement has been reached with the customer the gold and silver enter the <i>pool</i> . Precious metals in the <i>pool</i> cannot be uniquely identified in the process of refining until it becomes fine metal cast into an ingot, at which time it has left the <i>pool</i> .
PPTT	Parts per ten thousand
PPM	Parts per million
Residues	Catch-all term for dry <i>by-products</i> which contain small percentage of precious metals. These <i>by-products</i> are collected, sampled, <i>assayed</i> and sent out to External Refiners for precious metal recovery.
Salt Slag	The rock like by-product resulting from the chlorination or <i>TBRC</i> process. The Slag contains metallic chlorides (silver & copper) and would also contain between 3.0% to 4.0% gold.
Silver Chloride Cake	Remaining material after <i>de-golding</i> chlorination.
Spent Electrolyte Liquor	The electrolyte from the <i>electrorefining</i> operation eventually becomes poisoned with copper and becomes unusable. The electrolyte (liquor) is treated with iron-salt to eliminate the dissolved gold. The retained platinum group metals are recovered by an outside refiner.
Sweeps	Residues which are swept off the floor. This includes precious metals which fall to the floor during processing. Typically, the <i>sweeps</i> are burned in the incinerator to recover the gold content which is sent to chlorination.
TBRC	Top Blown Rotary Converter is a melting process to reduce the copper content of the silver from 25% to 10% or lower as suitable for feedstock for the <i>HSSE</i> . Silver is melted in the <i>TBRC</i> crucible and then on oxygen lance is inserted into the melt to oxidize the excess copper.
Umpiring Protocol	A previously agreed to qualified third party to provide unbiased test results for commercial settlement.

1. EXECUTIVE SUMMARY

1.1 The Undertaking

Giffels Associates Limited/IBI Group (GAL/IBI Group) was retained to conduct a technical review of the refinery operations at the Royal Canadian Mint in Ottawa with the primary objective of determining whether losses due to technical processes could have contributed to the un-reconciled differences of the precious metals as at October, 2008. More specifically, GAL/IBI Group's scope of work involved the following:

- a) Undertaking a thorough process review of the refinery operations including observing key processes at different times for a long duration
- b) Identifying potential sources of losses in the refinery operations
- c) Conducting independent testing to determine the extent of losses
- d) Providing a comparative analysis of the independent testing, previous test results, and testing done by RCM
- e) Providing benchmark assessment of RCM losses comparison to industry standards
- f) Estimating loss quantities of key processes
- g) Providing a technical opinion on the un-reconciled difference of precious metal

1.2 Approach

1.2.1 THOROUGH PROCESS REVIEW

GAL/IBI Group assigned a team of senior professionals, experienced in every aspect of precious metals refining, to undertake each of the technical review elements. The team included an expert metallurgist firm, J. Fairley Associates, and a world renowned sampling and testing firm, SGS Mineral Services. The team conducted a thorough review of all the refinery processes, interviewed technical and operation staff, developed processes detailed flow diagrams, reviewed available procedures, and reviewed previous reports and studies prepared since 1996.

It is important to note that, the RCM precious metal refining process has the same characteristics as any other refinery process; losses are inevitable and unavoidable. Process losses are considered to be either "apparent" or "unrecoverable" but are only quantifiable to a certain extent. Typical to all refineries, losses cannot be defined when they occur at a rate below the lower accuracy limit of the weighing and *assaying* equipment used. For significant loss candidate materials, an upper limit can be derived by assuming worst case scenarios.

Key processes and areas of potential losses within each process were identified. These areas were assessed for "importance" and "risk" of generating *unrecoverable losses*. Out of all the processes reviewed, a number of areas associated with chlorination, *Hydromet* and Chlorination Slag were identified as having a higher potential for generating *unrecoverable Losses*. These specific areas are the focus of this technical review.

1.2.2 INDEPENDENT TESTING

Considering the complexity and the number of variables involved with each key process, it was necessary to develop specific tests complete with detailed procedures in order to verify some data and validate the efficiency of the processes and accuracy of techniques used. These tests were either done by reputable and independent third party or were independently witnessed and recorded by GAL/IBI Group staff.

Batch Balance Test

A Batch Balance Test was conducted by tracking three separate material batches as they went through the critical Chlorination and *Hydromet* equipment. This test was conducted to confirm that the amount of precious metals entering these two key consecutive processes is being completely recovered at the discharge points. As part of the mass balance test, the chlorinated Slag from the three (3) material batches was melted and six (6) dip samples were drawn and analyzed.

Sampling and Assaying

As part of testing, the commissioned third party testing firm supervised the drawing of samples and carried out independent *assaying*. All testing was independently witnessed and documented by GAL/IBI Group staff. The assay results produced by SGS and RCM were then compared to verify the accuracy of the sampling and assay techniques used by RCM. Our expert metallurgist examined RCM metallurgical processes and methodologies and to provide a benchmark assessment of same. An independent expert was also dispatched to the third party refiner, used by RCM, to observe the sampling and *assaying* techniques of chlorinated Slag at their facility.

Another key independent test was conducted on five drums of Slag material that were prepared to simulate, as much as possible, the Slag material previously shipped to External Refiners. The five drums were then shipped to the independent testing agency for thorough mixing and proper splitting. Two and half drums remained at SGS for sampling and testing and the other two and half were shipped to a third party refiner. SGS produced 8 samples from the drums for assaying by various parties and for comparison purposes. The preparation of the drums, the mixing and the splitting processes were witnessed and documented by GAL/IBI Group from the start to the end.

1.2.3 LOSS ESTIMATION

Considering that the losses within each process are apparent (material is in transitional state within the plant), a macro approach was adopted to calculate the *unrecoverable losses* through the refinery operation. This method considers the refinery operation as a whole and includes *unrecoverable losses* due to stacks, giveaway, building fabric, retention, outside refining, and *by-products*. The losses were calculated based on lower and upper limits.

1.3 Findings

1.3.1 PROCESS REVIEW

We have carried out a technical review of all processes of the refinery operations and, in general, found them to be at par with industry standards. Specifically, *assaying* and the technical expertise at the RCM exceed those standards. The level of expertise of the RCM staff was demonstrated in the level of detail they provided and the in-depth knowledge of each process.

On the other hand, improvements can be made to plant layout and sampling. Other observations are detailed in the report.

1.3.2 BATCH BALANCE TEST

Batch balance testing showed that gold metal mass was conserved through the chlorination and *Hydromet* processes. For each of the three (3) batches that were tested, the amount of gold discharged from the equipment was within 1% of the amount of gold that was fed into the equipment, and that is within industry standards.

1.3.3 SAMPLING AND ASSAYING

There are minor differences between the results of the independent testing and the testing done by RCM and witnessed by GAL/IBI Group, of the *Doré* and jewellery gold pintube samples. These results show high correlation and indicate that the RCM sample and assay method used for these materials is repeatable, verifiable and reliable.

Testing of the *by-products* sent out for precious metal recovery included *by-products* that are difficult to sample and assay and/or products containing gold. Findings related to precious metal content in Slag are typically variable due to the non-homogeneous nature of the material and the manual nature of the chlorination and Slag process.

Based on the sampling approach and the samples prepared by SGS, the tests for the gold content in the slag showed consistent results between SGS and RCM. Also, based on the sampling approach and the samples prepared by an External Refiner (ACC), the tests for the gold content in the slag showed consistent results between ACC and RCM. In addition, based on the two different sampling techniques used by SGS and ACC, for the same slag batch, the gold content in the Slag showed consistent results for SGS, ACC and RCM.

The accuracy of the test results of the remaining by-products is within $\pm 5\%$ (worst case scenario) of the SGS test results. Although, this range is less accurate than the accepted industry standard ($\pm 0.2\%$), in our estimate, this would represent approximately 970 oz of unrecoverable losses.

1.3.4 LOSS ESTIMATES

We have calculated the annual lower limits of *unrecoverable losses* for 2008 using historically established data as well as calculated factors. The upper limits were based on "maximum justifiable loss". These losses are summarized in Tables 5.3 & 5.4 and are calculated based on the following criteria:

- a) Annual for 2008, gold production of 2,952,000 oz.
- b) Stack Losses
 - Using latest RWDI latest stack test report (2008) for the lower limit and 10% increase factor for the upper limit.
 - Stock losses are affected mostly by the operating condition of the Cottrell, Scrubber and the Baghouse. It is assumed that these are in proper working order.
 - It should be noted that there has been a substantial increase in the gold recovery in the exhaust system since 2006, due to the upgrades to the system.

- c) Giveaway Assay
- Using a factor of 0.4 oz/10,000 of production for the lower limit and a factor of 0.8 oz/10,000 of production for the upper limit, based on an ongoing assay bias in favour of the customer.
 - Assay losses are based on accurate pintube assays. Biases in the assay are controlled by the umpiring protocol.
- d) Giveaway Weight
- Using a factor of 0.5 oz/10,000 of production for the lower limit and a 10% increase factor for the upper limit.
 - Weight losses are influenced by the RCM product mix and the accuracy of RCM weight scales. There are varying weight loss factors for various RCM products. The loss factor used is a composite.
- e) Giveaway in Silver Bars
- The lower limit was based on 9 PPM and the upper limit was based on 100 PPM retention of gold in silver bars for an annual silver production of 799,000 oz.
 - The gold content in the silver is influenced by the amount of gold in the HSSE circuit.
- f) Physical Loss in Plant
- The lower limit was based on the available windfall data of gold recovered from building and equipment demolition. A 100% increase factor was applied for the upper limit.
 - The physical losses are gold trapped in the fabric of building and equipment. It can be recovered through an aggressive dismantling and cleaning of the building and equipment.
- g) By-product Processing (Slag) – the lower limit is included in “Retentions”. The upper limit is based on an additional 10% of the gold content recovered by the RCM from Slag. The gold content recovered was 1.86%, the addition of the 10% (0.186%) is to account for the difficulty in sampling and *assaying* the chlorination Slag. For 2008, this would represent 2976 oz.
- h) By-Product Processing (others) - Based on total recovered gold; annual by-products of 49,463 oz out of which 30,000 oz could be attributed to Slag; and the $\pm 5\%$ in variation of testing accuracy between SGS and RCM results, our estimate of maximum total gold losses associated with all by-product, “other” than Slag is 972 oz.
- i) Retentions
- Were calculated for the year for all by-products.
 - The External Refiner retentions are fixed by contract. Therefore, the greatest influence on retentions is the quantity of gold in *by-products* sent to the External Refiner.

Based on the above, the lower limit of total losses is estimated to be 760 oz per year. Similarly, the upper limit of losses is estimated to be 5,500 oz per year.

The following is a tabulated summary of same:

Table 5-3 – Estimate of RCM Refinery Losses

	Estimated Loss Limits (2008)			
	Lower		Upper	
	Oz	PPTT	Oz	PPTT
Stack	89	0.30	98	0.33
Giveaway Assay	118	0.40	236	0.80
Giveaway Weight	147	0.50	162	0.55
Giveaway in Silver Bars	7	0.02	80	0.27
Physical Loss in Plant	104	0.35	664	2.25
Total	465	1.57	1,240	4.20

Table 5-4 – Estimated Losses of External Refiners

	Estimated Loss Limits (2008)			
	Lower		Upper	
	Oz	PPTT	Oz	PPTT
Retentions (excluding Slag)	297	1.0	326	1.10
By-product Processing (Slag)	0*	0	2976	10.08
By-product Processing (others)	0	0	972	3.29
Total	297	1.0	4,274	14.47

* The gold content in Slag is highly variable due to the manual nature of the Chlorination and Slagging process. As a result of the percent factor assumed, this variation can affect the lower limit to swing between a loss and a gain. Also, often actual gold recovered by third party refiners exceed accrued value. For the purposes of this table, it is assumed that there are neither losses nor gains for the lower limit.

1.4 Conclusion

Based on our review and analysis of the refinery operations, available data and previous studies as well as the independent testing done on key processes, we conclude that the total annual refinery losses at RCM could be within 465 oz (1.6 PPTT) to 1240 oz (4.2 PPTT) per year. RCM reported 886 oz. (3.0 PPTT) for the refinery losses in 2008. The reported losses are comparable to the above estimated range.

The total losses associated with External Refiners could be in the range of 300 oz (1.0 PPTT) to 4,300 oz (14.5 PPTT) per year. RCM reported 150 oz (0.5 PPTT) for the External Refiners Losses in 2008. The total losses associated with the by-product processing, including Slag and all other materials, could be within 0.01% to 0.13% of total gold production.

Given the improvements in the past few years such as those to the exhaust system (Cottrell replacement, new Scrubber, etc..) and the introduction of the Hydromet process, in our opinion these improvements will enhance the refinery efficiency and, as such, the amount of process losses in the future should be lower than those indicated.

As such, in our opinion, refinery process may have contributed to some additional un-reconciled gold losses. However, it is highly unlikely that the gold losses were primarily due to the refinery processes.

2. INTRODUCTION

As part of its continuous improvement program, the Royal Canadian Mint (RCM) is undergoing a major initiative to improve the efficiency and performance of their operations at the Ottawa facility. The initiative includes many aspects of the operation, in particular, reconciliation accuracy, incorrect transactions, physical loss, and system error or fraud. Two significant portions of the physical loss aspect may be related to Process Loss and Assay Sampling. GAL/IBI Group was commissioned to conduct a technical review of the refinery operations including the various facility and operation upgrades that have been undertaken since 2005. The scope of this study involves the following operations:

- a) Reviewing existing operations; technical studies; engineering reports; drawings and specification with the primary objective of enhancing overall efficiency.
- b) Reviewing the following key processes: assay; pre-melt receiving; chlorination; electrolysis; *Hydromet*; electrostatic precipitator and scrubber; silver refinery including process loss estimates; product quality giveaways, stack and effluent loss estimates and others.
- c) Visiting the Royal Canadian Mint Ottawa facility to observe current operations and assess the level of adherence to existing processes, procedures and industry standards.
- d) Reviewing and tabulating the findings of reports prepared by various consultants since 1996.

The work involved extensive coordination between GAL/IBI Group team, independent testing service providers, and precious metals metallurgical specialists. The RCM staff assisted in obtaining the available documents, responding to technical questions raised by various parties. The primary objectives of this study include, but are not limited, to the following:

- e) Identification of sources of the potential losses across each process (i.e. chlorination, assay, electrolysis, etc).
- f) Estimation of maximum potential losses and their degree of significance, for each process.
- g) Validation, through testing, of the loss factors associated with each process.
- h) Modeling of the entire operation to forecast losses based on the validated testing.
- i) Developing a "gaps analysis" based on existing procedures/documentation and present operations, with a focus on loss control and operational integrity.
- j) Benchmarking the loss factors to best industry practices.
- k) Making recommendations on remediation to minimize the losses to be within best industry practices.
- l) Making recommendations on safeguarding against unexpected losses due to equipment and/or operational failure.
- m) Making recommendations on testing intervals and on preventative maintenance of key equipment and processes.
- n) Developing an implementation plan for the recommendations including order of magnitude cost estimates of the recommendations.

3. PROCESSES

In this section, we provide a description of each process complete with a simplified process flow diagram for each; the procedures associated with each process potential losses and source(s) of same; and recommendations on reducing such losses and enhancing efficiency.

3.1 Pre-melt and Casting

The premelt and casting are the first steps of the refining process during which an assesses the value of the incoming precious metals, for the purpose of completing the settlement with the customer and advancing gold and silver into the refinery, occurs. See Diagram 3.1 - Gold Receiving, Premelt and Casting.

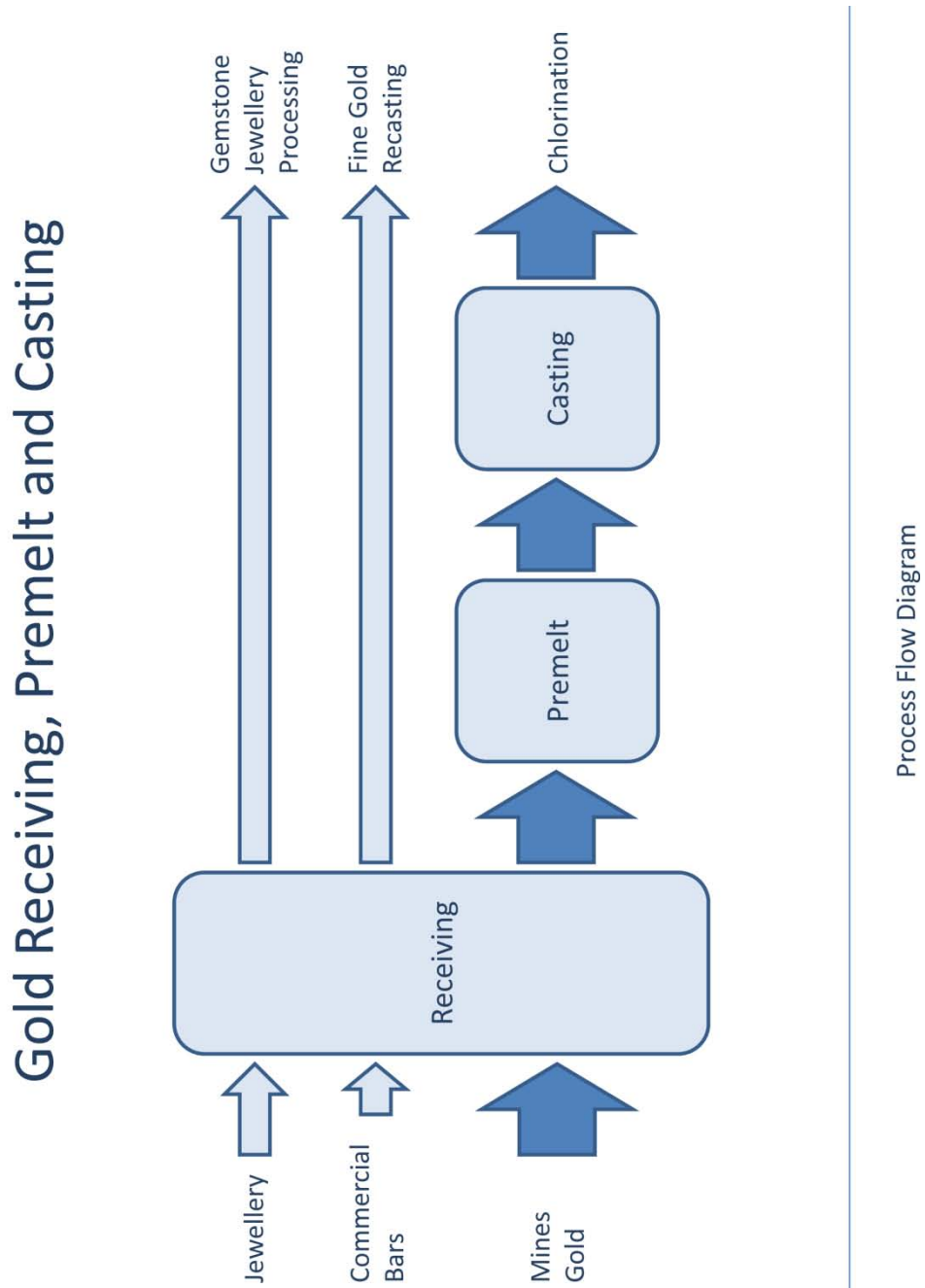
3.1.1 PROCESS DESCRIPTION

- a) Rough gold bars (*Doré* bars) arrive at the Pre-Melt furnace in lots by Customer with 2 or 3 lots on a pallet. Jewellery arrives at the Pre-Melt Induction Furnace in metal pans in lots by Customer.
- b) Each lot (jewellery or *Doré*) is accompanied by a Rough Deposit Log sheet. The maximum weight of a lot is 1200 Troy Ounces.
- c) The refiner selects the Customers crucible from the crucible shelf and places it in the furnace.
- d) The refiner writes the Deposit Number on a wooden marker which is placed on the furnace to keep track of the lot in the furnace. This wooden marker follows the lot through the entire Premelt process.
- e) The lot is placed in the crucible and heated in the induction furnace until it melts into a homogeneous mixture. Borax is added to encourage the material to fluidize and to become more homogeneous. An overhead hood directs fumes to the exhaust collection system.
- f) The refiner draws samples from the melted lot by either the dip method or pin method. The refiner follows instructions on the Rough Deposit Log sheet pertaining to the number of samples and the method of sampling. The refiner records the weight of the samples.
- g) Typically, one pin tube sample is sent to the RCM Assay lab; one is returned to the Customer for their analysis; and one is placed in the RCM vault in the event an umpire is required for the negotiated settlement.
- h) The melted lot is cast by pouring it into Premelt bar moulds. Two bar moulds are required for each 1200 Troy Ounce lot.
- i) During casting, the borax and any Slag floats to the top. The bar moulds are tipped on their sides and the borax and Slag is stripped off and disposed in the *sweeps* by-product or returned to the customer.
- j) The bars are dumped out of the moulds and briefly quenched in a vat of water.
- k) The refiner lightly polishes the bars with a power buffer tool and writes the lot number on each bar with a felt marker using the wooden marker for reference.

- l) The Premelt bars for the shift are assembled on a cart along with the Rough Deposit Log Sheets and are transported to the Receiving Department where they are weighed and stamped with the Deposit Number and Lot Number.
- m) Premelt bars are placed in the vault until they are selected to become part of a batch to go into the chlorination process.

The following is a simplified flow diagram of the above mentioned process.

Figure 3.1 - Gold Receiving, Premelt and Casting



3.1.2 PROCEDURES

Pre-melt procedures are documented, in the Royal Canadian Mint's RWI-P-01 procedure (September 2008). This is essential to ensure errors do not occur and that the integrity of individual customer batches is preserved. Tracking of individual customer batches is highlighted as a key procedure.

Pre-melting is carried out in one of two small high frequency lift-off induction furnaces. The carbon bonded silicon carbide crucible has a nominal capacity of 1200 oz Au. If desirable, a little borax flux is added during melting. No temperature measurements appear to be carried out; instead, the color of the molten metal is carefully observed. Melting is rapid due to the efficiency of the furnace and mixing is provided by the AC current. The resulting fume, particularly from jewellery scrap is controlled well.

The furnace body is lifted mechanically and the crucible is lifted manually, with some mechanical help, the molten is poured into 600 oz moulds. Lampblack is used to dress the mould. Some splashing occurs during the pouring process.

Reference is made in the RCM procedure document, to inputs materials that segregate and procedures to minimise the effect described.

Sampling is carried out using reliable and well established vacuum tubes; a dip or button sample is also taken. The samples are cleaned on a grinding wheel to remove glass and other contamination. The procedures are documented.

3.1.3 POTENTIAL LOSSES

The potential for significant gold loss in a well run pre-melt furnace is viewed as low. However, with the pre-melt furnace being located in the same process area as the chlorination furnace, there is the potential for a mix-up in material. The potential losses can be identified as follows:

Melting Losses to Crucible

A small amount of bullion remains in the crucible after pouring. Given that the operating temperature is adequate and the melt is sufficiently fluid, losses from this source are minimised. Some material may also penetrate the crucible refractory.

Volatilisation Losses

Significant gold loss is unlikely at standard operating temperatures of the pre-melt. Larger, but still probably small, losses of Ag may occur. The use of a borax flux at these temperatures may increase silver losses to the Slag.

In the case of carat gold scrap some weight loss will occur due to zinc fuming but this will not impact on gold or silver losses.

Equipment used for capturing gold and silver in the fume are appropriate. They may be positioned too far from the furnace and, as a result, some condensation or precipitation of containing precious metal particles will accumulate in the ductwork.

Pouring Losses

Some loss of material is unavoidable during this process. As mentioned above, there is no provision to effectively capture spillage, that is swept up by the operator. Material collected is returned to the chlorination process sweeps.

Integrity of Customer Batch at Premelt

With the pre-melt furnace being located in the same process area as the chlorination furnaces, there is the potential, however unlikely, for a mix-up of incoming Doré bars and outgoing gold bars.

3.1.4 OBSERVATIONS

- a) Efficient and accurate evaluation of customer materials is the number one priority in this business. The set up at the RCM of this part of the operation can be considerably improved. A dedicated, separate area for customer and internal evaluation melting will dramatically enhance the accuracy and reliability of this process.
- b) The pre-melt and sampling area is located adjacent to the silver granulation furnace and opposite the *TBRC* and chlorination furnace. This would allow for potential cross-contamination and errors due to treatment of the material in the wrong furnace. Although, the crucibles for silver and premelt are different, and there is no evidence that cross contamination has occurred, the potential of this to happen should be eliminated. It is usual practice to restrict access to the pre-melt and evaluation area to all but those who need to be working in there. The opportunity for staff to deliberately or accidentally produce biased samples needs to be minimised.
- c) Work-in-progress appears to be stored on an ad-hoc basis and does not appear to have a clearly defined and checkable location. This issue has been raised in previous reviews (Mooiman 2008) and needs to be addressed.
- d) The pre-melting furnaces are small, as they are not large enough to handle some of the customer lots in a single operation resulting in the need to have sequential melts are necessary. A larger furnace would be more efficient as to production, sampling, handling. However, this would require more capital and space.

3.1.5 RECOMMENDATIONS

- a) A separate room needs to be found for the pre-melt area or at the very least a physical barrier needs to be installed such that the pre-melt area is isolated from the general work area. Only those who need access should be permitted in the area. Dedicated storage for work-in-progress and re-melted and evaluated bars is essential.

The ability to carry out these tasks successfully will depend on improved management of the available space. The reduction of the amount of backlog and internal recycling would help facilitate this.

- b) The material control systems should ensure that the operator has the correct batch; he should be part of the process but not key. Improved material control systems will minimise the potential for error.

3.2 Sampling and Assay

Sampling and assay go hand in hand in evaluating materials in the RCM refinery. The assay lab at RCM has a world class reputation, but without an equally strong representative sampling program, the assay lab results would be compromised. Representative sampling is one of the most important issues for a precious metal refinery. Refer to Figure 3.2 – Sampling and Assay flow diagram at the end of this section.

Data from the sampling and assay are used to complete negotiations with customers and External Refiners to calculate losses and gains to the RCM precious metal pool.

3.2.1 PROCESS DESCRIPTION

Sampling covers two main areas of practice; molten metals and *by-products* comprising sludges, *salt Slag*, liquids (spent electrolyte, depleted *Hydromet* liquor, jewellery waste), filter cake (cu-Fe carbonate, Ag chloride), *Sweeps* (*Cottrell* dust, crushed crucibles) . Refer to Fig. 3.2 for a simplified flow diagram of the Sampling and Assay process.

Sampling of Doré

Some of the key applications are considered below with some general comments.

The sampling of high value inputs and payable outputs is carried out for the following reasons:

1. To identify the composition of the *Doré* – this is carried out on new inputs to ensure that the feed is suitable for treatment. Drilled samples are used.
2. To determine the payable metal content – representative sampling and accuracy are essential and vacuum tube samples of molten gold are used.
3. To ensure that the product, e.g. 99.99% Au conforms to requirements. Representative sampling and accuracy are essential and vacuum tube samples of molten gold are used.

With regard to item 1 above, the drill samples are required only to determine the integrity of the *Doré* and to ensure that it will not cause problems during processing, e.g. arsene gas due to the presence of arsenic. The aim is to produce as close to 100% assay content as possible to ensure fitness-for-purpose.

The Pin Sample procedure used in items 2 & 3 consists of inserting an evacuated glass tube about 10 cm long and 5 to 10 mm diameter deep into the molten bullion. Set procedures are used. On entering the melt the tube fractures at the base and a liquid sample is drawn up the tube. It is withdrawn and the solidified bullion sample removed and any glass contaminant removed using a wire brush or grinding wheel. For the purposes of settlement, the Pin Sample is the best method to get an accurate sample of the molten metal.

Prior to analysis it is necessary to produce a representative sample of the pin sample from the melt. This is achieved by flattening the sample and cutting it into nine separate samples. This constitutes approximately half the original sample weight.

Sampling of Sweeps

This is more complex particularly where the material consists of coarse and fine particles and a mix of high value and low value materials, e.g. a small amount of gold in ground *sweeps* which has a wide particle size range.

In general terms a series of mixing operations is carried out in an attempt to homogenise the *sweeps* before milling and sampling.

From the information available - Procedure for *Sweeps* and *Cottrell* Mixing, Sampling and Barrelling, dated June 2004, it appears that the feed materials consist of:

1. *Sweeps* -50 mesh
2. *Sweeps* -20 and +50 mesh
3. *Cottrell* dust

A tumbling drum mixer is used to mix the materials and the sampling procedure involves scoop sampling of the discharge at the start, middle and end of drum filling.

From the information available - Procedure for Sample Preparation of *Sweeps*, dated May 2008, mechanical sub-sampling of the drum sample is carried out using a twelve portion spinning riffle. A slow feed rate is employed and this operation takes fifteen minutes.

Two samples are retained as a reference (MAIN) and a further two are sieved and comminuted until they pass 80mesh. A ring mill is used for final pulverisation.

The samples selected are milled to 80 mesh and re-sampled using a Retch eight portion mechanical sampler which divides the fed which is fed continuously via a vibratory feeder into eight representative samples. Three are submitted for analysis, one kept for reserve.

The procedures laid down for these stages are clear and comprehensive. (Refer to Figure 3.2 – Sampling and Assay flow diagram at the end of this section).

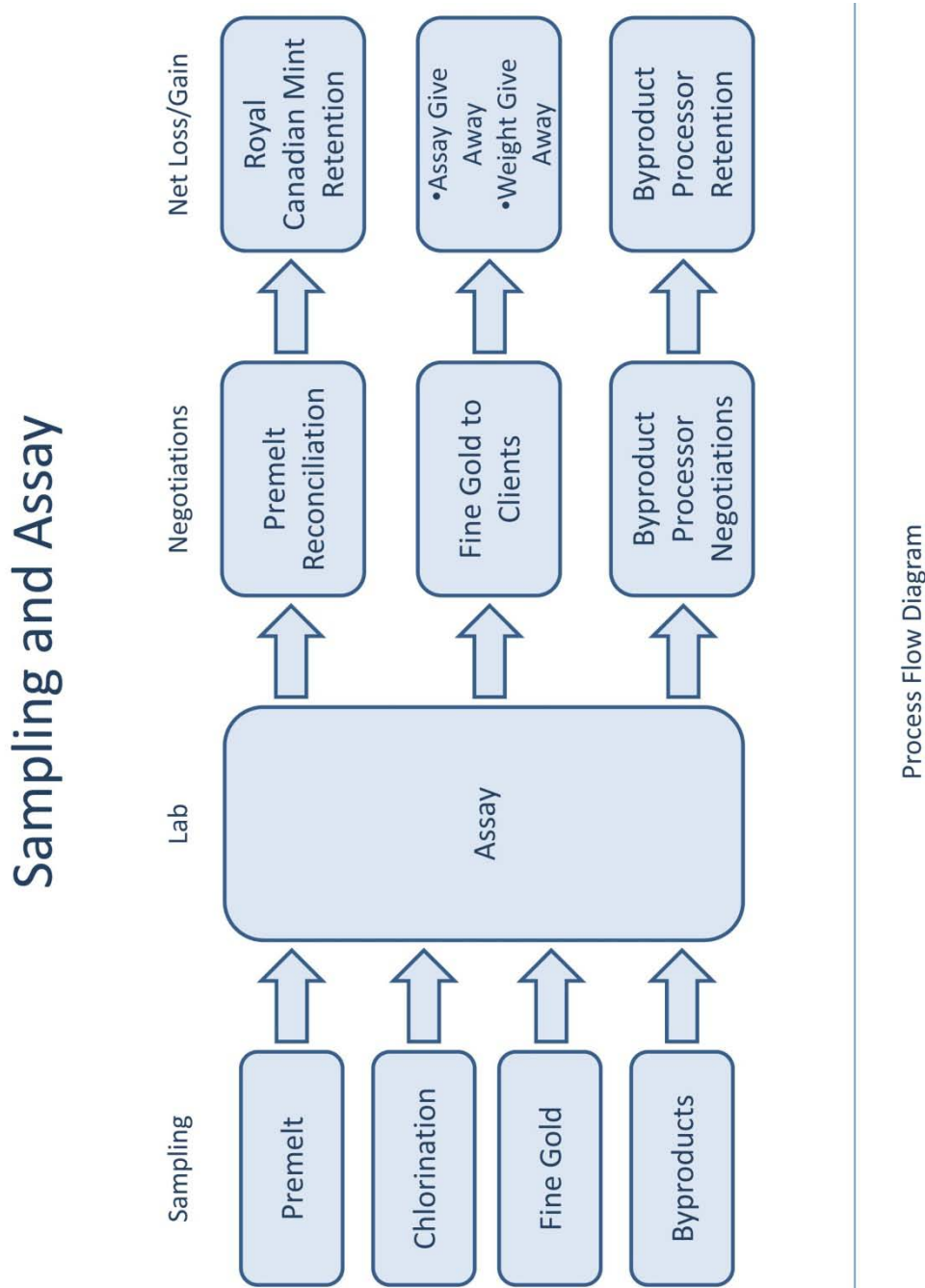
Sampling of Liquids

Spent electrolyte, depleted *Hydromet* liquor, and jewellery waste are drummed and a sample is taken for analysis of precious metals.

Sampling of Salt Slag and Sludge

Salt Slag which is processed by External Refiners is crushed only (not milled) and drummed and sample taken from top, middle and bottom sections of the drums. Samples are held but no assay is done. Sludge is drummed and samples are taken but no assay is done. Historical data is used to estimate the quantity of precious metal content.

Figure 3.2 – Sampling and Assay



Analysis & Assay

The assay techniques for the analysis of *Doré* and *fine gold* at the Royal Canadian Mint were reviewed.

The most important analytical techniques used are:

X-Ray Fluorescence (XRF)

A non-destructive examination tool that permits the characterisation of a wide range of elements through the identification of their elemental X-Ray signature. The button sample is ground to give a clean flat surface which is analysed. The process is rapid and reliable, as long as the matrix is consistent between samples and appropriate standards are used. It is not suitable for the lighter or low atomic number elements but will analyse for the range of elements which could have technical, environmental or economic implications as a result of refining.

It is not as accurate as the cupellation procedure used in the analytical laboratory for final analysis. However results are rarely more than 1% different and with some customers/materials it is practice to pay the customer on this result (at 98% of the payable content) and adjust when the fire assay result is available.

Fire Assay or Cupellation

When carried out correctly this is still recognised as the preferred method of analysing for precious metal values. But in general the process involves a small sample of the gold (typically 1g) is placed with a quantity of lead in a small cupel made of bone ash, which is heated in a muffle furnace with a draught of air flowing over the cupel. As a result the lead and any base metals are oxidised and absorbed into the cupel, while the gold and any silver remain as a small button. The silver is then dissolved out with nitric acid, leaving a pure gold 'cornet', which can be weighed and the gold content calculated by comparing with the original weight of the sample. Reference materials and statistical techniques are used to ensure precision and accuracy.

Six duplicate analyses are made for gold and three for silver. Statistical techniques are used to ensure that there is no bias in the results

The analysis of *fine gold* is carried using Induction Couple Plasma Analysis (ICP). It is a reliable and accurate technique used in the industry.

3.2.2 POTENTIAL LOSSES

The proper preparation of samples of *sweeps* Slags and residues is essential to obtain accurate assay results. An accurate assay is required for equitable settlements negotiation with by-product processes. Discussions with RCM personnel and review of available documents indicate the difficulty of predicting the precious metal content of *by-products*, especially Slags and sludges.

High Value Products

The sampling procedures seen for *Doré* are viewed as satisfactory and, as a similar technique is used for *fine gold*, then as a source of significant loss or error this is thought unlikely.

The analytical procedures employed are appropriate and rigorously applied. There is therefore a high degree of confidence in the analytical results.

Sampling and analysis of drillings from new customer material is not a factor in inventory control and is used mainly to evaluate new materials.

The procedures for sampling of *Doré* and *fine gold* products are appropriate. Overall the potential for significant loss from evaluation and analysis of high value inputs and outputs is viewed as small, and is not of immediate concern.

Sweeps and Slag

With regard to potential loss of silver and gold, together with the *salt Slag*, the production of significant amounts of low value *sweeps*, Slags, sludge and silver chlorides is the biggest technical challenge to any refinery, including RCM.

Sweeps and Slag are transferred to drums and the contents of *sweeps* is usually mixed and sampled, Slag is not mixed. It was noted that Slag samples from chlorination are not homogenised and significant variations in content were observed from samples taken from top, middle and bottom of the drum.

The limitation of the *sweeps* and Slag sampling system is the mixing and bulk sampling which could be prone to error. Mixing is a very complex operation and, given finely divided feed, the technique employed may be satisfactory. If it is not thoroughly mixed then the sampling technique employed (cutting at start, middle and end) will not produce a representative sample.

As long as the documented procedures are adhered to, the production of a representative sample of the scoop sample for analysis is achievable. However, clearly this will only be representative of what was taken from the drum via the scoops. Evidence has confirmed that the present mixing and sampling technique does not advance its objective (refer to Appendices B & C).

3.2.3 ASSAY SAMPLING METHODS FOR BY-PRODUCTS

The situation is complex for *sweeps*, Slags and sludges, where the material consists of coarse and fine particles and a mix high value and low value materials which have a wide particle size range. It appears that a disproportionate amount of effort is necessary to address course *by-products* and in terms of on-site storage, drums of *sweeps* and Slag dominate. Given the overall lack of space this situation needs to be addressed as a matter of urgency. Rationalised techniques should:

- a) Minimise bulk preparation time and effort – consistent with satisfactory sampling.
- b) Use mechanical sampling techniques throughout.
- c) Introduce more complex sample preparation and grinding only as the sample bulk is reduced in weight.
- d) Provide a representative analytical sample - mechanical techniques should be used to provide the final and reference samples.
- e) Regular checks are required to ensure compliance.

Together with the *salt Slag* the production of significant amounts of low value *sweeps*, Slags and sludges are the biggest major technical challenges for the RCM.

A thorough review of course *by-products* and sampling techniques and procedures is required.

In terms of process improvements the aims are clear - to reduce the amount of *sweeps* and residues and their gold and silver contents, e.g. gold should stay in the gold circuit and silver should stay in the silver circuit. Reducing the amounts reporting to *sweeps* will greatly reduce costs and contribute to increased profitability.

Mechanical sampling - bulk to analytical sample is key to understanding this process and remains the only reliable route to a final sample representative of the bulk. The most reliable machines for analysis, spinning riffles produce excellent representivity from a flowing stream of material, whether or not it is homogeneous. These are used downstream but not for the bulk sample and they were seen during the visit.

An independent assessment of the mechanical sampling technique below shows its superiority to other methods:

Table 3.1 – Estimated Sample Error for Standard Sampling Methods

Method	Standard Deviation (σ_n) %	Variance (P_n) %	Estimated Maximum Sample Error (E) %
Cone & Quartering	6.81	46.4	-
Scoop Sampling	5.14	26.4	17.1
Table Sampling	2.09	4.37	7.0
Chute Sampling	1.01	1.02	3.4
Spinning Riffle	0.13	0.02	0.42
Random Variation	0.08	0.01	0.25

In the context of *sweeps* and Slag evaluation the principal advantage of mechanical sampling of the bulk sample is that the feed preparation need not be precise; after preliminary preparation the bulk can be reduced to say ten, or even one per cent of the bulk (depending on the level of accuracy required) and this smaller intermediate sample ground to a more uniform size and re-sampled, as is now carried out.

It is also imperative that the final analytical sample is produced using a micro-riffle to ensure no bias is introduced in the analytical laboratory. The Micro Spinning Riffle (MSR) for example has a bulk capacity up to 25ml and extracts representative samples as small as one–twentieth of the bulk in one pass. The collecting vessels fit together to form a precision integrated dividing head.



3.2.4 OBSERVATIONS

It is concluded that unless there are appreciable amounts of platinum group metals (PGMs) or heavy metals, e.g. iron present, which could cause segregation in the melt, the vacuum tube approach for *Doré* and *fine gold* is appropriate. Mechanical sampling would only be possible if the *Doré*, for example, was re-melted and grained and atomised. This would give the best overall sample for analysis but there is no immediate evidence to justify evaluation of this alternative approach.

Mechanical sampling of the drillings from new customer material could be investigated to produce an analytical sample and reference samples but there is no immediate evidence of a problem here either. It is used as an in-house tool to evaluate new materials.

The SGS third party sampling and *assaying* show that RCM sampling and *assaying* techniques are reliable and accurate for measuring amounts of precious metals in *Doré* and pre-melt samples. However, there is high variability in the sampling and *assaying* techniques used for *by-products*. This inherent uncertainty can result in increased “*unrecoverable losses*” of precious metals in the *by-products* settlement.

3.2.5 RECOMMENDATIONS

- a) Review and determine efficacy of current sampling and *assaying* operations based on gold and silver contents. This is critical for by-product materials with high volume and significant precious metal contents, such as *salt Slag*, sludge and silver chlorides.
- b) Review analytical procedures and laboratory sample procedures with the aim of reducing preparation effort and cost and improving reproducibility.
- c) Establish the cost-benefits from proposed changes.

3.3 Chlorination/Anode Casting and Processing

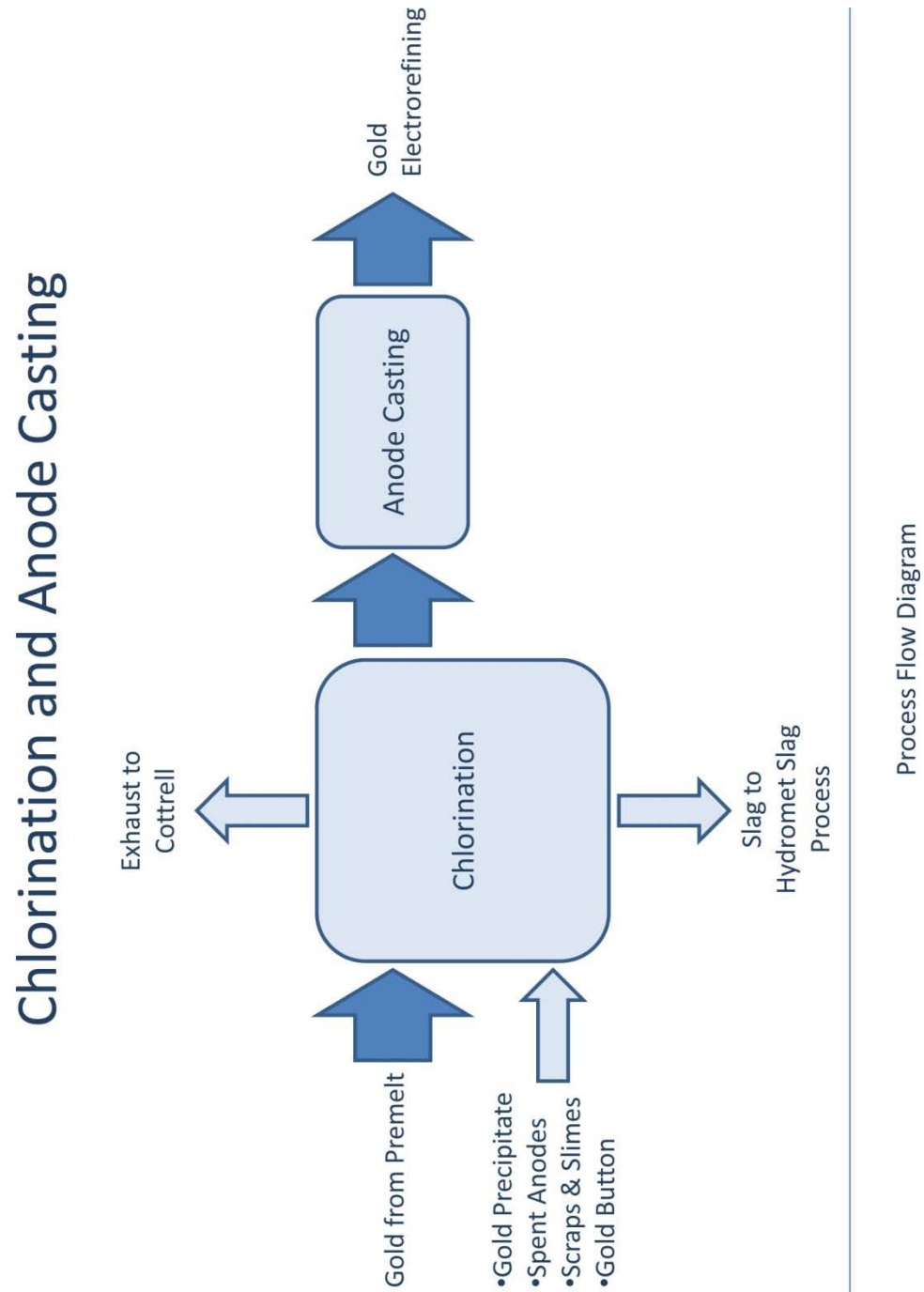
3.3.1 PROCESS DESCRIPTION

The chlorinating process is used to remove impurities and silver metal from the rough gold by the injection of chlorine gas into the molten metal inside an induction furnace. The impurities combine with chlorine gas to form gaseous compounds that escape through the exhaust system or chloride Slag that floats to the surface of the melt and is scooped off. The remaining gold will achieve a purity of 99.5% and will be cast into anodes to be fed to the gold *electrorefining* process. A simplified Process Flow Diagram of Chlorination and Anode Casting is provided in Figure 3.3 below. The main process steps can be described as follows:

- a) Chlorination and anode casting are a batch process.
- b) The sources of gold to be chlorinated will come from premelted customer deposits from the vault, gold bars from Premelt, dissolvomat inerts, *HSSE* slimes, anode skeletons or anode slime.
- c) A charge of 8,500 Troy ounces is made up and is melted in crucibles in one of two induction furnaces.
- d) The molten gold is injected with chlorine gas by using a sparger tube.
- e) The flow of chlorine gas is controlled by the operator by the manual adjustment of a valve.
- f) The chlorine gas is supplied from chlorine cylinders.
- g) The chlorine gas reacts with impurities such as silver, zinc, lead, iron and copper to form chlorides which float to the top of the melt.
- h) The chlorides are manually bailed out with a scoop by the operator as Slag from the surface of the molten metal and poured into moulds.
- i) There is 110 to 160 kg of Slag produced from one charge and approximately 1500 kg per week..
- j) The Slag is sent to Slag recovery using an internal *Hydromet* process or processed by an outside refiner.
- k) The fumes escaping from the top of the furnace are captured by a hood and vented through the *Cottrell* electrostatic precipitator.
- l) The fumes escaping from the bailing operation are captured and vented through the packed scrubber.
- m) The chlorinated or refined gold remaining in the crucible varies from 990 to 996 purity, depending on the desired fineness.
- n) Assay samples are taken from the melt by the XRF method.
- o) Borax is added to the melt to assist in the removal of the Slag and achieving the desired gold fineness.

- p) Upon reaching 99.5% purity on the XRF analyzer the chlorination is stopped and the chlorine sparger is nitrogen purged.
- q) The refined gold is usually poured in the form of anodes, quenched in a water tank, to be fed to the gold *electrorefining* operation.
- r) Occasionally, the refined gold is poured in the form of bars. These bars are then re-cast into Lowbars (100 oz. bars with a minimum purity of 99.5% Au).

Figure 3.3 - Chlorination and Anode Casting



3.3.2 PROCEDURES

A brief review of the following Refinery Work Instructions has been carried out: RWI-CL-02 Rev 02 Gold Chlorination Process

Overall, we have found that the content of the procedure was extensive and complete; especially the list of reagents and the required personal protective equipment. We offer some comments below:

- a) The addition of a list of the applicable MSDS documents (i.e. Chlorine Gas) to the procedure would be helpful.
- b) The last revision to the procedure was in June 2004 and some sections would benefit from an update, for example, the cartridge filter mask type mentioned in subsection 15.1.7 is not specified.
- c) Providing more specific details in Section 10 relative to the procedure to be followed for assay sampling of gold in the furnace would be helpful.
- d) Providing standardized instructions as to how the chlorination anodes log book should be filled out would make reviews easier, but no inventory issues were noted.

3.3.3 POTENTIAL LOSSES

Chlorination

This is the key gold refining stage, in which volatile base metal and silver chlorides are removed and collected, mostly as a chloride Slag, which is removed continuously throughout the process. The operation proceeds in two stages:

- a) Slow reaction of chlorine gas with the base metal impurities forming volatile chlorides.
- b) Rapid production of non-volatile chlorides (*salt Slag*) which is skimmed from the surface of the melt.

The aim is to produce 99.5% gold and, in general terms, gold losses increase as the gold purity increases. Although it is possible to produce 99.9% gold refiners, do not use the Miller Chlorination process to produce more than 99.5% gold in order to avoid losses by volatilization but often the process is stopped at 99% gold.

In general, losses occur in the chlorination process through either salt Slag or volatilisation

Salt Slag

The biggest issue is retained gold. Given the manual procedures used, which have not been refined since its first development in the late 19th century, it would be extremely difficult, if not impossible, to eliminate losses - although with skilled operators it can be minimised. Significant amounts of gold can be scooped up with the Slag through this stage, e.g.

- a) Typically the feed material consists of up to 70% gold containing up to 8,500 oz gold.
- b) This produces 100 – 150Kg of Slag, which can contain up to 5Kg or more than 150 oz gold.
- c) Therefore the potential loss is of the order of 2% which is in line with industry standards.

However, given the heterogeneity of the Slag and bullion mix appropriate sampling procedures are crucial to determine the amount of gold present in the Slag and hence potential loss. Sampling and therefore assay are regarded as major potential sources of error and hence loss.

The *salt Slag* is an input into the silver refinery and theoretically what is lost here will be recovered there. But given the number of physical, chemical and electrochemical operations involved it is possible for the gold to become disseminated and “lost” through the numerous sampling and evaluation stages.

Ultimately recovery is carried out by internal processing in the *Hydromet* or by an outside refiner, when necessary. Standard commercial terms will mean that not all the revenue from the content will be received from an outside refiner.

Volatilisation

- a) The process is predicated on the stability and production of base metal and silver chlorides but not gold. AuCl_3 can form but decomposes at around 400oC. Generally, the end point of the process is achieved by looking for a blue sheen of AuCl_3 on the melt and condensing it from the gas phase onto some refractory.
- b) The amount of volatile gold losses from the Chlorination Process will depend on operating temperature and end point.
- c) Entrained gold and to a greater extent silver should be collected in downstream fume scrubbing equipment and a very old *Cottrell* electrostatic separator.
- d) The efficiency of the *Cottrell* is probably poor but offers some recovery such that overall losses are low.

Anode Casting

Horizontal gold anodes are cast directly from the chlorination furnace, which are positioned on a circular rotating table. A total of sixty anodes is produced each weighing 110 oz .The potential losses in this process fall into three categories:

- a) Pouring and spillage
- b) Fume
- c) Crucible

Pouring and Spillage

Some loss of material is unavoidable during this process and splashing was observed during this operation. There is no provision to capture spillage. It is swept up by the operator and collected.

Fume

A dedicated cartridge filter is used to treat fume from the gold casting room and casting furnace. This was not studied in any detail but, given adequate controls and testing, efficient recovery of trace amounts of gold in the fume would be expected and therefore as a loss mechanism it should be amongst the lowest to be considered.

Crucible

A small amount of bullion may remain in the crucible after pouring. Losses from this source are likely to be small. Some may penetrate the crucible refractory and will not be immediately visible. Any gold retained in the crucible is recovered by crushing the crucible and sending it to the swaps.

3.3.4 OBSERVATIONS

Chlorination

The operation of the chlorination process is described in RCM's Refinery Work Instructions Number RWI-CL-02.

- a) Space is a major issue at RCM. The proximity of the chlorination furnace to the pre-melt and to a lesser extent the *TBRC* has already been reported as very undesirable, as opportunities for errors due to mixing charges are small but potentially significant, although there is no evidence that this has occurred. Bullion for chlorination was seen in a pile in front of the furnace; it did not appear to have a set location which differentiated it from other materials in the work area.
- b) The elimination of the potential for errors due to mixing of lots is necessary. Inter-departmental controls would be improved if such operational procedures were rationalised.
- c) The induction furnace works well; melting is rapid, injection of the chlorine gas is effective and fume extraction is very efficient, with no chlorine in evidence in the atmosphere. Monitoring of the working environment is carried out. The operator was equipped with a standard face shield however, provision for splash protection was not immediately apparent.
- d) No flux is added to the process, although Slags from the pre-melt and other processes are often added; it is usual to add a mix of borax-sand-sodium carbonate to assist with fume collection.
- e) Once molten bailing of the Slag into an enclosed crucible commences it continues for approximately two hours. The efficiency of this process is extremely operator dependent, but to be able to carry out this procedure with "no loss of gold" is unlikely ever to be achieved. No attempts are known to have been made to automate this process.
- f) The endpoint of the process is determined, by observation, at the point when the Slag ceases to form.

Salt Slag

- a) Typically the charge would comprise up to 70% gold containing up to 8,500 oz. The Slag produced weighs 100 – 150Kg which can contain up to 5Kg or more than 150 oz gold. Therefore the loss is of the order of 3% to 4%. The bulk of this loss is particulate gold carried over during the skimming and transfer operation.
- b) Presently, Chlorination Slag enters the *Hydromet* in one of two ways; mechanical milling or granulation. Slag which is mechanically milled is manually *de-golded*, the worker breaks the Slag and removes metallic gold. This reduces gold content to between 1.5% to 2%.
- c) Slag which is granulated is in effect *de-golded* by remelting the Slag and letting the gold sink to the bottom of the melt. The Slag is poured off the top and the gold button remaining at the bottom is returned to chlorination. This reduces the gold content to 0.1% to 0.2%

Therefore, the ability to maximise the recovery of entrained gold in the *salt Slag* before being processed for silver recovery is a key part of the process flow sheet. The goal is to be able to reliably quantify and control the loss to the Slag and to be able to recover the bulk of the gold before it enters the silver circuit. Techniques are discussed later where >95% gold recovery should be achievable. These are well known to the RCM.

Volatilisation

- a) In theory the gold loss due to volatilisation, given AuCl_3 decomposition at around 400oC, should be low. However, in practice and given the high levels of extraction dilution air, gold is often found condensed on cooler duct work adjacent to the furnace. It was noted that at RCM there was about fifty (50) feet of ducting between the furnace and the *Cottrell* which is undesirable but unavoidable. Care should be taken to clean out all condensed fume. However, overall gold loss by this process is not thought to be of major significance.
- b) Key to recovery of gold and particularly silver is fume scrubbing. Given its age and the duty which it performs, treating a highly acidic hygroscopic gas phase, the *Cottrell's* overall efficiency must be doubtful. It is also maintenance intensive. As a result it is about to be replaced with a high pressure venturi scrubber.
- c) Even given these factors, as long as the *Cottrell* is functioning, "high" recoveries of gold and silver should be achieved, although they will not be optimal. An independent report (RWDI) puts this at 80%, which is viewed as optimistic. This however is also not of major significance as, an overall source of loss, this will be small; the above test work indicated measurable gold with the *Cottrell* off and on at 0.6 g per day and 0.3 g per day respectively. The performance is significantly worse than their 2001 results, indicating perhaps that a change is desirable. At present, the *unrecoverable losses* of gold to atmosphere from the exhaust system were measured at 89 oz/year.

Anode Casting

- a) Splashing and spitting were observed during the anode casting process. A small loss of material is unavoidable. It was noted that vertical height between casting and the anode could have been usefully reduced via the use of a tundish, which would have smoothed out the flow and perhaps the mould dressing compound and procedure used should be reviewed.
- b) There appeared to be no provision to minimise or capture spillage and it is swept up by the operator and collected.

Crucible Failure

The crucible, although robust and reliable, is used in successive operations. Of significance is the impact of a crucible failure by cracking on process operation and gold loss. Provisions for capture and recovery were not apparent. This is viewed as of minor concern.

Overall

A significant amount of gold 2% to 3% is retained (176 PPTT per charge) in the chlorination stage. This gold is considered an *apparent loss* and is recovered in the *Hydromet* process. Most of the gold recovery takes place at the remelting of the Slag during granulation and the remaining gold button settled at the bottom of the crucible is returned to chlorination. As a result, the Slag entering the *Hydromet* process contains 0.1% to 0.2% gold (17.6 PPTT) per charge or 8500 oz.

3.3.5 RECOMMENDATIONS

Overall Operation

- a) Dedicated storage for work-in-progress is required to minimise charging errors.
- b) Air-stream helmet and adequate splash protection (if not already used) are pre-requisites for the operator.
- c) Provisions for crucible failure needs to reviewed.
- d) Pouring operation needs to be reviewed and benefits of a tundish system evaluated.
- e) Effectiveness of mould dressing and application should be reviewed.
- f) Vertical anodes would make operation less prone to splashing and loss but would necessitate a major redesign – the benefits are viewed as probably insufficient to justify costs.

Chlorination

- a) Review the impact on the electrolytic gold refinery of reducing target gold purity from 99.5% to 99%. Particularly impact on process time and overall gold loss versus build up of impurities in electrolyte. We suspect that it could be overall advantageous to reduce to 99%.
- b) Given the proposed changes to the fume scrubbing arrangements and the removal of the Cottrell, then the allocation of space in the refinery needs to be reviewed, particularly given the earlier comments regarding proximity of unit operations and potential for error and cross contamination.
- c) The key recommendation is to formulate and review plans to reposition the chlorine furnace and de-golding furnace close to the new venturi scrubber such that they still integrate with the silver chloride treatment area.
- d) Although not of major concern it will be necessary to establish the efficiency of the new scrubber and optimum operating conditions established.
- e) Crucially, sampling procedures for the salt Slag need to be developed and validated in order to address the extent and variability of the loss.
- f) A series of plant tests (three) is recommended to:
 - 1. Evaluate low (50% Au), medium (60% Au) and high (70%Au) content *Doré* under standard operating conditions to determine the deportment of impurities and to produce a gold and silver mass balance for the process. This test work would indicate, if technically and commercially, it was possible to operate at lower gold levels without detriment to production; It would be particular relevant if the aim of 99% Au was to be adopted c.f. 99.5% Au.
- g) Establish the ability of the gold and silver refinery to accommodate the outputs needs to be confirmed.
- h) Produce an overall gold and silver mass balance.
- i) The tests recommended in item 6 were completed as part of this report. See section 3.7.1.

3.4 Gold Electrorefining & Gemstone Recovery

3.4.1 PROCESS DESCRIPTION

Refer to Figure. 3.4 at the end of this section for a simplified flow diagram.

Gold Electrolysis

The gold *electrorefining* process is used to increase the fine purity of gold from the 99.5% which is achieved at the chlorination stage to 99.99% and 99.999%. Gold anodes are dissolved in a bath of hydrochloric acid and the gold is plated on cathode plates by electrolysis. The *fine gold* is then fed to the *Fine gold* Room for transformation into bars or gold grain. The main steps in the process are described below:

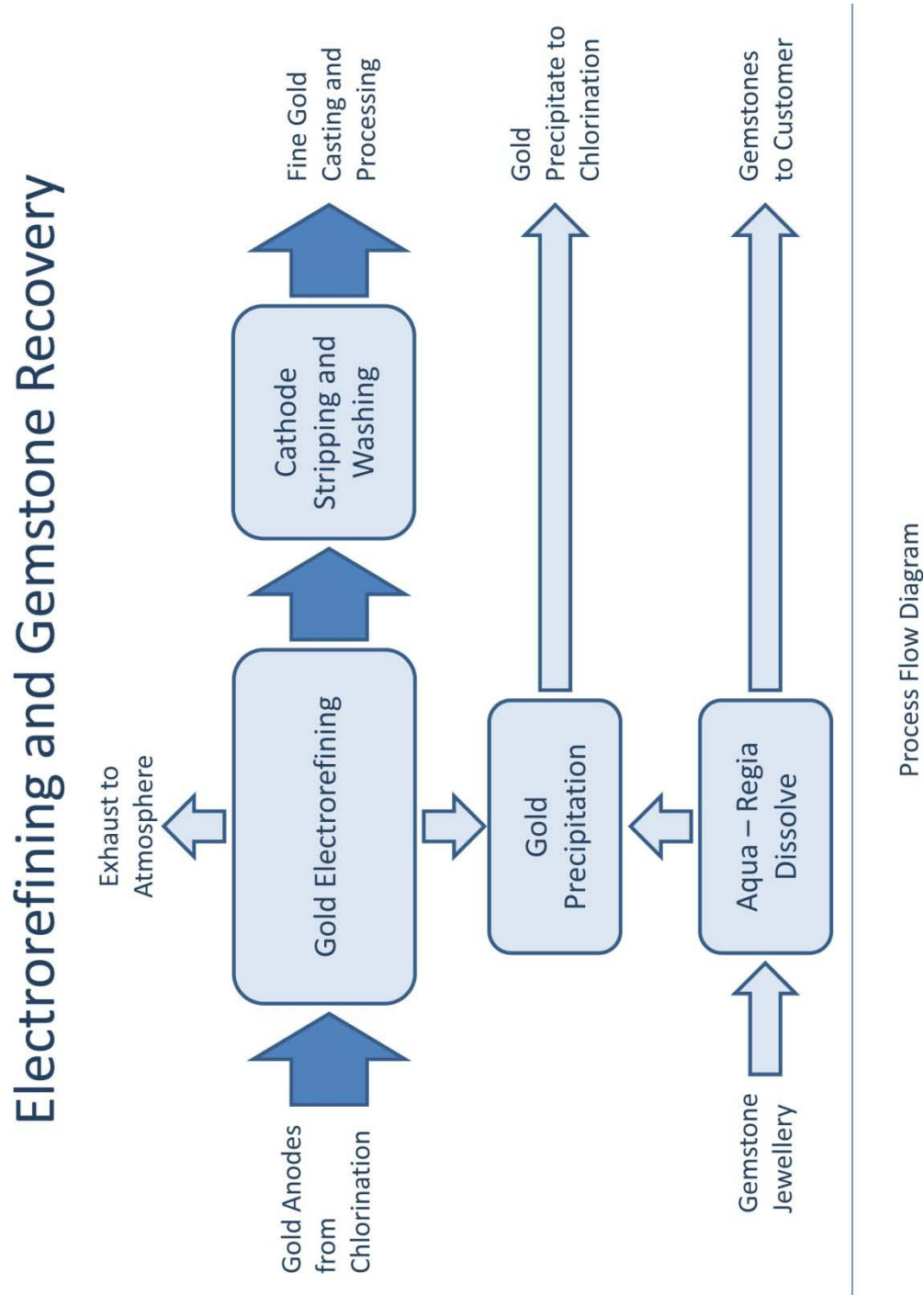
- a) A Process Flow Diagram of the gold electro-refining process is presented in Section 3.4 of the present report.
- b) Gold anodes of approximate purity of 99.5% are received from the Chlorination Process and are put through the Electro-refining process in order to produce 99.99% gold and a small quantity of 99.999% gold.
- c) The Electro-refining process consists mainly of electrolysis cells in ventilated cabinets where the gold anodes are dissolved in a hot electrolyte solution of hydrochloric acid and electroplated back on titanium cathodes as a gold sponge.
- d) The cells are made up of plastic tubs of about 12" x 12" x 16" in size which are heated by means of an electric heater through an oil bath.
- e) After approximately 30 to 48 hours, the cathodes are removed from the cells, washed with deionised water, and the plated gold commonly referred to as gold sponge is separated from the titanium cathode plates with the use of a scraper.
- f) The gold sponge is weighed and sent to the *Fine gold* Room.
- g) Spent anodes which have been depleted to less than 10 oz in weight are removed from the cells, weighed and sent to the Chlorination process as spent anode skeletons.
- h) The slime which has collected at the bottom of the cells is pumped out of the cell tanks at that time. The slime, which consists of 90 to 95% gold, some copper, lead, platinum, palladium and silver chloride, is filtered, rinsed with deionized water, dried on hot plates, and sent to the Chlorination process as Anode Slime.
- i) The rinse water is collected, filtered and reused as make-up water to offset evaporation in the cells. The filter paper is burned in the gas furnace.
- j) The electrolyte is replaced after approximately six months of production. The gold in the spent electrolyte is recovered by precipitation with iron salt in a precipitation reactor and sent to the Chlorination process as gold precipitate. The liquid is *assayed* to confirm that the gold concentration is less than 1ppm, drummed, weighed and sent out as spent electrolyte solution to External for recovery of platinum and palladium metals.
- k) The *electrorefining* cabinets and the gold precipitation tank are exhausted to atmosphere.

Gemstone Recovery

The gemstone recovery process is used to dissolve gold and precious metals from gemstone jewellery into a bath of aqua-regia solution. The dissolved gold and precious metals are precipitated out and fed back to the chlorination process and the gemstones are recovered and returned to the customer. The main steps of the process are described below:

- a) The base jewelry alloy, as received from customers, is a mixture which contains gold, silver, copper, and lesser concentrations of zinc, nickel and platinum group metals.
- b) The jewelry is processed in lots of 800 to 1000 Troy ounces.
- c) The jewelry is dissolved in an aqua-regia solution, a mixture of hydrochloric and nitric acids, in ventilated cabinets in the Jewelry Room.
- d) The gold-rich acid solution is sent to the gold precipitation reactor and the gold is recovered as gold precipitate, dried and sent to Chlorination.
- e) The residue of diamonds, precious and semi-precious stones, silver chloride and small undissolved metallic pieces is screened, washed, sorted and picked. The diamonds and gemstones are returned to the customer. The remaining residue is dried and sent to the Premelt process.
- f) Any spent solutions are stored into WHMIS labelled drums and sent to external for disposal.
- g) The cabinets are exhausted to a packed bed caustic scrubber

Figure 3.4 - Electrorefining and Gemstone Recovery



3.4.2 PROCEDURES

A brief review of the following Refinery Work Instructions has been carried out:

RWI-E-01 Rev 04 Procedure of Gold Electrolysis
RWI-E-05 Rev 03 Recovery of Gemstone from Jewellery
RWI-E-03 Rev 03 Procedure for Gold Recovery from Solutions (Iron Salt)

The content of the procedures is extensive and generally complete. The list of reagents and the required personal protective equipment are listed in the procedures. We offer some comments below:

- a) Procedures RWI-E-01 and RWI-E-03 do not include a list of the applicable MSDS documents. We believe that it would be helpful include one.
- b) Section 8.3 in procedure RWI-E-01 refers to a Diagram relative to the placement of anodes. It would be helpful to include a copy of the Diagram in the procedure.
- c) Section 5.39 in procedure RWI-E-05 instructs the operator to wear a respirator in the case of a ventilation flow alarm. The respirator type and details are not provided in Section 4 Safety Equipment in the procedure. It would be helpful to provide these details.
- d) A list of applicable Quality Records is provided on page 19 in procedure RWI-E-01. It would be helpful if more detailed instructions were provided as to how these records should be filled out.
- e) We understand that a separate instruction is used for the production of 99.999% purity cathode gold sponge.
- f) We understand that the cathode gold sponge, anode slime and spent anode skeletons are being weighed prior to transfer to the *fine gold* Room. Adding weighing instructions or adding a reference to an existing weighing instruction would be useful.

3.4.3 POTENTIAL LOSSES

Electrolytic Refining

- a) Gold refining is carried out in the Wohlwill Process. This is a well established and reliable operation. The RCM cells contain 300-400gpl AuCl₃ solution and therefore the gold inventory is relatively high at about 15,000 oz of gold. The AuCl₃ solution is produced in-house.
- b) In the process the 99.5% Au anodes are electro-refined to 99.99% and the pure cathodes are sent for the *fine gold* room for casting. Silver is precipitated as AgCl and the platinum group metals (PGMs) form an anode slime. The base metal impurities remain in solution.
- c) The anode skeletons are returned to the chlorine furnace, as are the anode slimes.
- d) There are two main avenues for losses of electrolyte liquor and dissolved gold:
 1. Losses of some or all of a batch of AuCl₃ electrolyte down the sink – either accidentally or deliberately.
 2. Spillage, loss or theft during downloading and replenishing the electrolyte.

- e) The key issue in the Wohlwill Process is maintenance and recycling of the electrolyte. Impurity levels must not exceed preset levels and therefore it is necessary to periodically clean up the electrolyte. In the RCM process the whole electrolyte is downloaded every quarter and the gold precipitated with ferrous sulphate and re-melted in the pre-melt area.
- f) As the spent gold solution still contains nearly 4,000 oz of gold this represents a significant transfer of metal between departments.
- g) The available data indicate that the resulting chloride solution after precipitation, which is sent for platinum and palladium recovery externally, contains <1 ppm Au.
- h) The sampling and analytical techniques involved have not been discussed. However, given the level of competence of the analytical department it is anticipated that significant errors here are unlikely. Therefore there are no serious concerns regarding recycling of the electrolyte.
- i) There is no floor drain in the electro-refining room, therefore the probability of accidental spillage of significant amounts of AuCl₃ is viewed as low.

The potential for significant gold loss, based on the evidence available, is viewed as small.

Gemstone Recovery

- a) Aqua Regia is used to dissolve gold and precipitate silver as AgCl. Separation of the AuCl₃ solution from the silver chloride should ensure sufficient washing to minimise gold carry over into the silver refinery.
- b) As above, the gold in the chloride liquor is precipitated with ferrous sulphate and returned to the pre-melt. The available data indicate that the resulting chloride solution is sent out to DPW for disposal without recovery of palladium.
- c) The sampling and analytical techniques involved have not been discussed. However, given the level of competence of the analytical department it is anticipated that significant errors here are unlikely.
- d) Fume from the reaction is treated in a caustic packed bed scrubber.
- e) The silver chloride and gemstones are returned to the customer. Loss of entrained gold will occur if the washing is not effective or the leach conditions not optimised.

The potential for significant gold loss, based on the evidence available, is still viewed as small.

3.4.4 OBSERVATIONS

Electrolytic Refining

- a) It is more usual in the Wohlwill Process to withdraw a bleed stream and continuously replenish the cells with clean electrolyte to maintain the level of impurities below the critical level. The reason for this is that in a large operation the gold inventory required precludes the generation of a new batch of AuCl_3 while the contaminated electrolyte is being treated. This approach reduces the amount of gold in process at any one time outside of the cells.
- b) The scale of operation at the RCM is modest and the approach taken is to replenish the entire contents of the cells at quarterly intervals. This will result in a steady build up of impurities in the process, whereas the alternative route maintains them at constant level. It is worth considering a change in the operating strategy to continuously replenish the cells with clean electrolyte to allow 99% Au in preference to 99.5% Au.
- c) Other Wohlwill Processes operate successfully at 99% Au in the anode and some as low as 98.5% Au. This reduces the pressure on the chlorine refining stage and allows slightly lower levels of gold in the input *Doré* to be accommodated. However, too much silver in the anode will result in silver chloride building up on the anode surface preventing dissolution of the gold.
- d) In discussions, it was reported that the increased build up in impurities has an adverse impact on performance and therefore it was not been considered further. It is not clear whether the issue is silver, base metals or both. Copper is usually regarded as the key metal contributing to fouling of the electrolyte.
- e) Silver chloride precipitates in the cells and any PGMs present form an anode slime which is recycled to the chlorine furnace. It is questionable whether recycling of the anode slimes is the best option as the process does not offer an apparent route for their removal, other than periodically. It is difficult to accurately establish loss value but build up, or more importantly, loss within the process is undesirable.

Gemstone Recovery

- a) Aqua Regia is commonly used to dissolve gold and it effective for parting gold and silver. This process is probably the most widely at the small-medium scale and the biggest issue is NO_x emission which is highly toxic if it is carried out at elevated temperatures.
- b) It is common practice to grain the scrap to increase its surface area and treat it with a series of aqua regia acid additions, with the aim of maintaining only a small excess of acid without leaving any undissolved gold. Gentle heating will speed up dissolution, but a balance is required between kinetics and NO_x production.

3.4.5 RECOMMENDATIONS

Electrolytic Refining

- a) Review potential advantages and disadvantages of treating $\leq 99\%$ Au in feed, c.f. 99.5% Au. This should be reviewed in association with (2).
- b) Determine the impact of changed operating procedures on the longevity of the electrolyte... is it possible and advantageous to extend the period between downloading and replenishing the electrolyte? Will a bleed stream approach be advantageous above?
- c) Review recycling of PGM anode slimes to chlorine furnace... could they be physically separated from lump gold and sold? What are the commercial benefits of recycling to upgrade the slime? Weigh against the cost of External refining.

Gemstone Recovery

- a) Graining scrap may help with dissolution and reduce NOx emissions (if they are an issue)
- b) Establish best practice for washing silver chloride free of gold.

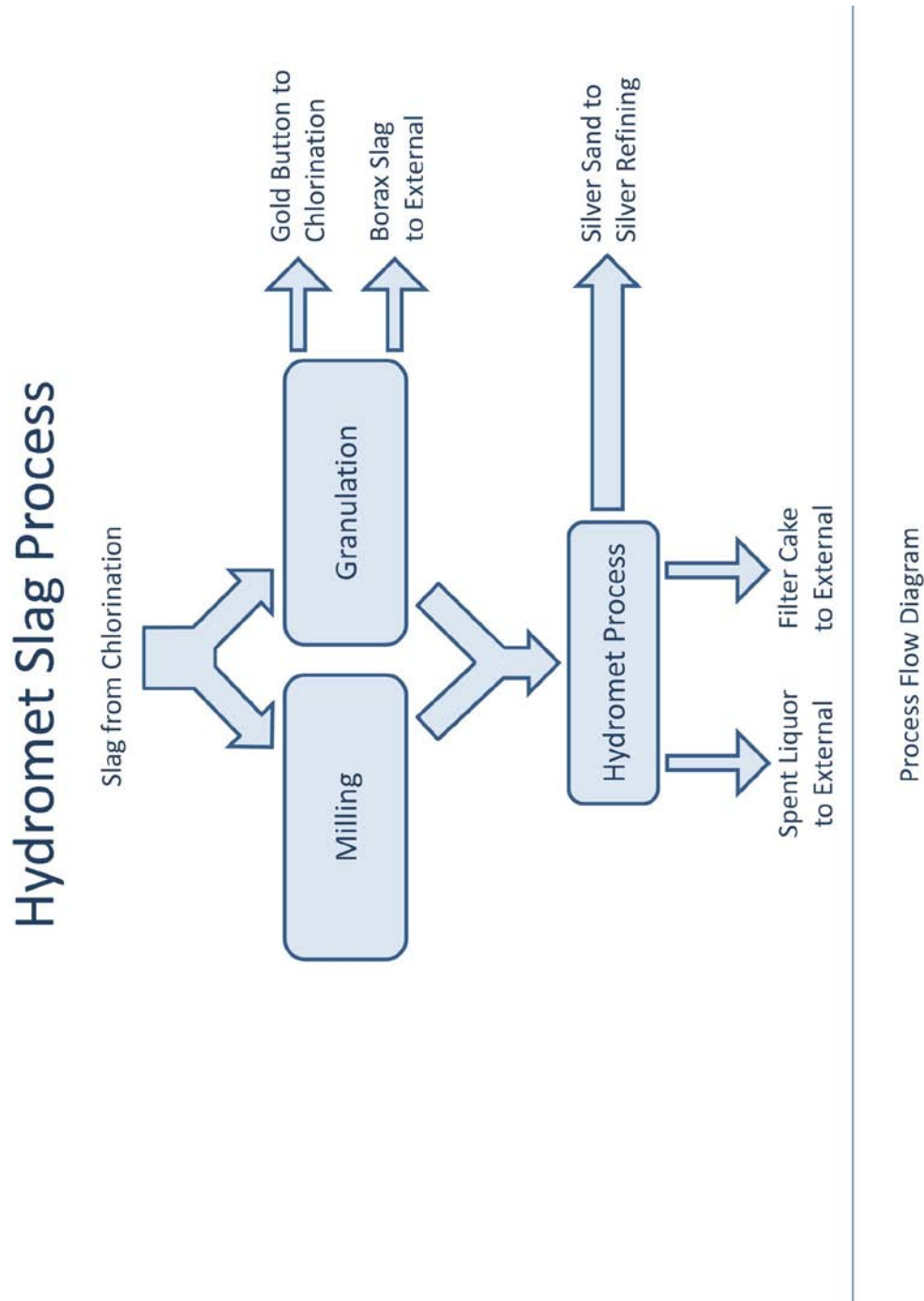
3.5 Hydromet Slag Recovery

3.5.1 PROCESS DESCRIPTION

The *Hydromet* Slag Recovery process is used to recover gold and silver from the silver chloride Slag that is generated by the Chlorination process. The Slag is crushed or granulated and fed into a *Hydromet* process. The main steps of the process are described below:

- a) A Process Flow Diagram of the *Hydromet* Slag recovery process is presented in Figure 3.5.
- b) Chloride or *Salt Slag* is a by-product of the chlorination process and may contain up to 25% silver, 2% gold and 25% copper.
- c) *Salt Slag* is received as bricks in moulds from the chlorination process and it is demoulded and prepared by one of two separate methods before feeding into the *Hydromet* process; one is through milling and the other is through granulation.
- d) The milling method or stream consists of crushing the Slag bricks, milling them and weighing the milled Slag before feeding it into the *Hydromet* leaching tank.
- e) The granulation method or stream consists of remelting the Slag bricks in an induction furnace and pouring the molten Slag into a cold water granulation tank. The granules are pumped to the *Hydromet* leaching tank. A gold-silver button is recovered from the bottom of the granulation tank and returned to the chlorination process. Borax Slag is collected and sent out to external for processing.
- f) Excess Slag is sent directly from crushing to outside refinery for gold and silver recovery when necessary.
- g) The *Hydromet* process is operated as a batch process with batch sizes of 150 kg milled Slag or 210 kg of granulated Slag.
- h) The Slag is first leached in a liquor of muriatic acid in order to dissolve the copper that is present in the Slag.
- i) The silver chloride is filtered out of the liquor and then converted into silver sand by cementation using iron powder. The silver sand filter cake is weighed and sent to the silver refining process. Excess silver chloride wet solids are sent to External Refiners, when necessary.
- j) The dissolved copper and Iron is precipitated out of the liquor by the addition of soda ash and is filtered out as copper and iron carbonate filter cake and sent to external.
- k) All *by-products* are weighed and *assayed* before being sent to external.
- l) Depleted *Hydromet* liquor is sent to external.
- m) Dust generated during Slag demoulding, crushing and milling is exhausted through the cartridge dust collector.
- n) The Slag remelt and granulation operations are exhausted through the *Cottrell* precipitator.

Figure 3.5 - Hydromet Slag Process



3.5.2 PROCEDURES

A brief review of Refinery Work Instructions RWI-HYDRMET-01 (approved July 16, 2009 - no revision date) *Hydromet* Slag Treatment Process was carried out. The content of the procedures is extensive and generally complete. The list of reagents and the required personal protective equipment are listed in the procedures. We offer some comments below:

- a) Assigning a Revision number to the procedure would assist with the management and updating of procedures.
- b) Specifying the model and type of the half mask air purifying respirator listed in Subsection 1.0 a.v. would help ensure that the correct respirator is being used.
- c) Providing more details in Subsection 5.0 h., 5.0 u. and 5.0 nn. as to how the operator should be taking the copper-iron filter cake samples for *assaying* would help to ensure that the sampling results are as representative as possible of the entire barrel.
- d) There are no details in the procedure as to when and how the operator is to prepare and sample depleted *Hydromet* liquor and excess silver chloride wet solids for sending to External Refiners providing such details would be useful.

3.5.3 POTENTIAL LOSSES

A review and comparison of the potential source of losses from the chlorination furnace has been carried out and the *salt Slag* identified as the biggest technical and commercial challenge for the RCM. From available data it is concluded that it can contain 2% to 3% of the gold in the charge.

This gold is considered an *apparent loss* and recovered in the *Hydromet* process. Most of the gold recovery takes place at the remelting of the Slag during granulation and the remaining gold button settled at the bottom of the crucible is returned to chlorination. As a result, the Slag entering the *Hydromet* process contains 0.1 to 0.2% gold (17.6 PPTT) per charge (8500 oz).

Gold which is not recovered before entering the *Hydromet* process will attach to the silver chloride or silver sand and enter silver refinery system. This gold will be an apparent loss until it is returned to the refinery via the HSSE silver slime.

3.5.4 REVIEW AND COMPARISON TO DE-GOLD PROCESS

De-golding of the *salt Slag* is an integral part of gold refining process and is the key sampling and analysis point between the gold and silver refinery sections.

From available information it appears that a *de-golding* furnace was part of the flow sheet up to 2005. In a simple two stage process sodium carbonate flux was added to the *salt Slag* and after melting a Au-Ag bullion recovered which was recycled to the chlorination furnace. The impure silver-copper chloride was melted under reducing conditions and a Ag-Cu alloy produced.

Presently, Chlorination Slag enters the *Hydromet* in one of two ways; mechanical milling or granulation. Slag which is mechanically milled is manually *de-golded*, the worker breaks the Slag and removes metallic gold. This reduces gold content to between 1.5% to 2%.

Slag which is granulated is in effect *de-golded* by remelting the Slag and letting the gold sink to the bottom of the melt. The Slag is poured off the top and the gold button remaining at the bottom is returned to chlorination. This reduces the gold content to 0.1% to 0.2%

Optimisation of this step will greatly reduce the loss of gold from the gold area, improve confidence in the processes and reduce significantly the effort needed to evaluate and recover gold from downstream processing. It is however unlikely to remove any of the individual unit operations.

3.5.5 OBSERVATIONS

- a) RCM no longer sends the Chlorination Slag to External Refiners. The Slag is processed internally with the *Hydromet* process.
- b) The *Hydromet* granulation process effectively removes gold content to less than 0.15% (see results of Mass Balance test results 3.7.1)
- c) There is little or no difference in the gold removal provided by the previous *de-golding* furnace and the *Hydromet* granulation operation.

3.5.6 RECOMMENDATIONS

- a) Conduct a mass balance test to determine the metal balance from chlorination furnace through the *Hydromet* Slag recovery.

This mass balance test was completed as part of this report– see Section 3.7.1.

- b) RCM should consider providing a holding furnace for Slag to eliminate the reheating of Slag bricks.

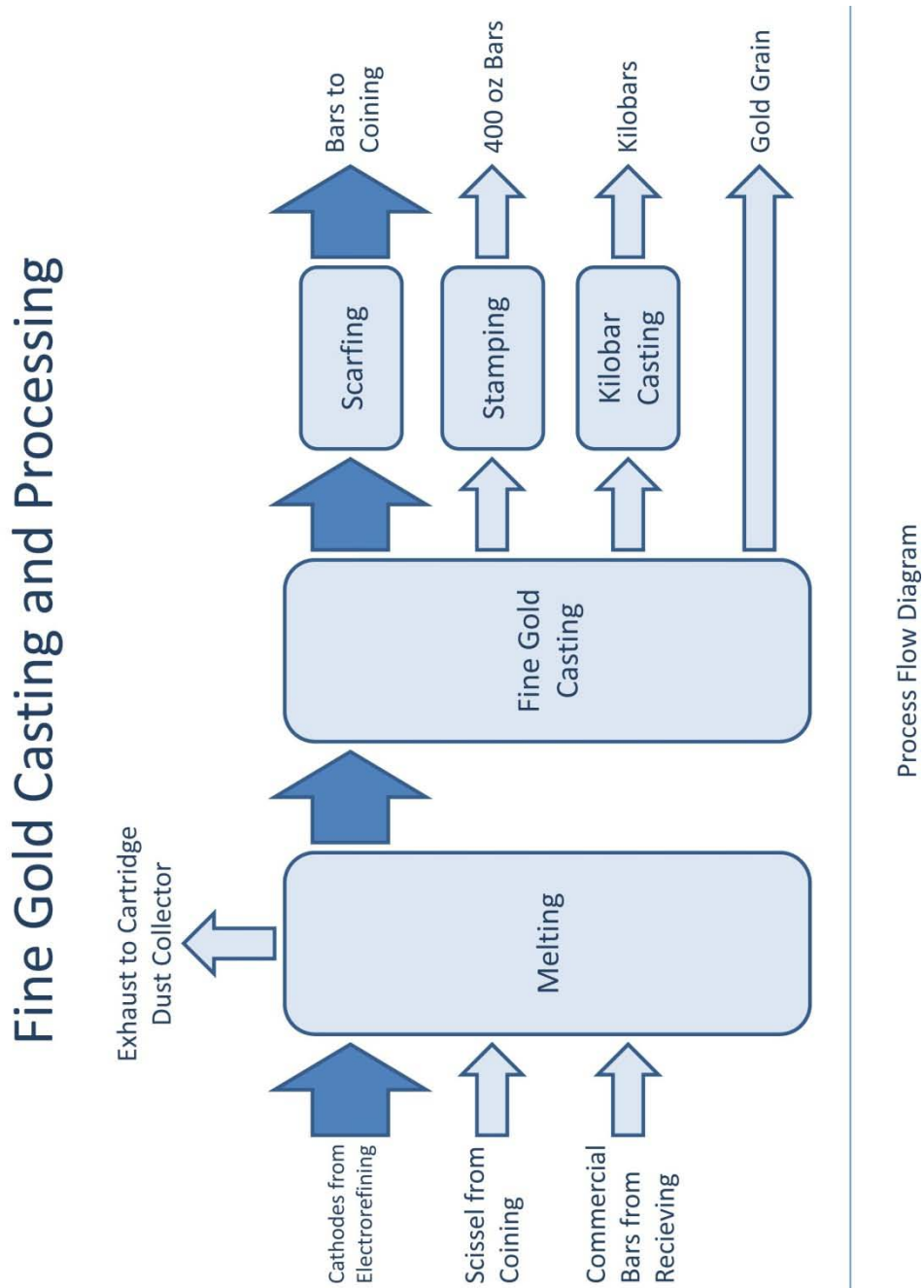
3.6 Fine Gold Casting and Processing

Fine gold casting is the final step in producing saleable *fine gold* bars and grain. This is carried out in a separate room of the refinery to control the access and purity of the gold. A process Flow Diagram of the *Fine Gold* Casting is presented in Figure 3.6 below.

3.6.1 PROCESS DESCRIPTION

- a) 99.99% (4-9's) gold scrapings arrive at the *Fine Gold* room in large plastic tubs (crocks) on pallets using the hoistway from the Electrolysis Room on the third floor.
- b) Each crock holds approximately 14,000 Troy Ounces.
- c) There are two induction furnaces in the *Fine Gold* Room; one for 4-9's gold and one for 5-9's gold. Each furnace has a crucible that will accept an 8,000 Oz charge.
- d) 4-9's and 5-9's gold is seldom mixed between furnaces. 4-9's gold is put into a 5-9's crucible perhaps twice a year when the 5-9's crucible is due for replacement.
- e) The 4-9's and 5-9's furnace products are GML bar, 400 T.Oz bars, 100 T.Oz bars and gold grain.
- f) Each bar type is cast with a different set of closed moulds. The mould is assembled and clamped. The gold is poured into the mould, the mould is broken and the gold bar is quenched and stacked on a cart.
- g) In order to produce 5-9's gold products in the electrorefinery, the 4-9's gold is poured into open top anode moulds, demoulded, quenched and stacked for delivery up the hoistway to the gold electrolysis room.
- h) Gold grain is created by pouring the gold from the furnace into a water filled copper kettle with agitation. Gold is poured into the kettle at 2,000 Oz per pour, then the gold grain is dewatered and dumped into a container for further packaging in the receiving area.
- i) The *Fine Gold* Area has a third furnace that is designed to produce gold kilo bars from a 1 kg charge of gold grain prepared in the receiving area in a specialized container.
- j) GML Bars are moved on a cart from the *Fine Gold* Casting room through the chlorination room to the Scarfing Room where a mill is used to trim the corners of the gold bars so that the bars are suitable for coining operations. Bars are weighed into the scarfing area. After each cart load of gold bars is processed, the scarf is gathered and compressed into a block and *sweeps* are gathered into a container. Every cart load of scarfed bars, baled scarf and *sweeps* is weighed out of the scarfing room.
- k) 400 and 100 Troy Ounce Bars are taken to the Receiving area for weighing and recording. The fineness and the actual weight of each bar is stamped onto the bar.
- l) All finished gold products are stored in the vault until shipped. All *fine gold* work-in-process is stored in the vault during off-shifts.

Figure 3.6 - Fine Gold Casting and Processing



3.6.2 PROCEDURES

- a) The written procedure for this process was unavailable for review.
- b) The procedures were not posted or seen at the *Fine Gold Area*

3.6.3 POTENTIAL LOSSES

The following are the process steps from the electro-refinery where 4-9's and 5-9's gold products are produced:

- a) Cathode Melting and casting
- b) Grain casting

The products include:

- a) Gold for coinage 9999 and 99999
- b) Grain 9999 and 99999
- c) 400 oz bars 9999
- d) 1 kg bars 9999

The feed material for producing 99999 gold is 9999 anodes, which are re-refined in dedicated Wohlwill Cells.

The major source of scrap production is through surface cleaning or scarfing of the 9999 and 99999 cast materials. These are returned to the chlorination furnace.

Inter-departmental procedures are in place regarding the transfer of 9999 and 99999 gold for the coining operations.

Crucibles will contain economically significant amounts of gold and these are crushed and the gold retreated by OSR's

3.6.4 KILO BAR FURNACE

The new kilo bar continuous induction tunnel furnace is in the course of proving trials. It is viewed as state-of the art and, once fully operational, it should improve the efficiency in respect of the following:

- a) Less metal volatilisation and spillage losses
- b) Semi automated process will save operations costs and increase productivity
- c) Higher quality product as a result of smoother more refined surface finish and bar shape

The next steps to completely automate the process would be to introduce robot arms at one end of the furnace to weigh out and load individual charges for melting, and at the other end lift off, stamp the bars and pack in boxes.

3.6.5 OBSERVATIONS

- a) The *fine gold* casting area is separate from the refinery. There did not appear to be any restrictions on access.
- b) Provision for spillage and crucible failure was not evident.
- c) Scraps from scarfing are returned to the chlorination furnace. The purity of the gold is likely to be high, as there are no major sources of contamination, and it is unclear why this is carried out. It may be of sufficient purity to be re-melted into anodes directly.
- d) With regard to graining, it is assumed that the grain outside of the specifications is recycled with the scraps.
- e) Overall, a dedicated scrap and fumed gold recovery process which provides high gold recoveries without dilution and keeps the gold in the *fine gold* area is viewed as beneficial.

3.6.6 RECOMMENDATIONS

- a) The aim should be to account for all the gold leaving the *fine gold* area, other than products. This should be minimised to reduce inter-departmental transactions and incorporation into processes where dilution and loss are possible.
- b) A feed preparation system and re-melting furnace could be incorporated into the *fine gold* area which would address the recovery and recycling of the major sources of loss in the *fine gold* area. The only input material (other than product) leaving the area should be crucibles and consumables.

3.7 Testing

The need for testing of some of the processes arose after an analysis of gold potential losses highlighted some areas of vulnerability. A list of the sources of potential gold losses was compiled. The sources were evaluated as to magnitude of exposure. The advantages to be derived from testing by third party specialist were reviewed with the RCM and a list of priority testing areas was agreed upon. The list of these tests is included in Appendix G.

Based on the above analyses, it was decided to carry out a mass balance testing of the chlorination and Slag Recovery process. The results are presented in Section 3.7.1 below. It was also decided to carry out third party sampling and *assaying* of certain *by-products* by SGS, a firm specializing in these areas. The *by-products* tested and the results are presented in Section 3.7.2 below.

3.7.1 MASS BALANCE TESTING

Mass Balance Testing was conducted at the RCM from August 20 to August 26, 2009. Testing was directed and witnessed by GAL/IBI Group staff. Weighing and test sampling was completed by RCM refinery personnel. *Assaying* was completed by the RCM Assay Lab and results were transmitted to GAL/IBI Group for analysis.

Objective

- a) The objective of Mass Balance Testing is to confirm that the mass of material that goes into a process is equivalent to the mass of material that comes out of a process. In this case, the Mass Balance is conducted to track the amount of gold and silver that goes into and out of the Refinery Chlorination and *Hydromet* processes.
- b) A secondary objective of this test is to confirm that the percentage of gold and silver in the Slag and by-product process streams is within expected tolerances.
- c) It is difficult to run an accurate test in a production environment such as exists at the RCM Refinery for the following reasons:
 1. There are many people involved in handling the various materials and there are several sub-processes occurring that could impact the mass balance results.
 2. The Chlorination Batches are run in lots while the *Hydromet* Process is a batch process and generally does not run according to the same chlorination lots.
 3. At each test point, the material must be weighed, sampled and *assayed* to determine the percentage of Gold and Silver in the process stream. It can be difficult to obtain representative samples of the materials generated.
 4. The materials to be sampled include molten metal, molten slag, hygroscopic Silver Chloride slag bricks, filter press cakes and ground slag residues.

Methodology

- a) The material flow for the Mass Balance Test is shown on Figure 3.7. A list of the test samples and the chlorination test results for three batches are included in Appendix B.
- b) The sketch identifies the points in the process at which weights were taken, samples were drawn and assays were conducted by the RCM Assay Department.
- c) A total of 3 Chlorination Batches were tracked through Chlorination and the *Hydromet* Processes. Weights were taken for all materials containing precious metals. A total of 13 different samples were drawn for assay from each of the three chlorination batches. Together with the startup Slag sample, a total of 40 samples were drawn for assay from the 3 batches.
- d) Timed Slag Dip Samples - A subsidiary test was run on the Slag in the Melt Furnace for each Chlorination Batch. Each Chlorination Batch was melted in 2 lots in the Melt Furnace and three dip samples were taken from each lot at timed intervals of approximately 4 minutes. A total of 3 samples were taken from each lot, 2 lots per chlorination batch for a total of 18 timed dip samples of the Slag.

Summary of Results

- a) Comparison of gold OUT vs IN of the Chlorination/*Hydromet* process.

Test No	Gold
90381	+0.6%
90382	-0.1%
90383	+0.6%

- 1. Gold into chlorination is equal to gold out of *Hydromet* to within 1% on each of the three tests.

- b) Percentages of Metals in the Slag going into the Melt Furnace

Test No.	Gold	Silver	Copper
90381	2.4%	25.9%	16.7%
90382	2.1%	26.6%	52.8%
90383	1.7%	13.1%	39.8%

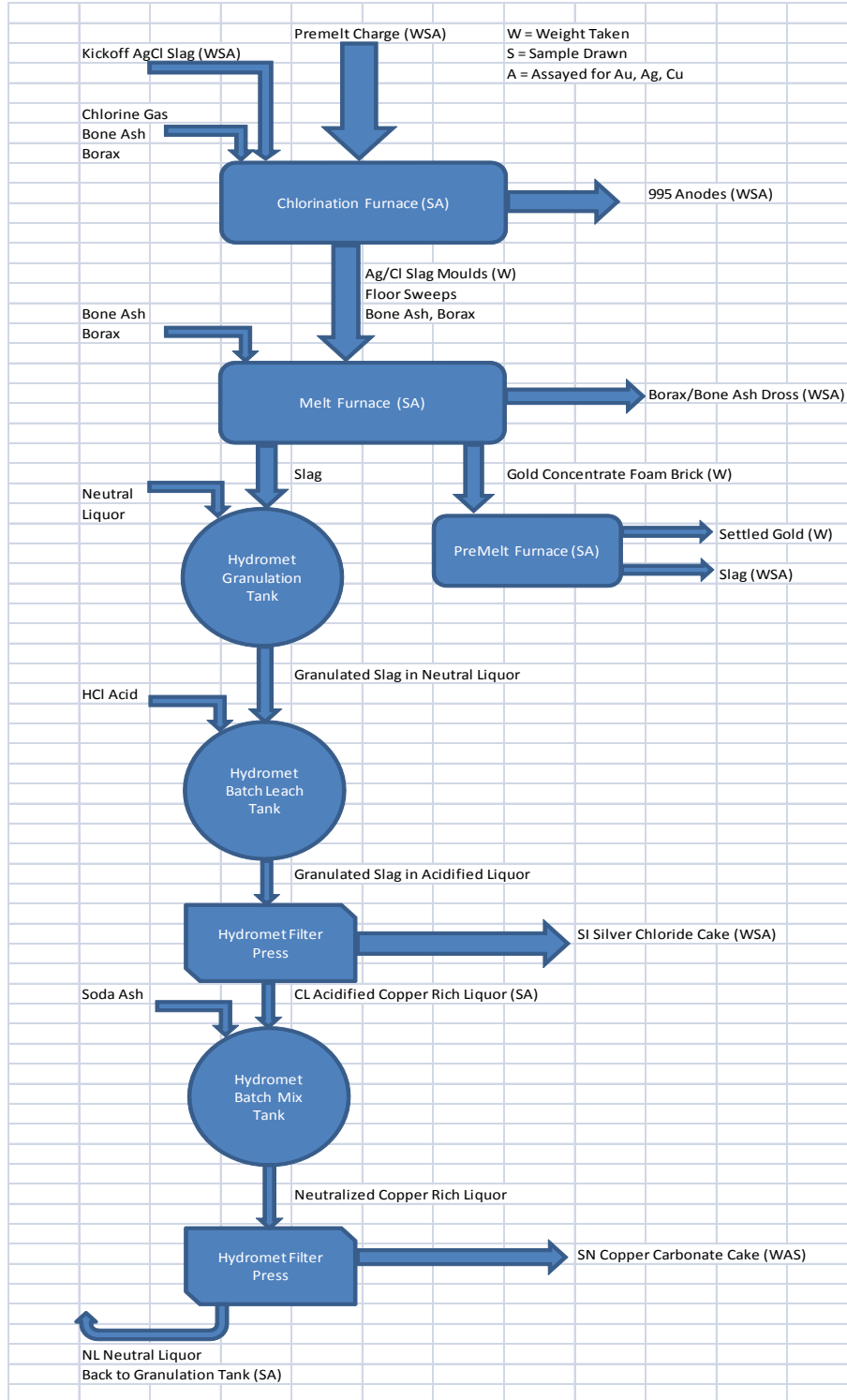
- 1. Gold and silver content in the Slag shows that the chlorination and baling process is generating the expected gold purity levels.
- 2. Copper content is generally expected to be volatilized off in the fume during chlorination. Further investigation would be required to determine why copper content is so variable.

- c) Timed Slag Dip Samples – Results showed minor variation in the percentage of silver, gold and copper in the Slag after it had been melted. With the exception of one of the 18 samples drawn, all samples showed that the remaining gold was within 0.001 and 0.12%. The exception sample was likely drawn too deeply in the melt resulting in gold content at 1.19%. This demonstrates for these three tests that the gold had sufficient time to settle before pouring Slag was poured into the *Hydromet* process.

Observations

- a) Results of the gold mass show that gold mass was conserved across the Chlorination and *Hydromet* processes.
- b) At the start of the *Hydromet* process test, the Chlorination Slag composition was 2.0% to 3.0% gold. This was reduced to less than 0.12% after granulation. This is a similar result as achieved by *de-golding*.

Figure 3.7 - Mass Balance Test Process



REPORT

a) Photographs Taken During Mass Balance Tests

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Photo 1 – Chlorination Batch



Photo 2 – XRF Machine used to analyze dip samples from the chlorination furnace to determine if gold is refined to 995 or better

Note: All photos are published with approval from RCM.

REPORT



Photo 3 – Pouring, Quenching & Stacking 995 Anodes



Photo 4 –Moulds of Slag taken from Chlorination Batch 90382 ready to be demoulded and remelted

REPORT



Photo 5 – Demoulded Slag from Chlorination Batch 90381 ready to be remelted



Photo 6 – Timed Slag Dip samples drawn from remelted Slag



Photo 7 – Timed Slag Dip samples bottled for transport to Assay Lab

3.7.2 THIRD PARTY SAMPLING AND ASSAY

SGS conducted sampling at the RCM from August 26 through to August 28, 2009. Testing was directed by SGS personnel and witnessed by GAL/IBI Group staff. Weighing and test sampling was completed by RCM refinery personnel under the supervision of SGS staff.

Objective

- a) The objective of Third Party Sampling and Assay Testing is to confirm that sample methodology followed by the RCM provides results that are repeatable and verifiable by a third party testing agency.
- b) A second objective is to identify alternative sampling strategies where the RCM's current sampling methodology could be improved.

Methodology

- a) Potential areas of process loss were identified by GAL/IBI Group on the attached chart. Each area was assigned a risk for loss and materials considered at high risk for process loss or for high variability were identified for third party sampling and assay testing. Materials identified were:
1. RCM received Doré and jewellery submitted for refining
 2. Silver Sand from *Hydromet* process
 3. Copper Carbonate filter cake from *Hydromet* process
 4. *Silver Chloride cake* from *Hydromet* process
 5. *Cottrell* dusts / Sludges from bottom of the *Cottrell* collection system
 6. Depleted Hydromet Liquors from Hydromet process
 7. Spent Electrolyte from gold Electrolyte cells
 8. Chlorinated Slag from the Miller Chlorination process
- b) Samples were generated using SGS sampling protocols. The purpose of this approach was to compare the results achieved by RCM vs. Independent testing.
- c) Samples were prepared and analyzed by the SGS laboratory in Lakefield, Ontario, for Au, Ag and platinum group metals
- d) RCM samples were analyzed at RCM Assay laboratory for comparison
- e) The Chlorination Slag sampling and test was completely carried out by an independent testing agency (SGS Mineral Services). The test was designed to determine the amount of precious metals in the Chlorination Slag by simulating the process of sending the Slag to an outside refinery. Refer to Appendix C for a complete step by step sequence of events, as documented by GAL/IBI Group.

The following is a summary of the methodology used to conduct the Chlorination Slag test:

- a) The Slag was shipped in sealed drums (5) to SGS for uniform mixing and splitting. Two and half drums were returned to RCM to forward to a third refinery for sampling, assay and processing. The other two and a half barrels remained at SGS and were prepared for sampling by a series of screening and grinding steps to get the material to 110 mesh.
- b) Eight samples were prepared; two were retained by SGS for moisture determination and assay and the other six returned to RCM
- c) There was a total of 860 grams of gold nuggets recovered. This gold was melted in the SGS furnace and sampled by drilling a number of holes. The shavings were assayed for gold and silver content. The gold button and the remaining shavings were returned to RCM. RCM assayed the received shavings for gold and silver content.

SGS Test Results

The results of SGS testing are contained in SGS detailed report in Appendix A.

The SGS report describes the details of both the RCM and SGS sampling protocols for each material type, as well as details of the sample preparation performed by SGS in order to generate samples suitable for metals analysis

Analytical results, including the Slag tests, for the materials sampled, prepared and assayed by SGS Minerals Services are published in the Certificate of Analysis included in Appendix E.

Summary of Test Results

The following table summarizes the test results and includes both the SGS and RCM assay results.

Table 3.2 – Summary of Test Results

Item	Material	Sampling* Methodology by	Assay Results by	Gold (g/kg)	Silver (g/kg)	Platinum (g/t)	Palladium (g/t)
1.	Dore RCM Deposit #4464	RCM	SGS	832.68	143.24	<0.02	<0.02
			RCM	832.25	144		
2.	Dore RCM Deposit #4465	RCM	SGS	832.20	142.76	<0.02	<0.02
			RCM	832	144		
3.	Dore RCM Deposit #4466	RCM	SGS	829.50	143.10	<0.02	<0.02
			RCM	829.75	145		
4.	Jewellery Scrap RCM Deposit #4467	RCM	SGS	545.13	85.55	121.3	587
			RCM	546.25	82		
5.	Dore RCM Deposit #4489	RCM	SGS	999.04	0.88	18.9	57.8
			RCM	998.4	0		
6.	Electrolysis Slime CAB #7-8 25-08-09	RCM	SGS	951.53	27.45	34.2	96.7
			RCM	965	28.0		
7.	Spent Electrolyte Soln Pt/Pd 09-06-15 Fe Treated Include residue	SGS	SGS	26.951	0.0981	3580	4791
			RCM	26.361	0.0953	3475	4668
			RCM	32.780	0.1293	4855	6426
8.	Copper/Iron Carbonate Cake Batch 550-C	SGS	SGS	0.128	4.528	<0.02	0.14
			RCM	.0119	2.830	<0.02	0.04
			RCM	N/A	N/A		
9.	Silver Chloride Paste Lot 549-M	SGS	SGS	42.10	462.03	6.80	59.7
			RCM	75.22	436.21	6.25	46.5
			RCM	49.3	420.9		
10.	Depleted Hydromet Liquor Lot 149 Include residue	RCM	SGS	0.00012	0.499	<0.02	<0.02
			RCM	<dL**	0.554		
11.	Depleted Hydromet Liquor Lot 150 Include residue	RCM	SGS	0.00006	0.498	<0.02	<0.02
			RCM	<dL	0.551		
12.	Depleted Hydromet Liquor Lot 151 Include residue	SGS	SGS	0.00008	0.523	<0.02	<0.02
			RCM	<dL	0.576		
13.	Depleted Hydromet Liquor Lot 152 Include residue	SGS	SGS	0.00161	0.557	<0.02	<0.02
			RCM	<dL	0.618		
14.	Silver Sand RCM Lot 157	RCM	SGS	34.35	483.97	1.46	13.5
			RCM	39.78	519.60		

Item	Material	Sampling* Methodology by	Assay Results by	Gold (g/kg)	Silver (g/kg)	Platinum (g/t)	Palladium (g/t)
15.	Silver Sand RCM Lot 160	RCM	SGS	31.21	328.74	2.15	17.8
			RCM	26.4	325.5		
16.	Silver Sand RCM Lot 164	RCM	SGS	50.43	558.28	2.44	18.2
			RCM	28.1	402.4		
17.	Silver Sand RCM Lot 181	RCM	SGS	41.14	468.88	3.89	25.1
			RCM	42.8	478.3		
18.	Silver Sand RCM Lot 211	RCM	SGS	46.21	515.62	9.72	32.7
			RCM	41.4	517.3		
19.	Silver Sand RCM Lot 218	RCM	SGS	47.60	576.07	7.34	43.7
			RCM	46.1	575.5		
20.	<i>Cottrell</i> Dusts/Sludge SLD09 03-46	RCM	SGS	95.963	34.806		
			RCM	51.086	33.721		
21.	<i>Cottrell</i> Dusts/Sludge SLD09 03-44	RCM	SGS	41.279	26.487		
			RCM	45.635	31.979		
*	All sampling was conducted in the presence of the independent testing agency.						
**	dL: Detected Limit						

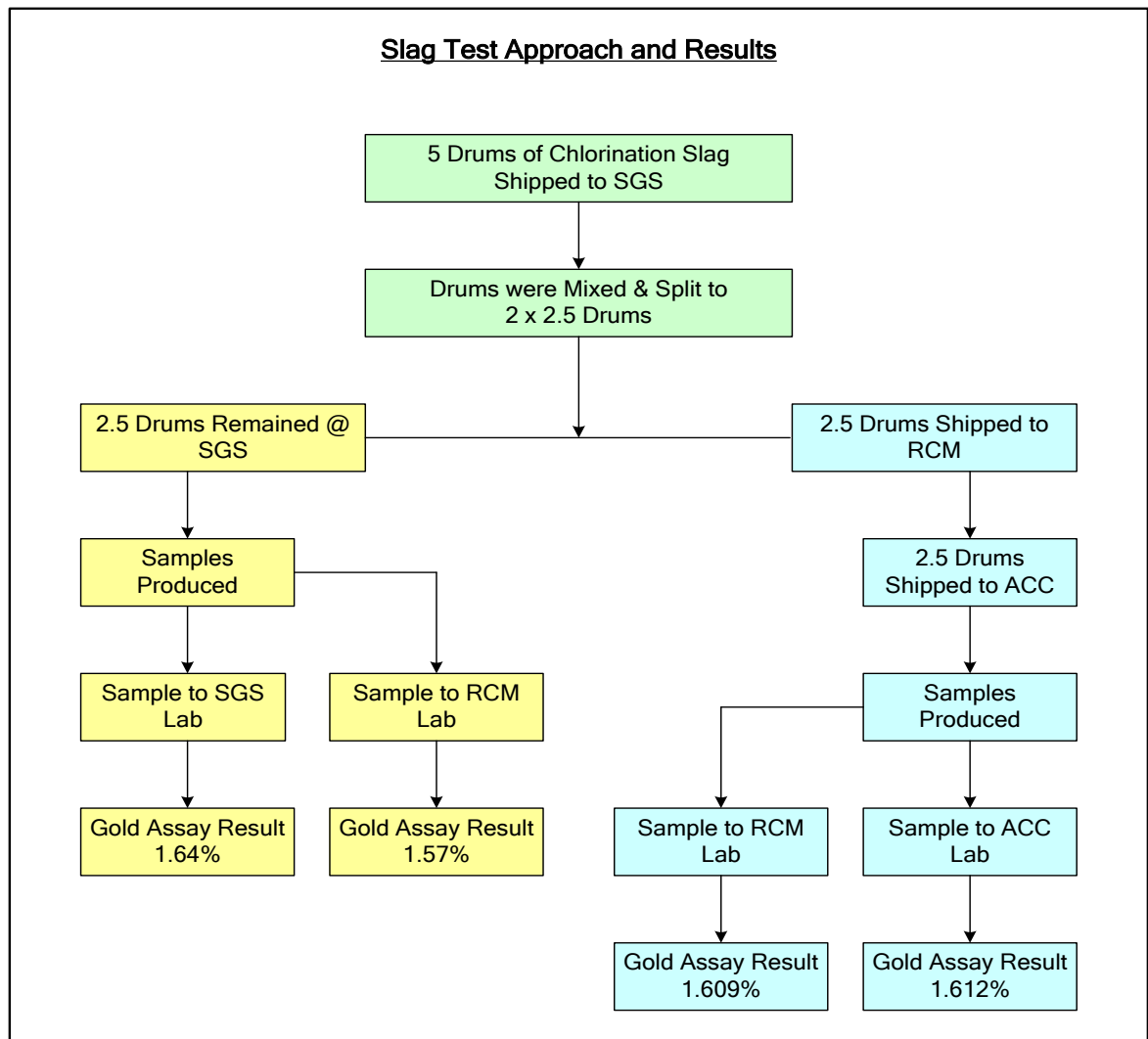
The following table summarizes the Slag test results from SGS, ACC and RCM.

Table 3.3 – Summary of Slag Test Results

Chlorination Slag	Sampling Methodology by	Gold%	Silver%
SGS	SGS	1.624	13.545
RCM	SGS	1.573	13.774
ACC	ACC	1.612	14.383
RCM	ACC	1.609	14.143

The following flow chart summarizes the steps of the slag test carried out by RCM, SGS and ACC.

Figure 3.8 – Slag Testing Comparison



Observations

- a) There was a greater than expected amount of gold (target 1 ppm, actual 26,500 ppm) in the spent electrolyte solution. The solution was re-treated with iron-salt to reduce the gold content to 1 ppm.
- b) There was good agreement between SGS and RCM assay of the SGS prepared Chlorination Slag sample.
- c) Based on the sampling approach and the samples prepared by an External Refiner (ACC), the tests for the Slag gold content showed consistent results between ACC and RCM.
- d) Based on the two different sampling techniques used by SGS and ACC for the same slag batch, the slag gold content showed consistent results between SGS, ACC and RCM.
- e) There were minor differences between the results of the independent testing and the testing done by RCM and witnessed by GAL/IBI Group, of the *Doré* and jewellery gold pintube samples. These results show high correlation and indicate that the RCM sample and assay method used for these materials is repeatable, verifiable and reliable.
- f) The accuracy of the RCM test results of the remaining by-products is within an average of $\pm 5\%$ (worst case scenario) of the SGS test results. Although, this range is less accurate than the accepted industry standard ($\pm 0.2\%$), it represents an insignificant amount of unrecoverable losses.

3.7.3 ACC SITE VISIT

GAL/IBI carried out a site visit to external refiner ACC to observe the *salt Slag* processing, sampling and assay methods. In general, the ACC facility was found to be well run and, with the exception of sample preparation, the procedures for receiving, weighing, storing, milling and mixing, and *assaying* the *salt Slag* were in the whole satisfactory. Also, staff adhered to those procedures in the conduct of their operations.

While on site, RCM representative was also available and provided documentation pertaining to his role of overseeing the testing of RCM's materials. The following summarizes the observations made during this site visit:

- a) The record keeping and dispatch weighing procedures at RCM are inconsistent. At times, the number of barrels of Slag being recorded as having identical weights is too high.
- b) The RCM representative at ACC does not have detailed standardized monitoring procedures.
- c) There are no standardized procedures for the preparation and sampling of the Slag shipments at RCM, and the processing and sampling of the Slag at the ACC refinery.
- d) The bulk sample preparation and the sampling method (by taking spear samples) at ACC needs to be validated. The present method which rejects the coarse and fine fractions of the melted Slag can be improved upon.
- e) Monitoring and control of silver salt shipments to ACC can be improved upon if these shipments were made regularly and consistently.

- f) Batches received at ACC should be linked to those treated at the RCM.
- g) Lot identification and weighing procedures as well as storage facilities were found to be acceptable.

Note: As at the time of the site visit, by-products were received from the RCM but were not processed.

3.8 Process Exhaust

The refinery's many processes generate gases, fumes and dust which are evacuated through a system of wet scrubbers, electrostatic precipitators, fume hoods and dust collecting equipment. A general description of the system is provided in the Process Flow Diagram, Figure 3.9 included below. A detailed schematic of the process exhaust systems is provided in Refinery Process Exhaust Flow Sheet SK-M004 in Appendix F.

3.8.1 SYSTEM DESCRIPTION

In the refinery processes fumes are generated, captured and exhausted to the atmosphere. Depending on the characteristics of the fumes, some of the exhausts are treated with abatement systems prior to emission to the atmosphere. This is to comply with the Ministry of the Environment (MOE) Air Emission limits and also to recover the precious metals that may be present in the exhaust streams. A brief outline of the process exhaust streams is shown in the process exhaust flow Diagram 3.8 included herein.

- a) For processes that generate both acidic fumes and dust like the Chlorination process, the exhaust will be treated with an Electrostatic Precipitator (ESP) followed by a caustic Scrubber.
- b) For processes that generate dry dust, like the Premelt, Silver Melt, *Fine Gold*, *TBRC* and Slag processes, the exhaust will be treated with a dust collector before emission to the atmosphere.
- c) For processes that generate acidic fumes, like the Gemstone and Jewellery Dissolve process, the exhaust will be treated with a caustic Scrubber prior to discharging to the atmosphere.
- d) For other general operations, the exhaust will discharge directly to the atmosphere via stacks.

A greater detail of the overall refinery process exhaust flow at the Ottawa facility is included in Appendix F. The following is a description of the exhaust system for each of the processes.

Pre-melt Process

In the pre-melt process, the fumes from the furnace IF-01 and IF-02 fume rings exhaust to the #1 Cartridge dust collector. In each of the induction furnaces there is a ring of slot, about 50 mm (2 inches) high around the top of the furnace, which sucks the hot air together with any particulate matters from the furnace to the exhaust system.

#1 Cartridge dust collector is designed for high static pressure and low air flow volume it is dedicated to all furnace fume rings and the pouring hood except for the furnaces of the chlorination process. All other exhausts from the pre-melt mould prep booth, and the bar buffing are extracted through to #2 Cartridge dust collector, which is designed for low static pressure and high air flow volume.

Silver Melt Process

The exhausts from fume rings of furnace IF-3A and IF-3B and the new IF-10A and IF-10B go to the #1 Cartridge dust collector. Other exhausts from mould prep hoods and overhead canopies go to #2 Cartridge dust collector.

Chlorination Process

During the chlorination process and to convert gold to 99.5% purity, volatile metal chlorides including gold and silver and other metals are generated. The fume ring exhausts from IF-06 and IF-07 go to the *Cottrell* Electrostatic Precipitator via two exhaust fans. The chlorides in the exhaust tend to attract moisture in the air to form hydrochloric acid and create dust sludge in the ductwork. Currently, a simple condensation system consists of a flexible hose and a drum located just below the furnace in the basement level is used to collect the sludge before being carried over to the *Cottrell*. There is also a U trap in the ductwork prior to the fan to occasionally drain off any additional condensation in the ductwork.

Inside the *Cottrell*, the particulates in the exhaust stream are charged by high potential electric field and collected by discharge electrodes. After the *Cottrell* precipitator the exhaust flow is directed to a wet packed tower scrubber where caustic solution is used to remove the residual chlorine and hydrochloric acid derived from the chlorination process prior to emission to the atmosphere via the main refinery stack.

As part of the chlorination process, Slag is generated mainly from silver and copper chlorides which form a crust floating on the molten metal surface. The Slag is manually bailed out and poured into Slag moulds. Bailing hoods are used to capture the fumes from the hot Slag and the exhaust goes directly to the paced tower scrubber for treatment. Other exhaust from the mould prep booths and overhead canopies will go to #2 Cartridge dust collector.

Fine Gold Process

The 99.99 *fine gold* from the gold electrolysis is re-melted in IF -04 and IF-09 and cast into bars or ingots. The exhaust from the furnace fume rings goes to #1 Cartridge dust collector, while the exhaust from the mould prep booth and kilo bar furnace goes to #2 cartridge dust collector.

Gold Electrolysis Process

The final stage of the gold refining process is by electrolysis. The gold electrolysis reaction is completed in a series of cabinets containing electrolysis cells. The cabinets are equipped with fume hoods which are connected to two independent exhaust fans and stacks EF-27 and EF-28. Another fan EF-99 and stack is for the exhausts from the washing and drying of the gold plating electrodes.

Silver Refinery Process

The exhaust from the silver dissolvmat and the silver hydrolysis goes to atmosphere via fan EF-313. The exhaust from the High Speed Silver Electrolysis (*HSSE*) goes to exhaust manifold of fans EF-66A or EF-66B. EF-66A and EF-66B will work on a lead/lag system to equalize runtime. One fan runs continuously while the second serves as a back-up.

Laboratory Fume Hoods and Assay Area

Eight laboratory fume hoods together with the engineering laboratory are connected to the exhaust manifold of fans EF-66A and EF-66B. The Fire Assay furnaces are connected to exhaust fan EF-11. The Fire Assay area is exhausted to atmosphere via fan EF-14.

Gemstone Process

The current Gemstone process generates hydrochloric acid and nitric acid fumes and the exhaust is treated with a caustic scrubber before releasing to the atmosphere via fan BL-04. A new Gemstone process is being developed to eliminate the nitric acid emission. EF-306 will be used for the new Gemstone process.

The RCM employs an aqua regia solution (nitric and hydrochloric acids) to recover gemstones from old jewellery. Acidic fumes from the vessel where this reaction takes place are scrubbed in a unit that employs approximately 300 litres of 50% caustic soda solution. The caustic scrubber solution performs two basic functions, namely, it neutralizes fume acidity and precipitates heavy metals (including precious metals).

Once every month, the aqua regia scrubber is shut down for several hours (usually on weekends) to permit suspended solids to settle out for easy retrieval. The resulting clear supernatant solution is sampled for precious metals, placed in drums and shipped off-site for final treatment/disposal. The suspended solids are filtered, dried and returned to the chlorination area for precious metal recover.

Slag Granulation and Hydromet Processes

The exhaust from the Slag granulation process is connected to the manifold of the chlorination furnace ring IF-06 and it goes to the *Cottrell* precipitator for further treatment. The exhaust from the silver recovery Hydromet process goes directly to the packed tower scrubber.

Miscellaneous Exhausts

There are other miscellaneous processes which generate dusty fumes will have the exhaust connected to the ductwork of the #2 Cartridge dust collector. These are for *TBRC* furnace, Gas Burning furnace, crushing, milling, sieving, separating and *sweeps* exhausts. The overhead exhaust canopies in the areas are also connected to #2 Cartridge dust collector.

Main Refinery Exhaust

The main refinery exhaust system includes one *Cottrell* electrostatic precipitator with two furnace booster fans, one packed tower caustic scrubber with redundant fans and two cartridge dust collectors. Most individual pieces of refinery equipment are equipped with exhaust air control dampers, user switches and for furnaces indicating lights. When equipment is to be used, the appropriate user switch will be turned on. In the case of the furnaces, the green indicating light will turn on when the exhaust damper is open and the appropriate fan is in operation.

The refinery operation is exhausted primarily through 3 different exhaust streams which are then discharged to the atmosphere via one Refinery stack.

- a) Furnace rings for IF-06 and IF-07 are exhaust through the lower *Cottrell* and the packed tower scrubber while the bailing hoods for IF-06 and IF-07 are exhausted directly through scrubber.
- b) The furnace rings with the exception of IF-06 and IF-07 are exhausted through #1 (small) Cartridge dust collector.
- c) The general exhaust from cabinets, hoods and the *sweeps* area is exhausted through #2 (large) Cartridge dust collector.

Cottrell Electrostatic Precipitator

The electrostatic precipitator is the original unit supplied by *Cottrell* in 1935. There were two ESP (Upper and Lower) used originally in treating the refinery process exhausts. Since the recent modifications (from 2005 to 2007) to the exhaust system, only the lower *Cottrell* ESP remains in operation and is used to treat the chlorination exhaust from furnace rings IF-06 and IF-07. The upper *Cottrell* has been replaced with two cartridge dust collectors for capturing exhausts from other furnaces. The lower *Cottrell* consists of two cells in series. The original *Cottrell* design was based on positive pressure, 35,000 cfm (cubic feet per minute) with 99% particulate removal. The retrofit converted the *Cottrell* ESP to a negatively pressured and reduced flow system. The total maximum air flow requirement through the lower *Cottrell* is 5,000 cfm intermittently. Each chlorination furnace is equipped with a booster exhaust fan with 2,500 cfm capacity.

On request for exhaust system operation from the user switch at furnace IF-06 or IF-07, the respective booster fan will start and the *Cottrell* will be able to operate. When the *Cottrell* is requested to run, the isolation damper will open and each of the two cells will be turned on. Each cell in the ESP is monitored for faults. The *Cottrell* cleaning cycle consists of shaker and rappers. The shaker will operate for 5 seconds when the *Cottrell* is turned ON, and will operate every 4 hours after that. One minute after the shaker operates the rapper will operate for 5 seconds. The dust/sludge from the *Cottrell* will be manually cleaned out (normally during stock take day) and sent to outside for further treatment to recover the precious metals.

Cartridge Dust Collectors

As part of the recent modification of the exhaust system, the upper *Cottrell* ESP was removed and replaced with dust collector system. The system consists one small (#1) and one large (#2) cartridge dust collectors. Each dust collector is equipped with a variable speed drive exhaust fan. All the dry exhausts from the Pre-melt, Silver Melt and *Fine Gold* and *Sweeps* processes will be treated by the dust collector system. The dust collectors are downflow type with oval cartridge filters as supplied by Torit. High efficiency Ultra-Web Nanofiber cartridges are used with 99.9% filtration efficiency on 0.2 to 2.0 micron dust particles.

#1 Cartridge (small) has a capacity of 7,500 cfm and serves all the fume rings in furnaces IF-01, IF-02, IF-03, IF-04, IF-09 and IF-010. It operates whenever one of the furnaces is being requested by its local user switch. The furnace fume ring damper will open and the running light will turn on. The unit's variable speed drive will modulate to maintain static pressure in the duct. The fan will shut down if none of the furnaces is being used and the local switch is OFF.

#2 Cartridge (large) has a capacity of 35,000 cfm and serves the general exhaust from all mould hoods, overhead canopies and *sweeps* in the refinery areas. It operates whenever the refinery operation is being done and its operation switch is in AUTO or PURGE position. Once #2 Cartridge is switched ON it will run continuously. The local hood damper will be open if it is switched on to operate. The variable speed drive on the unit will modulate to main the static pressure in the duct.

The dust collectors are equipped with automatic filter cleaning system using compressed air to pulse off dust from the surface of the filters. The dust is collected in drums at the bottom of the hopper. Currently the cartridge filter replacement is about two to three months. The collected dust and the spent filters are sent out for further treatment to recover the precious metals.

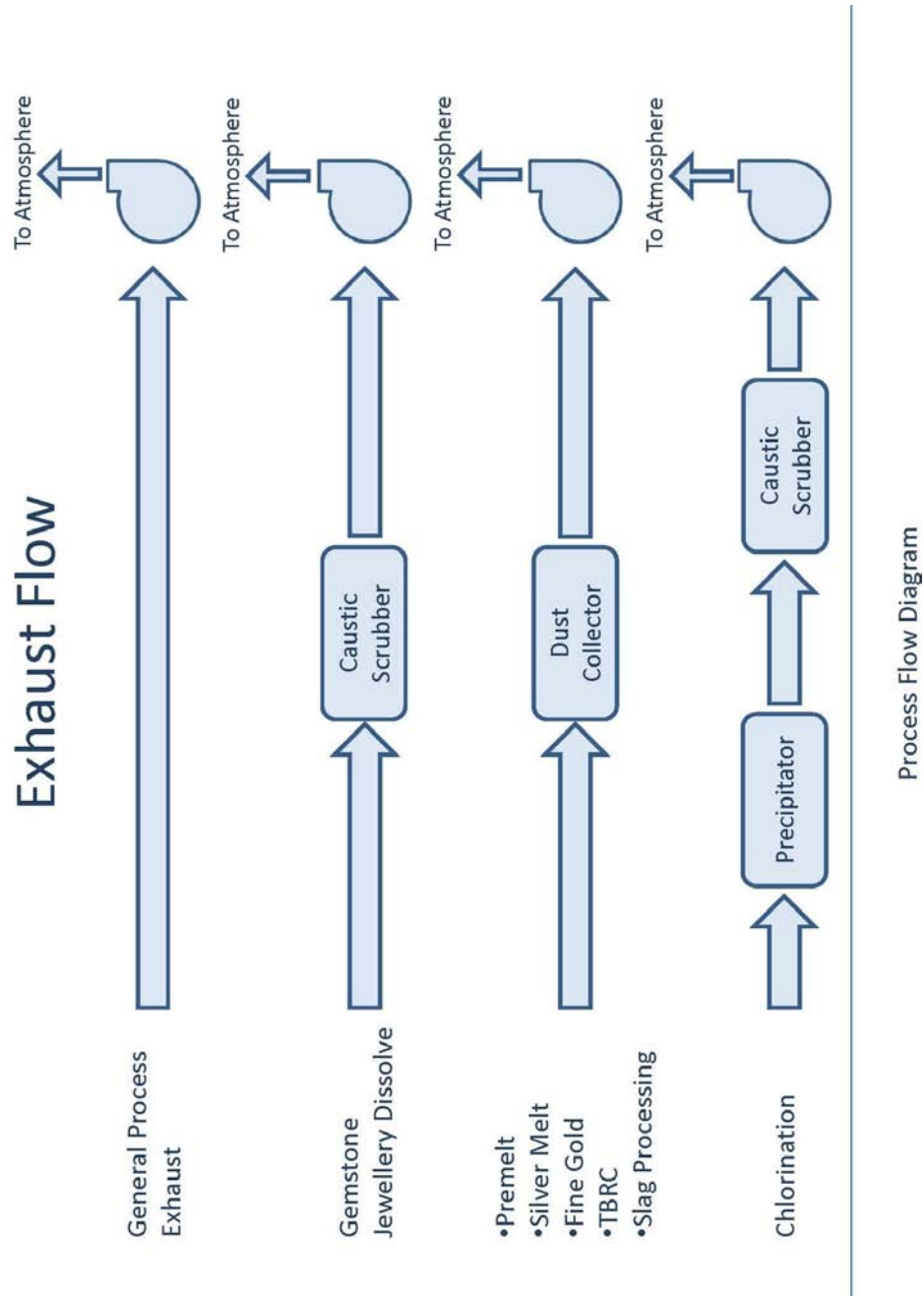
Packed Tower Scrubber

During the Chlorination process there is residual chlorine gas and possible formation of hydrochloric acid in the exhaust streams. The exhaust has to be treated with a caustic scrubber before emitting to the atmosphere. These are the exhausts from the *Cottrell* and the bailing hoods for IF-06 and IF-07. The wet scrubber uses caustic solution as the scrubber agent circulating in a loop with pH controlled for addition of the caustic and bleed off the solution and with integral mist eliminator at the gas outlet. There are two scrubber fans and they are configured for redundant operation. One is running while the other is a back-up. Each fan has variable speed drive to control and maintain a negative 2" water gauge static pressure at the inlet of the scrubber. The spent scrubbed solution is collected and sent out for further treatment to recover any precious metals.

The packed tower scrubber utilizes approximately 1500 litres of 50% caustic soda solution to neutralize acidic fumes and to precipitate heavy metals present in those fumes. Once every two to three months, the scrubber is taken out of service (usually on weekends) for several hours to facilitate the process of solids/liquid separation as happens with the aqua regia scrubber. The clarified scrubber effluent is removed by a vacuum tanker truck for off-site/treatment disposal while the "sludge" (settled solids and caustic soda solution) is processed for precious metal recovery either on-site or off-site.

RCM officials advised GAL/IBI Group that a form of mercury has been detected in the clarified scrubber effluent and this precludes its discharge to the municipal sewer. Ottawa's sewer-use bylaw restricts mercury levels to one part per billion (1 ppb) and this is probably the most stringent requirement in Canada. (Toronto permits 10 ppb mercury and Winnipeg, 100 ppb).

Figure 3.9 – Exhaust Flow



3.8.2 PROCEDURE

The operation procedures of the exhaust systems are included in the System Description section.

3.8.3 POTENTIAL LOSSES

The potential losses of precious metals in the exhaust streams could be the following:

- a) Loss to the atmosphere via stacks
- b) Loss in the ductwork system
- c) Loss in the *Cottrell* and the precipitated dust/sludge
- d) Loss in the scrubbed solution
- e) Loss in the dust collector in the dust and entrapment in the filters

However the only permanent loss of gold and silver is through the stacks to the atmosphere. The 2008 RWDI Air Emission Report indicates that the site wide emissions of gold are 0.0002g/s and silver is less than 0.00027g/s. We can assume that these are the rates of gold and silver loss to the atmosphere during production. If we assume 16 hours per day and 240 days per year of production, then the calculated stack loss will amount to about 89 oz of gold and 120 oz of silver per year. This is a conservative estimate since the actual process operation to generate the fumes would not be continuous for the entire duration used in the calculation.

All other potential losses are captured for treatment to recover the precious metals. The ductwork from chlorination to the *Cottrell* is taken apart to clean out the build-up dust and collected in drums. The *Cottrell* is cleaned out and the dust and sludge are collected in drums. The dust from the dust collectors and the spent filters are saved in drums or collection bins. All these *by-products* are sent to External Refiners for treatment to recover the precious metals. The shipment will be *assayed* and the actual amount of precious metals will be adjusted in the calculated ending stock. The equipment clean out process is normally performed during stock take for the period. It is indicated in the reconciliation report that the total amount of gold recovered from the refinery exhaust dust /sludge was 11,250 oz in 2008, which was about 0.40% of the gold refinery output.

3.8.4 STACK SAMPLING

RWDI Air Inc. was retained by the RCM to conduct a detailed site wide air emissions assessment for their facility located in Ottawa. The air emissions were developed using a combination of RWDI stack testing performed in November 2008, past stack testing reports, engineering calculations and emission factors. The stack sampling and testing was to identify and quantify the air emissions from the process exhaust points at RCM Ottawa site and to determine the off-site impacts of the emissions using the air dispersion modeling as defined by MOE.

There was a stack testing done in 2001 and the report indicated that the site wide emissions rates of 0.0000314g/s for gold and 0.000187g/s for silver, which were far less than those of 2008.

In order to reconfirm the stack loss for the Ottawa facility it is requested to engage RWDI to perform additional air emission tests specifically for gold and silver on certain stacks. It was noted that in the 2008 report only the refinery stack was tested for gold.

3.8.5 DUST COLLECTOR EFFICIENCY

A brief discussion with the plant indicated that the dust collector systems have been operated well since their installation in 2007. There was an efficiency test done on #1 Cartridge and the results are in-line with the manufacturer's specified performance.

3.8.6 LOWER COTTRELL ELECTROSTATIC PRECIPITATOR EFFICIENCY

The historical test data (from 1936 to 1972) indicated the *Cottrell* has been operated with over 97.5% efficiency removal of particulates and over 95% efficiency of removal for gold and silver. There is no recent efficiency test done on the *Cottrell* unit.

The plant is in the process of replacing the *Cottrell* ESP with a venturi scrubber by the end of the year 2009. The venturi scrubber can provide just as good particulates removal efficiency as the *Cottrell* but with minimum maintenance. The selection of a high pressure drop (41" of water gauge) venturi throat will give high efficiency for collection of extremely fine particles. A source testing of the gas emissions from the induction furnace IF-07 was performed by Aqua Terre in October 2008. The results of the Particle Size Distribution (PSD) testing indicate that 70% to 80% of the particulate matter was below one micron in size.

3.8.7 PROCESS EXHAUST SYSTEM OBSERVATIONS

In general the process exhaust systems are performing to their design. The ventilation system seemed to be balanced. The fumes generated during the process operation dissipated quickly and captured in the exhaust systems. During the site visit one of the two cells in the *Cottrell* failed to operate. The housekeep in the *Cottrell* room needs to be improved. It was noticed that in the dust collector room there were too many drums stored in the area and blocking the maintenance access to the receiving hoppers.

The ductwork between the chlorination furnaces to the *Cottrell* is too long to have potential chloride sludge build up inside the duct. The existing sludge condensation collection system (hose connected to Y connection of the ductwork and drop into a drum) is not efficient since the duct velocity is too high for the heavy particulates or the wet sludge to settle into the drum.

On the roof, the area is generally in good condition. No noticeable dust accumulation or discoloration of the roof are observed. Some rusty spots are noticed near some of the roof vents or exhaust fans and equipment. The stacks are generally too low and most of them are at or below the intakes of the air make up units. This may cause process exhaust infiltration into the fresh air supply system if the wind blows towards the air intakes.

3.8.8 GOLD RECOVERY FROM REFINERY EXHAUST

Based on our review of the two exhaust stack reports prepared by RWDI Air Inc., in 2001 and 2008 respectively, the amount of unrecoverable gold loss through the exhaust stack is less than 100 oz per year. These results may vary depending on the refinery operating conditions at the time of the tests. A more reliable approach to ensure a properly operating exhaust system would be to introduce a continuous stack monitoring systems.

3.8.9 RECOMMENDATIONS

- a) Review the gold recovered in 2009 from *by-products* in the RCM exhaust system to quantify the rate of gold recovery and compare the recovery against data from continuous stack monitoring to establish a baseline of performance for the exhaust system.
- b) Replace the duct condensate collecting drum system for IF-06 or IF-07 furnaces with a gravity separator (drop box). The gravity separator consists of a fiberglass reinforced plastic (FRP) chamber or housing in which the velocity of the gas stream is made to drop rapidly so that the larger dust particles and condensate settle out by gravity. The size of the chamber will depend on the size and the characteristics of the particles to be captured. In this application a capture velocity of 200 to 300 fpm will probably work. The chamber will be equipped with a hopper section so that a drum can be placed at its bottom to collect the dust and condensate.
- c) Install a chlorine detection and monitoring system in the chlorination room to alarm and activate an automatic valve to shut down the chlorine supply in case of chlorine leaks or malfunctioning of the chlorine sparger system.
- d) Increase the height of the exhaust stacks to above the intakes of the air make-up units so that the resulting plumes do not enter the high turbulence region upwind of the air intakes to contaminate the fresh air supply.
- e) In the 2008 Air emission report it was indicated that the plant is out of compliance for hydrochloric acid emission. More than 55% of it came from the Gold Electrolysis process stacks EF-27 and EF-28. There is no abatement in the present system. It is recommended to investigate the installation of caustic scrubber systems to treat the acid in the exhausts.
- f) Also more than 18% of the hydrochloric acid emission came from the Gemstone process scrubber. It is recommended to examine the scrubber closely to see if improvement could be made or to install a higher efficiency scrubber. The plant is currently adding a new Gemstone process and it has no scrubber. A scrubber system is recommended to add to the new gemstone process to treat its exhaust.
- g) Also more than 15% of the hydrochloric acid emission came from the refinery stack. It is recommended to re-evaluate the packed tower scrubber operation and make adjustment to improve its scrubbing efficiency.
- h) We recommend the installation of instant monitoring with alarm on the main refinery stack. This additional monitoring would alarm on loss of integrity of the Cottrell, the dust collectors or the scrubber, and prevent loss of precious metals with the air exhaust stream.

3.9 Transactions

The transaction processes at the Refinery are critical to the bottom line of the RCM in that they determine and establish the quantity and fineness of the precious metal that is being received. The quantity and fineness that is being sold to customers or sent to coin productions and how much is sent out for recovery by External Refiners with *by-products*. Transactions of precious metal are subject to assay and weight gains and retention, give away and potential losses. A description of the transaction processes follows.

3.9.1 EXISTING PROCESSES

Receipt of Precious Metals

- a) Precious Metals are received via armoured carrier as gold *Doré*, silver *Doré*, or jewellery. Occasionally, Customers will bring in their own gold. The shipment may be sent back unrefined if the incoming paper work shows high levels of arsenic or less than 45% gold.
- b) Receivers perform a piece count to confirm that that Weigh Bill has correct information on it. Piece count could be bags, pallets, bars depending on what has been itemized on the Weigh Bill. If the piece count is wrong, Receiving HOLDS the receipt until the count is sorted out with the Customer.
- c) A Rough Deposit Number is assigned in sequence from the log book and a photo is taken of the deposit. The Receiver enters the deposit into the system to get a PO# assigned by RSS system.
- d) The Receiver takes a 'Before Melt' weight of the received materials and fills out a Rough Deposit Log which includes the "Deposit No.", "Lot No", Customers "Stated Weight" and the RCM's "Before Melt Weight".
- e) The deposit is broken into lots of Maximum 1200 T Oz for Gold Deposits and 4400 T. Oz for Silver Deposits to suit the maximum size of the Premelt Furnaces.
- f) It takes ½ to 1 hour for the receipt to be prepared to be sent to Premelt. The Rough Deposit Log goes with the deposit to the PreMelt Department.
- g) Premelt bars are brought back to Receiving with the deposit number and lot number hand written on each bar. Receiving stamps the deposit number and lot number on each bar and takes an 'After Melt' weight
- h) RCM weights are measured on a *Fine Gold Scale* or on *Rough Gold Scale*.
 - i. *Fine Gold Scale* measures 400 oz at 99,992 ±0.005 oz accuracy (399.987 to 399.997 oz)
 - ii. *Rough Gold Scale* measures 500 oz at 499.944 to 500.044 oz
- i) A Quick Assay order at Receiving is prioritized at Receiving. With a Quick Assay order, the RCM is committed to 3 to 7 day turnaround.
- j) Samples are drawn by RCM refiners using their RCM preparation and sampling methods.

- k) The agreement of Precious Metal content between RCM and the Customer is reached based on three RCM pin tube samples. One sample is sent to the Customer, one is sent to RCM Assay and one is kept in RCM vault in event a third party Umpire assay is required. By contract, some customers also require dip samples.

Outside Processing of Materials

- a) The main *by-products* sent to External Refiners are:
1. Slag from the Miller Chlorination Process – material is prepared by the RCM by jaw crushing and rod milling the Slag cakes to 50 mesh powder which is put in drums for shipment
 2. Electrostatic Precipitator Sludge – material is extracted as a wet sludge and is placed in drums for shipment
 3. Flue and Bag House Dust – fine dust is extracted from the equipment and is placed in drums for shipment
 4. PGM Solutions – solutions are placed in drums for shipment. Solutions generated include:
 - i. Silver slimes generated from *HSSE* process
 - ii. Pt and Pd rich solution remaining after spent gold electrolyte has been processed by decanting and addition of Iron Powder to remove Au to less than 1 PPM per RCM specifications
 - iii. NL Liquor that exceeds capacity of surge tanks in the Hydromet process
 - iv. Copper Carbonate – damp cake generated from Hydromet process
 - v. *Sweeps* – material is collected from the various drums around the refinery and includes, floor sweepings, equipment sweepings, broken crucibles, broken baking cups, borax Slag from Pre-Melt, retrieved dust from equipment being disposed and other materials not categorized into other by-product streams. Material is jaw crushed and rod milled to 50 mesh powder which is put in drums for shipment.
- b) Samples of solid materials and damp cakes are taken by RCM grab method at the start, middle and end of the drum fill for shipment. Samples of liquids are taken by dip tube to the full depth of the drum. These samples may or may not be *assayed* by RCM depending on the material.
- c) Samples are drawn by the Outside Refiner using their preparation and sampling methods.
- d) Agreement on Precious Metal content is reached based on the External Refiners samples. A Third Party Umpire is retained to perform an assay if the RCM and Outside Refiner assays exceed standard industry splitting limits.

Bullion Transactions Between Refinery and Coining

- a) GML bars are cast in TP Lots (Tip/Pour) and collected on a cart. Each lot is transported on a cart to the mill for scarfing. Scraps and *sweeps* are collected into a pot and the entire lot is transported to Receiving for weighing.
- b) Scarfed GML bars are sequentially weighed on a scale in Receiving and the scale automatically inserts GML bar weights into the TP spreadsheet fields.
- c) GML bars are stored in the vault until picked for coining.

- d) Transfer of Bars to Coining
 - 1. GML bars are picked by TP Lot according to the Picking Slip and the attached list of bars comprising that lot. For example, the Picking Slip calls for Picking TP CH09000033 and the attached list identifies three bars (33-1, 33-2 and 33-3) that comprise this TP lot.
 - 2. Picking slip shows the product and weight of the TP Lot and the TP list identifies the weight of each bar.
 - 3. The picked GML bars are delivered on a cart to Coining where a Coining Operator checks the bars on the cart and dates and signs the picking slip
- e) Coining collects scrap onto carts in preparation for transfer back to the Refinery. The scrap is in form of scissile or defective coins in pans. Pans have their tare weights on the side and contain a paper with handwritten weight of scrap.
- f) Transfer of Scrap to Refinery
 - 1. Transfer Order shows total weight transferred back to the Refinery
 - 2. Attached sheet itemizes the trays and individual weights
 - 3. Coining operator delivers the cart to the Refinery where the Refinery Operator checks, dates and signs the transfer order.
 - 4. The scrap is kept in the vault until it is selected as part of a chlorination lot.

Sales of Fine Gold and Silver Bullion Products

- a) The refinery can purchase from the customer the agreed contents or return the metal physically to the customer. The refinery may transfer physical metal internally to coin minting or externally to bullion bank vaults.
- b) The physical metal is most often in the form of 400 T. Oz gold delivery bars, 100 T. Oz kilo bars or gold grain.
- c) Purity can be fineness of 995, 999, 999.9 or 999.99 in parts per thousand.
- d) Samples are drawn by RCM refiners using their RCM preparation and sampling methods.
- e) Precious Metal content is stamped onto bullion bars based on RCM samples.

3.9.2 PROCEDURES

During their site visit, SGS recorded scale serial numbers and noted observations regarding care and maintenance of the weigh scales.

3.9.3 ANALYSIS OF PRODUCT GIVEAWAY FACTORS

RCM Calculation of Giveaway on Gold Trade Bars (400 T. Oz)

- a) Gold Trade Bars of 400 Oz from one TP Number are weighed sequentially by bar number and the weights are automatically entered into the fields on a spreadsheet from the weigh scale.
- b) Each bar is weighed twice and the weight is averaged to provide Actual Average Weight. Bar number and Actual Average Weight is stamped on each bar.
- c) The Actual Average Weight is rounded down to the nearest 0.025 T. Oz. to determine Rounded Weight which is multiplied by Fineness to determine the Final Weight of gold in the bar.
- d) The Rounded Weight is subtracted from the Actual Average Weight of the bar to calculate Giveaway. The spreadsheet automatically highlights bars that are over or underweight and the operator arranges to scrape or remelt the bar.
- e) Each bar is weighed a third time as part of ISO procedures to verify against the previous two weights.
- f) The information is totalled at the bottom of the sheet to provide the Final Weighing Report.

Fine Gold Giveaway Loss Assay (addressed in Section 5.0)

Fine Gold Giveaway Loss weight (addressed in Section 5.0)

Fine Gold Giveaway Loss Assay to coining (addressed in Section 5.0)

Giveaway Loss – Fine Gold in Silver Bars (addressed in Section 5.0)

3.9.4 POTENTIAL LOSSES

External Processing of Materials

- a) Process *by-products* are sold or refined for a retention fee by External Refiners
- b) The potential for loss revolves around whether the material is prepared to a homogeneous state, sampled and *assayed* accurately prior to external shipment. Then the process should be replicated, exactly, at the external refiner under expert witnessing.

Sales of Fine Gold and Silver

- a) Refined Bullion is sold to Customers and Terminal Markets
- b) The potential for loss revolves around the accurate weighing and *assaying* of the refined products. Except in the case of London Gold Delivery bars; it is industry practice to sell refined products with a minimum of the specified weight and purity.
- c) Weight and purity levels must be monitored and kept within tight specifications in order to avoid unbudgeted losses.

Observations

a) External Processing of Materials

1. In order to control and receive the most accurate return from any material sent outside for refining the following measures should be taken:
 - i. The material should be prepared to a homogeneous state and sampled accurately in house, before shipping to External Refiners.
 - ii. An approved and secure shipping company should be used with due compliance to any hazardous materials legislation.
 - iii. At destination, RCM should be represented by a fully qualified independent representative who oversees all steps and stages of the evaluation process. This representative should follow exactly the receiving and sampling protocol agreed and recorded between the RCM and the external refiner. The representative should report to RCM immediately any problems or deviations from the protocol.
2. The production area designated to prepare and sample by-products for external refining is cramped and the equipment is in the main, antiquated.
3. By far the most important in terms of volume, value and complexity is the Miller Slag. According to Deloitte, at the time of the October 2008 inventory, the gold contained in the Miller Slag was approximately 40,000 ozs (68 tonnes at approx 1.87%) this represented x% of the WIP at the time; 49 tonnes of this was eventually shipped to External Refiners. This material is particularly difficult to homogenize and sample representatively. Recommendations on this have been made in section 3.5 of this report and in the report following the visit to ACC, Rhode Island.
4. It appears that sampling protocols are not comprehensively agreed between the RCM and the External Refiners and the appointed independent representative is not fully briefed in performing a comprehensive role.
5. Sales of Fine Gold and Silver

According to discussions with RCM personnel and Deloitte's report, procedures to measure and account for refined bullion product weights and assays relating to sales of absolute amounts and unavoidable giveaways are in place and working properly.

Recommendations

- a) Where practically possible, process *by-products* should be refined in-house.
- b) The amount of precious metal moving between refining departments should be minimized.
- c) Sampling procedures and protocols should be upgraded to ensure that all *by-products* and any subsidiary fractions are brought to a homogeneous state and sampled by agreed methods, before sending out to External Refiners.
- d) Identical sampling procedures and protocols should be followed by the External Refiners
- e) An independent witness should be present at the external refiner for all stages of the receiving and sampling processes and should be fully briefed with all the sampling procedures and protocol requirements.

3.10 General

3.10.1 REVIEW OF DELOITTE & TOUCHE REPORT

Introduction

Deloitte & Touche (D&T) were engaged to investigate the unaccounted differences arising from the October 2008 inventory reconciliation. Their investigation was limited to looking for accounting and/or transaction recording errors and only to this specific inventory reconciliation, not any previous ones, except for the mathematical accuracy of the October 2007 inventory reconciliation. They did not review 100 percent of the transactions but a very high proportion including:

- a) All schedules of the inventory reconciliation count
- b) The mathematical integrity of the inventory reconciliation count
- c) 91% of transactions related to refining material received
- d) 87% of transactions related to direct (refined metal) deposits
- e) Every transaction concerning disbursements to customers was checked
- f) All outside refining transactions – only as far as accounting accuracy
- g) All transactions between the refinery and the production departments
- h) All transactions and movements involving customer owned metals in their *pool* accounts. This included RCM's own owned metal *pool* account

Deloitte & Touche concluded that as a result of their investigation they could not find any material accounting errors related to the reconciliation process; in the physical stock count or in the recordkeeping of the transactions involved. In addition, they recommended that further work be done in conjunction with their report, such as the following:

- a) Investigation historic inventory results as far as is practical, as comprehensive information may not be available.
- b) Investigation of all technical processes involved
- c) Investigation of all security aspects

Overview

According to the report, the D&T review was conducted in a comprehensive and competent manner. They only found some minor differences in the accounts covering the reconciliation process; the physical stock count, and the recordkeeping of the transactions in the year. Indeed the refinery unaccounted difference only changed by 113 ozs.

Their conclusion was that the large unaccounted difference did not appear to stem from an accounting error.

Observations

- a) The D&T report has been very thorough and it would seem very unlikely that any significant losses were incurred as a result of metal accounting errors such as double, missed, or mistaken entries in stock reports and documentation.
- b) However it does only refer to the metal accounts of the October 2008 reconciliation and any potential issues from previous inventory periods were not within the scope of the report.
- c) It has been reported that there were major changes in systems and personnel responsible for metal accounting during 2008. It is speculation, but if by whatever means, losses were incurred in prior years, and not detected or recorded, then the starting point for the October 2008 reconciliation could have been wrong. Consequently, the losses are uncovered by the new, more comprehensive accounting system.
- d) The findings of the D&T report do indicate that the metal accounting aspects of the October 2008 reconciliation were comprehensive as they did not find any material mistakes, either on entries or procedures.

3.10.2 GENERAL REVIEW OF HEALTH & SAFETY

As part of the Technical Review of the refinery operations, GAL/IBI Group was asked to provide general comments on health and safety aspects of the operations. As part of the site visits, GAL/IBI Group has noted some health and safety concerns, and some general comments and recommendations are being provided below. No detailed health and safety review was carried out and the comments being provided below are not meant, in any way, as being exhaustive.

- a) Chlorine gas could accidentally escape in the plant environment in the Chlorination Room. A detection device with alarm is in place but the location and quantity of emergency Scott Air Packs and the emergency evacuation procedure was not in evidence during the site visit. The recommended health and safety guidelines from manufacturers such as Dow should be reviewed and implemented as applicable.
- b) Nitrous Oxide gas could accidentally be generated and escape into the plant environment in the *HSSE* process area. Any detection devices and alarms, the location of any emergency Scott Air Packs, and the emergency evacuation procedure were not in evidence during the site visit.

- c) General machine guarding seemed to be inadequate in the chloride Slag crushing area. Guarding of all hazardous moving parts needs to be reviewed and safeguarding implemented as applicable. Emergency stop buttons should be installed at critical locations near the crusher and other exposed hazardous moving parts. In general, the crushing area is very congested and this is very conducive to strain and sprain type injuries. A more spacious work area needs to be considered and implemented.
- d) The replacement of crucibles and the relining of the induction furnaces, which is carried in situ in the process area, is a very strenuous, dirty and time consuming operation. Consideration should be given to relocating this operation to a separate work area. A system would have to be devised whereby the furnace frame could be relocated to that separate area so that the crucible could be replaced and the refitted furnace returned to the process area only when required.
- e) General congestion is evident throughout the plant process areas. Of particular note are the Chlorination area, the Hydromet area, the Slag crushing area and the Shipping area. Congestion is conducive to strain and sprain type injuries. Consideration should be given to reorganization and to freeing up room for these operations.

3.10.3 ENVIRONMENTAL REVIEW

A general review of the stacks and wastewater discharges from the refinery were reviewed for general environmental compliance. Recent sampling and testing reports of effluents as carried out by specialized firms were reviewed and compliance was confirmed. More details are provided below.

3.10.3.1 WASTEWATER MANAGEMENT

Currently, most of the process wastewaters generated at the Royal Canadian Mint in Ottawa are trucked off-site for treatment and/or recovery of precious metals. During the first seven months of 2009, over 30,000 litres of wastewater were trucked off-site with the bulk of this volume being spent scrubber effluent and nitric acid wastewaters from the electro-refining of silver. Minor volumes of wastewater from the Refinery are discharged to the municipal sewer on Sussex Drive after analyses for pH and precious metals. Wastewaters that are trucked off-site are also analysed for precious metals before being shipped off the premises.

Since April 2008, the Royal Canadian Mint's Ottawa complex has been in total compliance with the City's sewer-use bylaw with all analytical results being well below bylaw limits.

3.10.3.2 PURPOSE

The purpose of this study is to examine unit processes and operations in the Refinery that direct wastewaters to the municipal sewer, and to comment if any operation or process provides a potential pathway for losing different forms of gold and silver.

3.10.3.3 PROCESS DESCRIPTIONS

Production of Demineralised water

Demineralised water which is required for electro-refining processes is produced from City water using reverse osmosis (R/O) equipment. The 25%± fraction of water that is rejected (termed "concentrate") is discharged to the municipal sewer without treatment since it contains no toxic substances that would violate the City's sewer-use bylaw. The disposal of R/O concentrate to municipal sewers is an industry-standard practice that is widely used.

Quench Water from Chlorination & Premelt

There are three quench tanks in the chlorination area, one for each of the two chlorination furnaces and one for the premelt furnace. Each tank contains an estimated 30 to 40 litres of water. Over a period of time, the quench water becomes contaminated with particles of the sand/cement that is used to seal the annular space between a crucible and its containment chamber in the induction furnace.

Quench tank wastewaters are collected in a cylindrical plastic tank (Tank No.1) with a conical bottom where the sand/cement particles settle out. At regular intervals, when the solids/liquid separation is essentially complete, underflow from Tank No.1 (solids and water) are withdrawn from the conical bottom and pumped to a plate and frame filter press for dewatering. The dewatered solids are *assayed* for precious metals and then shipped offsite for disposal provided that the precious metal content doesn't warrant re-processing. Filtrate is sent to the municipal sewer. Tank No.1 is located in the basement area of the Refinery.

Quench Water from *Fine Gold* Room

There are two induction furnaces in the *Fine Gold* Room and each is equipped with its own quench tank. When the quench water is deemed to be "spent", it drains through a common trap and a filter before being discarded to the municipal sanitary sewer on Sussex Drive. The floor drains which receive spent quench water are covered when they are not in use. Suspended solids that are trapped in the filter are returned to the chlorination area for gold recovery.

Sinks & Floor Drains

RCM officials provided GAL/IBI Group with marked up floor plans showing the locations of sinks and floor drains in the Refinery, all of which are described below:

Second Floor

There is one floor drain and two sinks on the Refinery's second floor. The floor drain is located near the packed bed scrubber to receive the seal water of the scrubber effluent pumps.

The sinks are located in the gold electro-refining area and are used for washing glassware and other equipment. Wastewater from the two sinks is discharged through filter traps to the municipal sanitary sewer. Suspended solids trapped in the filter are returned to the chlorination area for gold recovery.

In the gold electro-refining area, there is also a cathode washing station where the titanium (cathode) plates with adhering "gold sponge" are rinsed with demineralised water to remove traces of adhering electrolyte solution. This wash water is recovered and used to prepare new electrolyte solutions or may shipped with spent electrolyte for gold recovery by precipitation using iron salts.

Ground Floor

There are six floor drains on the ground floor of the Refinery which serve the following area:

- a) Drain No.1 drains to Tank No.1 in the basement area. (Tank No.1 has been described in Item 2 above).
- b) Drain No.2 serves the silver granulation area and drains to Tank No.2 which is near Tank No.1 in the basement area.
- c) Drains No. 3, 4 & 5 serve the *Fine Gold* Room including the two quench tanks that adjoin the induction furnaces. Wastewaters entering these floor drains pass through a common trap and filter before being discharged to the municipal sewer on Sussex Drive. Drains 3, 4 & 5 are covered when they are not in use. Suspended solids trapped in the filter are returned to the chlorination area for gold recovery.
- d) Drain No.6 is a permanently covered floor drain in the *Sweeps* area.

There is one sink on the ground floor which is located on the west wall which separates the Chlorination/Silver Granulation Areas from the *Sweeps* Area. It drains to the municipal sanitary sewer on Sussex Drive.

Basement Area

There are two holding tanks, two sinks and four floor drains in the basement area of the Refinery:

- a) Tank No.1 has been described in Item 2 above. It receives spillage from Drain No.1 on the ground floor and spent quench water from the chlorination and Premelt Areas.
- b) Tank No.2 receives wastewaters from the Silver Granulation Area and these are recirculated for silver recovery.
- c) Sink No.1 is referred to as the "Hydromat Sink" and Sink No.2, the "Gemstone Sink". Both discharge to the municipal sanitary sewer.
- d) Drain No.1 in the Cottrell Room and Drain No.2 in the Sweeps Area are both covered. Drain No.3 receives wastewater from the filter serving Tank No.1 plus the heating system overflow. Both wastewaters are discharged to the municipal sewer. Drain No.4 is located near Tank No.2 and receives filtered water leaving the Sweco Separator. This filtrate is discharged to the Municipal sewer.

3.10.3.4 WASHROOMS & CAFETERIA

The washrooms on all three floors of the Refinery plus the Cafeteria are all connected to the municipal sewer on Sussex Drive.

3.10.3.5 POTENTIAL GOLD LOSSES

GAL/IBI Group carried out a cursory review of the system of floor drains and sinks in the RCM's Refinery area and has also studied marked-up floor plans of same. Based on that review, it has been concluded that essentially zero gold losses are likely to occur as a result of drain/sink malfunction(s). Possible sources of very minor gold loss might result from ineffective or careless floor sweeping and malfunctioning of traps and/or filters in drain lines.

3.10.3.6 Air

RWDI was retained by RCM to conduct a site wide air emissions assessment for RCM at the Ottawa facility in 2008. The study used the AERMOD dispersion modeling and the results are compared to the standards under O. Reg. 419/05 set out by the Ministry of the Environment (MOE). The MOE's regulation has three sets (schedules) of standards. Each schedule represents a more stringent standard and with a specific phase in period. Schedule 3 represents the standards that will ultimately apply to all facilities once they are phased in fully in February 2020. The schedule 3 supersedes Schedule 1 and 2 limits. This means if a facility meets schedule 3, then it is considered to be in compliance with Regulation 419. The RCM facility is currently under schedule 1 until February 1, 2010, after which it will be under Schedule 2, until February 1, 2020. Regulation 346 dispersion model is accepted by MOE until February 1, 2010 and after that only the MOE approved models must be used. The approved dispersion models listed in Regulation 419 include the three US EPA dispersion models: AERMOD, SCREEN 3 and ISCPRIME. For the purpose of this study the results of the AERMOD dispersion modeling were compared to Schedule 3 standard of Regulation 419.

The air emissions were developed using a combination of RWDI stack testing performed in October and November 2008, past stack testing reports, engineering calculations and emission factors. The stack sampling and testing was to identify and quantify the air emissions from the process exhaust points at RCM Ottawa site and to determine the off-site impacts of the emissions using the air dispersion modeling as defined by MOE.

The Air Assessment Report indicates that the RCM Ottawa facility is operating within the acceptable limits using AERMOD modeling when comparing to the MOE Schedule 3 Standard with the exception of hydrochloric acid emission. Presently hydrochloric acid emission is compliant with the Schedule 1 Standards using Regulation 346 dispersion model. However the hydrochloric acid concentrations will not be compliant Schedule 2 standard at nearby receptors when using either Regulation 346 model or AERMOD model. In other words the plant will not be in compliance with O. Reg. 419 by February 1, 2010 if the hydrochloric acid emissions were not reduced substantially.

Re-testing of stacks which showed high hydrochloric acid emission rates in 2008 has been carried out recently to confirm the results. Once the results are confirmed plant, with the assistance from RWDI, will work on a possible mitigation plan to reduce the hydrochloric acid emissions.

In order to reduce hydrochloric acid emissions to comply with the MOE standards Schedule 2 effective February 1, 2010, and ultimately Schedule 3 Standards, we recommend to install new or more efficient caustic scrubbers for those stacks.

3.10.3.7 OBSERVATIONS & RECOMMENDATIONS

- a) Several process wastewaters are currently trucked off-site for treatment/disposal at substantial costs. Because of the costs involved, the RCM is currently investigating the feasibility of on-site treatment of nitric acid wastewaters.
- b) It is recommended that similar investigation be undertaken involving other wastewaters such as scrubber effluents.
- c) Space is at a premium in the RCM's Refinery area. However, if space can be found for a central wastewater treatment facility, consideration should be given to including provision for handling non-refinery wastewaters such as spent burnishing solutions from coining and wastewaters from the electroplating of specialty medals, etc.

3.10.4 MAINTENANCE

The Preventative Maintenance (PM) scheduling system presently in use at the refinery was reviewed during a site visit and a meeting held with key RCM personnel. A description of the PM system and some observations and recommendations are provided below.

- a) The RCM incorporates a computerized Preventative Maintenance (PM) scheduling system. The system used is Microsoft Dynamics 2007 which has replaced the previous Maximo system.
- b) Pieces of equipment are listed in the PM maintenance scheduling program. PM scheduling is based on experience on older equipment and suppliers recommendations on newer equipment.
- c) Scheduled maintenance items are reviewed with production on a weekly basis every Wednesday to determine equipment availability and determine propriety and accessibility.
- d) Aged items, past due, for maintenance are identified when the time approaches a month. A more forceful request is put forth to production for equipment access that is past due for attention.
- e) Ventilation efficiency decay through filters and scrubbers are monitored by Siemens flow rate recording devices. Differential pressure information is sent by email to key Blackberry holders for corrective action.
- f) Other critical areas are monitored in this fashion such as high or low fluid levels.
- g) Furnace crucible are rebuilt after a predetermined number of melts to preclude crucible failure and potential molten gold leakage
- h) Duct cleaning used to be done every 6 months by owns staff now this has been increased to every 3 months and contracted out. Usually done at time of stock taking.
- i) Floor steel plates are replaced only when holes develop. Plating on floor exists to cover up old pits and in floor services.
- j) There are floor drains in parts of the building but they have trap filters. They are inspected and cleaned on a routine basis. The floor drains get used in the event of a cooling water leak or other leaks such as effluent over flows.

Observations

As a general comment there are many things that can influence effective maintenance such as:

- a) Computer systems and documentation may not necessarily reflect true shop floor level conditions.
- b) The effectiveness of a “good job” is based on the environment one has to work in.
- c) The facility is old with disjointed process flow and poor layout with products and by-products scattered and stored in any space available.
- d) Work areas are crowded, congested, dark and dirty influencing good access to equipment. This can create a work attitude of “good enough”.
- e) With the refining process have been updated over time the location of process equipment has been based on “where can we make it fit”. But this may be the only way due to building constraints.
- f) The entire refining process is located on multi levels which does not work well for the newer visual management concepts. There too many dark nooks and crannies within the building and process system where a failure could occur without notice. There are alarming devices to detect failures but these are “after the fact” device. Brighter areas with better visibility would help both maintenance and health and safety concerns.
- g) The facility may work well for coining but for the refining of such a high end product improvement could be made with relocation to a new facility.

4. PROCESS FLOW DRAWINGS

Process flow diagrams were developed for the Gold process and the Exhaust systems. Refer to Appendices D and F for drawings. This helped both the RCM staff and our team to have the primary processes of the refinery operations mapped out and simplified.

The general principle that was used in generating the Gold Flow Sheets was to have the materials containing precious metal to be fed from the left hand side of the drawing, the finished products to exit from the right hand side, exhaust gases to exit from the top of the drawing and for solid and liquid *by-products* and wastes to exit from the bottom of the sheet. The different major processes listed in the report have been identified by a hatched line and title on the flow Sheets.

The Gold Flow Sheet was prepared based on available drawings and sketches. A site visit and reviews with key RCM personnel were carried out, and the Flow Sheet was created to represent current conditions.

The Refinery Process Exhaust Flow Sheet was prepared following site visits and meetings with RCM personnel, and it represents current conditions at the refinery.

5. CALCULATION OF LOSSES AND GAINS

5.1 General

The flow of gold at the RCM refinery is controlled at the input and output of the process – see simplified flow sheet on the following page. Once gold enters the “*pool*” it is not and cannot be controlled as discrete parts or pieces. See figure 5.1

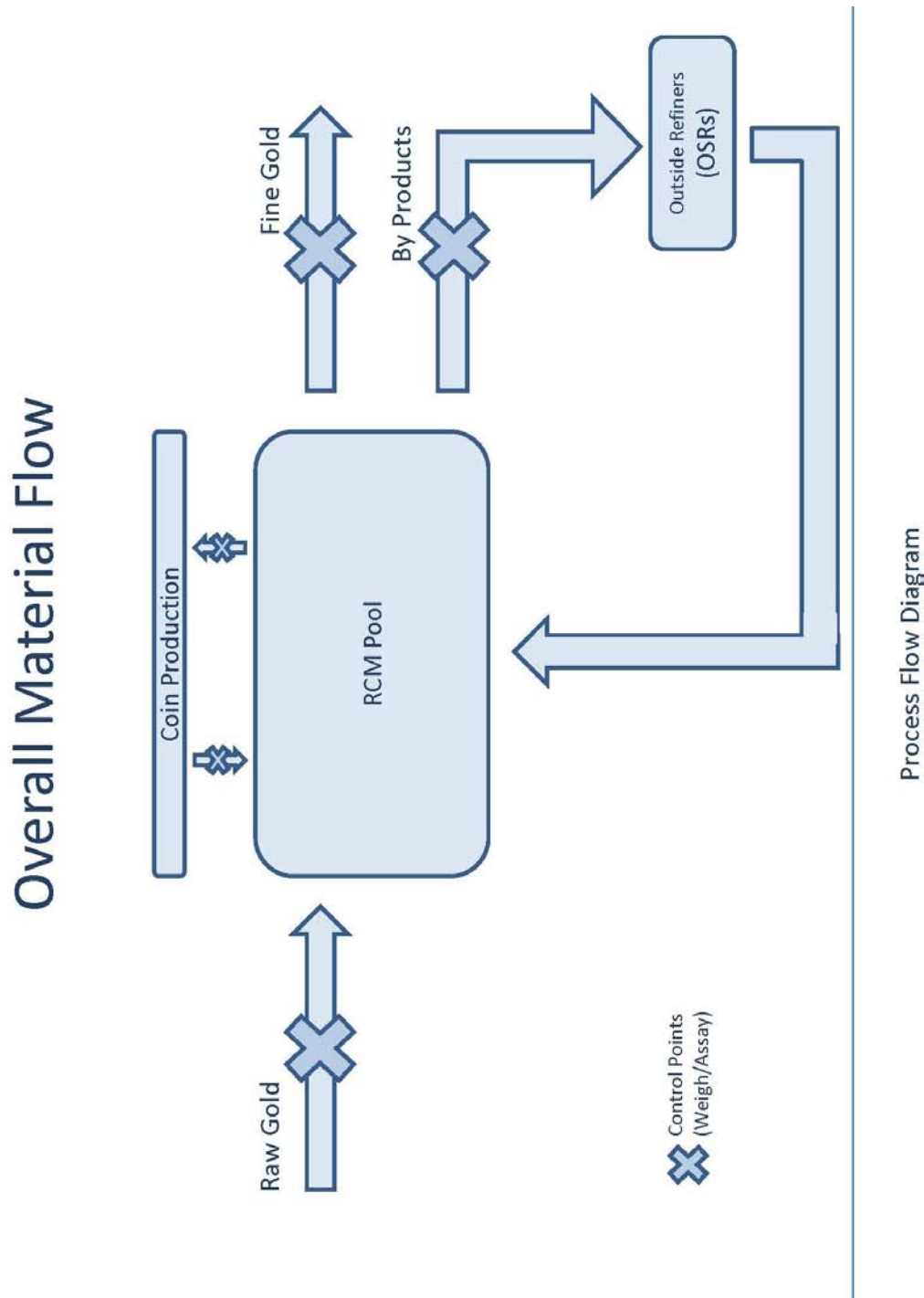
Therefore, losses and gains to the quantity of gold occur at the input and output only. While processing in the *pool*, gold can be retained or diluted within a by-product, and difficult to quantify, but it has not been lost.

Raw gold is *assayed* and weighed and a settlement reached with the customer and then the gold enters the *pool*. After gold enters the *pool* it separates into two streams; one increasingly pure and becoming 99.99 fine and the other more dilute as *by-products*. At the end of the process the *fine gold* is *assayed*, weighed and sold. *By-products* containing dilute gold are sampled, *assayed* and sent to External Refiners for processing and recovery of the gold and other precious metals or processed internally. There is a side stream process of *fine gold* and silver to the coining operation with a returning stream of scrap (scissel).

Our approach to the loss model follows the philosophy of the Overall Material Flow figure 5.1. Gold within the *pool* which is contained within *by-products* is an apparent loss. Losses which remove gold from the *pool* are *unrecoverable losses*. The *unrecoverable losses* are the basis of the model. These losses include environmental (stock and wastewater), weight and *assay* giveaways, retention of gold in silver, refiners retentions and physical loss in plant. It is industry standard to include all these components in the loss calculation.

REPORT

Figure 5.1 – Overall Material Flow



5.2 Loss Factors

There are a number of potential ways to lose/gain gold in the process. These are listed in Section 5.2.1 'Summary of Gold Refining Potential Losses'. These can be grouped into the following categories:

Negotiated

These losses are determined by contract, convention or by London Bullion Market rules.

- | | |
|--|----------------------------|
| a) <i>Fine gold</i> giveaway loss assay | approximately 0.4/10,000 |
| b) <i>Fine gold</i> giveaway loss weigh | approximately 0.5/10,000 |
| c) <i>Fine gold</i> giveaway loss assay to coining | approximately 0.4/10,000 |
| d) Giveaway loss – <i>fine gold</i> in silver bars | varies from 9ppm to 100ppm |
| e) By-product processing retention | approximately 2% to 2.5% |

Environmental

These losses are determined by the efficiency of the exhaust system to capture gold and the blocking and trapping of wastewater outlets.

- | | |
|-------------------------|---------------------|
| a) Exhaust stack losses | net 89oz/year |
| b) Wastewater | unknown – but small |

By-product

There are precious metals in dilute quantity that is retained in by-product. The most concentrated is Chlorination Slag at 2% - 3%. Chlorination Slag is presently processed in-house to concentrate and reintegrate gold and silver back into the process *pool*.

Precious metals retained in the *by-products* are potential losses, but the precious metals are returned by outside processors less the retention and processing costs. *By-products* presently leaving RCM are:

- | | |
|---|------------------------------|
| a) Copper Iron Carbonate | approximately 500ppm gold |
| b) Copper depleted liquor | approximately less than 1ppm |
| c) Silver Chloride retained to produce silver | Processed as a by-product |
| d) <i>Sweeps</i> – historically | approximately – 0.1 to 0.2% |
| e) Electrolyte depleted liquor | approximately 1ppm gold |
| f) <i>Cottrell</i> Sludge | approximately 1% to 3% gold |

Below is a "Summary of Gold Refining Potential Losses" which describes potential losses, the importance risk level and comments on the disposition.

Table 5.1 – Summary of Gold Refining Potential Losses

Revision B 11 September 2009

Item #	Process Loss Source and Description	Form	Magnitude (Importance)	Risk Level	Comments
1	Premelt Slag retention	Solid brick	Minor	Low	Either a Customer retention when required by contract or Mint retention in <i>sweeps</i>
2	Premelt dust	Dust	Minor	Low	To external recovery
3	Receiving weight error	Solid	Minor	Low	RCM weighing procedure
4A	Premelt assay error	Pintube	Major	Low	Accuracy is critical to settlement. The practice of taking of 3 samples (customer/Umpire/Mint) helps to minimize the risks.
4B	Gemstone premelt assay error	Pintube	Major	Low	Accuracy is critical to settlement. The practice of taking of 3 samples (customer/Umpire/Mint) helps to minimize the risks.
5	Premelt weigh error	Solid	Minor	Low	RCM weighing procedure
6	Premelt crucible	Solid	Minor	Low	Most premelt crucibles are assigned by customer and eventually returned to them. Crucibles are crushed when removed from service and sent to External Refiners for recovery of the gold.
7	Chlorination Slag internal assay error	Solid	Major	High	Accuracy is critical to settlement if processed by an Outside Refiner. Accurate sampling of Slag is difficult. Witnessing of the melting and <i>assaying</i> at Outside Refiner's premises is critical. Concentration can be as high as 2% to 5%.
8	Chlorination Slag weigh error	Solid	Minor	Low	RCM weighing procedure
9	Chlorination Slag retention loss		Major	Low	Negotiated with third party refiner
10	Chlorination bailing exhaust to scrubber	Dust & sludge	Minor	High	Ducts cleaned annually and dust and sludge is shipped to Outside Refiner for reclaim of gold. Accurate sampling of sludge is very difficult. Witnessing of the melting and <i>assaying</i> at Outside Refiner's premises is critical.
11	Chlorination exhaust to Cottrell	Sludge	Major	High	The sludge is shipped to Outside Refiner for reclaim of gold. Accurate sampling of sludge is very difficult. Witnessing of the melting and <i>assaying</i> at Outside Refiner's premises is critical. Concentration could be as high as 1% to 2%

Revision B 11 September 2009

Item #	Process Loss Source and Description	Form	Magnitude (Importance)	Risk Level	Comments
12	Chlorination crucible	Solid	Minor	Low	Crucibles are washed and crushed and shipped to an Outside Refiner for reclaim of gold
13	Chlorination - X Ref sample error	Solid	Minor	Low	Error may affect production of 9999 Gold in <i>Electrorefining</i> but gold is not lost to external.
14	Anode casting quench losses	Solid	Minor	Low	The gold is filtered from the quench water and recovered in the incinerator. The quench water is then drained into the city sanitary sewer.
15	Anode casting weigh error	Solid	Minor	Low	Weighed by RCM and retained in the refinery. No gold is lost to external.
16	<i>Electrorefining</i> exhaust	Gas	Minor	Low	Evaporation of gold to the atmosphere is extremely low.
17	<i>Electrorefining</i> slime	Wet solids	Major	Low	The slime is dried and returned to chlorination.
18	<i>Electrorefining</i> electrolyte accidental loss to drain	Liquid	Major	Low	Accidental loss to sanitary sewer is very unlikely because the electrolyte is stored in tubs.
19	<i>Electrorefining</i> electrolyte leak into warming bath	Liquid	Minor	Low	A leak is very likely to be detected before a large quantity of electrolyte has been lost to the warming bath.
20	Item not used				
21	Electrolyte precipitation spent liquor	Liquid	Major	High	The spent liquor is treated and <i>assayed</i> to reduce the gold concentration to less than 1ppm before shipping to external for recovery of Pt and Pd.
22	Electrolyte precipitation exhaust	Gas	Minor	Low	Evaporation of gold to the atmosphere is extremely low.
23	Cathode wash water accidental loss to drain	Liquid	Minor	Low	The wash water is captured and returned to the <i>Electrorefining</i> as electrolyte make up.
24	Cathode weigh error	Solid	Minor	Low	The weighing is by RCM and there is no loss of gold to external.
25	<i>Fine gold</i> exhaust	Gas	Minor	Low	Efficiency of the cartridge dust collector is high. The cartridges are sent an Outside refiner the recovery of gold.
26	<i>Fine gold</i> crucible	Solid	Minor	Low	Crucibles are crushed and sent to an Outside Refiner for recovery of the gold

Revision B 11 September 2009

Item #	Process Loss Source and Description	Form	Magnitude (Importance)	Risk Level	Comments
27	<i>Fine gold</i> bar and grain loss to quench water	Liquid	Minor	Low	Solid particles are filtered from the quench water and burned in the incinerator, The quench water is then drained into the city sanitary sewer
28	<i>Fine gold</i> assay error	Pin Sample	Major	Low	Operator dependent but <i>assaying of fine gold</i> follows well established procedures and is normally very precise.
29	<i>Fine gold</i> weigh error	Solid	Minor	Low	Operator dependent but scales are regularly calibrated. Gold is weighed three times per ISO. Two weightings are used for averaging.
30	<i>Fine gold</i> scarfing mass balance error	Solid	Minor	Low	RCM validates weight before & after scarfing. No gold is being lost to external.
31	Floor sweepings	Solid	Minor	Medium	Sweepings are sent out to an Outside Refiner for recovery of the gold. Accurate sampling of <i>sweeps</i> is difficult.
32	Chlorination Slag crushing exhaust to dust collector	Dust	Minor	Low	Efficiency of the cartridge dust collector is high. The cartridges are sent an Outside refiner the recovery of gold.
33	Chlorination Slag milling weigh error	Powder	Minor	Low	Weighing by RCM.
34	Chlorination Slag granulation exhaust to Cottrell	Dust	Minor	Medium	The efficiency of the <i>Cottrell</i> precipitator is high. The slime and dust is sent to an Outside Refiner for recovery of the gold. Sampling of slime and dust is difficult.
35	Depleted Hydromet liquor	Liquid	Major	Medium	The gold and silver have been removed as part of the process and only traces should remain in the spent liquor. The liquor is being sent out for recovery of the precious metals.
36	Chlorination Slag process copper-iron carbonate filter cake	Solid	Major	Low	The gold and silver have been removed as part of the process and only traces should remain in the filter cake. The filter cake is sent to an Outside Refiner for recovery of the precious metals.
37	Silver sand to external – gold loss	Wet solids	Major	Medium	Excess silver sand is sometimes shipped to an Outside Refiner for reclaim of the gold and silver. The concentration of gold in the silver sand can be important. Accurate sampling of silver sand is difficult to achieve.

Revision B 11 September 2009

Item #	Process Loss Source and Description	Form	Magnitude (Importance)	Risk Level	Comments
38	Chlorination process Silver Chloride paste or filter cake – gold loss	Wet solids	Major	Medium	Silver Chloride filter cake is shipped to an Outside Refiner for reclaim of the silver and gold. The concentration of gold in the filter cake can be important. Accurate sampling of silver chloride filter cake is difficult to achieve.

5.3 Calculation of Losses

The mass balance model calculates the predicted loss for the production year of 2008 based on known loss factors. The quantity of by-product gold is predicted by historical data of 1.36% of refinery production. The by-product retention is predicted by historical data of 2.58% of refinery production.

Loss Balance Model for 2008

This worksheet is a model to calculate the annual gold losses associated with production for the year 2008.

Total gold production 2008	2,952,125 oz
Total silver production 2008	799,000 oz
Total coining production 2008	1,044,000 oz

Table 5.2 – Loss Balance Model

No.	Source of loss	Losses in Oz per year	oz per 10,000	Comments
1.	stack	88.891	0.3011	Based on RWDI report
2.	Retentions	297	1.0	Based on Calculations from By-product Tracking spreadsheet
3.	Giveaway assay	118.085	0.4000	Based on SNC report
4.	giveaway weight	147.606	0.5000	Based on SNC report
5.	Giveaway gold retained in silver bars	7.19	0.0900	9 ppm of retained gold
6.	Physical loss in plant	104.000	0.3523	Refer to definitions of maximum physical losses below
7.	Physical loss for year	762.7	2.41	
8.	Giveaway assay gold coining	41.760		0.4 per 10,000
9.	Physical loss including coining	804.46	2.72	Calculated including coining giveaway
Calculated by-product and retention over a three year period				
10.	Gold production 2006		2,585,536	
11.	Gold production 2007		2,762,104	
12.	Gold production 2008		2,952,125	
13.	Total gold production for three years		8,299,765	
14.	Total by-product gold for three years		112,921	Based on Calculations from By-product Tracking spreadsheet
15.	By-product gold as % of three year production		1.361%	
16.	Total retention gold for three years		2,911	Based on Calculations from By-product Tracking spreadsheet
17.	Retention as % of three year by-product gold		2.58%	

No.	Source of loss	Losses in Oz per year	oz per 10,000	Comments
Calculate by-product and retention gold produced in 2008				
18.	Total gold production 2008		2,952,125	
19.	By-product gold as % of production		1.361%	
20.	By-product gold produced in 2008		49,463.62	
21.	Retention as % of by-product gold		2.58%	
22.	Retention gold produced in 2008		1,035.41	

The results of the model predict that the total loss of gold is 750 oz for the production year of 2008.

Maximum Losses for 2008

We have calculated the annual lower limits of *unrecoverable losses* for 2008 using historically established data as well as calculated factors. The upper limits were based on "maximum justifiable loss". These losses are summarized in Table 5.2 and are calculated based on the following criteria:

- a) Annual for 2008, gold production of 2,952,000 oz.
- b) Stack Losses
 1. Using latest RWDI latest stack test report (2008) for the lower limit and 10% increase factor for the upper limit.
 2. Stock losses are affected mostly by the operating condition of the Cottrell, scrubber and the baghouse. It is assumed that these are proper working order.
 3. It should be noted that there has been a substantial increase in the gold recovery in the exhaust system since 2006 due to various exhaust system upgrades.
- c) Giveaway Assay
 1. Using a factor of 0.4 oz/10,000 of production for the lower limit and a factor of 0.8 oz/10,000 of production for the upper limit, based on an ongoing assay bias in favour of the customer.
 2. Assay losses are based on accurate pintube assays. Biases in the assay are controlled by the umpiring protocol.
- d) Giveaway Weight
 1. Using a factor of 0.5 oz/10,000 of production for the lower limit and a 10% increase factor for the upper limit.
 2. Weight losses are influenced by the RCM product mix and the accuracy of RCM weight scales. There are varying weight loss factors for various RCM products. The loss factor used is a composite.
- e) Giveaway in Silver Bars
 1. The lower limit was based on 9 PPM and the upper limit was based on 100 ppm retention of gold in silver bars for an annual silver production of 799,000 oz.
 2. The gold content in the silver is influenced by the amount of gold in the HSSE circuit.

- f) Physical Loss in Plant
 - 1. The lower limit was based on the available windfall data of gold recovered from building and equipment demolition. The windfalls were assumed to have accumulated over a 60 year period, therefore a yearly average was calculated. A 100% increase factor was applied for the upper limit.
 - 2. The physical losses are gold trapped in the fabric of the building and equipment. It is only recovered when the building or equipment is dismantled.
- g) By-product Processing (Slag) – the lower limit is included in “Retentions”. The upper limit is based on an additional 10% of the gold content recovered by the RCM from Slag. The gold content recovered was 1.86%, the addition of the 10% (0.186%) is to account for the difficulty in sampling and assaying the chlorination Slag. For 2008, this would represent 2976 oz.
- h) By-Product Processing (others) - Based on total recovered gold; annual by-products of 49,463 oz out of which 30,000 oz could be attributed to Slag; and the +5% in variation of testing accuracy between SGS and RCM results, our estimate of maximum total gold losses associated with all by-product “other” than Slag is 0.05 x 19.439 oz = 972 oz.
- i) Retentions
 - 1. Were calculated for the year for all by-products.
 - 2. The refiner retentions are fixed by contract. Therefore, the greatest influence on retentions is the quantity of gold in *by-products* sent to the refiner.

Based on the above, the lower limit of losses is estimated to be 760 oz per year. Similarly, the upper limit of losses, however unlikely, are estimated to be 5,000 oz per year. As such, in our opinion, the total maximum loss possible is much smaller than the total amount of the unreconciled gold.

The following is a tabulated summary of same:

Table 5.3 – Estimate of RCM Refinery Loss Limits

	Estimated Loss Limits (2008)			
	Lower		Upper	
	Oz	PPTT	Oz	PPTT
Stack	89	0.30	98	0.33
Giveaway Assay	118	0.40	236	0.80
Giveaway Weight	147	0.50	162	0.55
Giveaway in Silver Bars	7	0.02	80	0.27
Physical Loss in Plant	104	0.35	664	2.25
Total	465	1.57	1,240	4.20

Table 5.4 – Estimated Losses to External Refiners

	Estimated Loss Limits (2008)			
	Lower		Upper	
	Oz	PPTT	Oz	PPTT
Retentions (excluding Slag)	297	1.0	326	1.10
By-product Processing (Slag)	0*	0	2976	10.08
By-product Processing (others)	0	0	972	3.29
Total	297	1.0	4,274	14.47

* The gold content in Slag is highly variable due to the manual nature of the Chlorination and Slagging process. As a result of the percent factor assumed, this variation can affect the lower limit to swing between a loss and a gain. Also, often actual gold recovered by third party refiners exceed accrued value. For the purposes of this table, it is assumed that there are neither losses nor gains for the lower limit.

5.4 Recommendations

- a) Revise the RCM loss calculation to conform to industry standards and make periodic adjustments to loss factors to account for revised refinery practices and equipment updates.
- b) The RCM retention should be compared to actual losses to ensure that the retention more than meets the losses.

6. RECENT IMPROVEMENTS

History

Royal Canadian Mint has undertaken numerous projects since 2005 to improve refinery operations and facilities. A list of these projects was provided by the RCM along with approximate implementation dates in order to assess if these projects could have resulted in additional process losses during the 2008 reconciliation period.

RCM projects involve the requirement to move old equipment out of the facility and bring new equipment into the facility. Old equipment may contain precious metals that have chemically bonded onto component surfaces or accumulated in cavities and the disposal of this equipment could result in unrecovered precious metals. The RCM procedure is to cut up old equipment into manageable pieces that can be individually inspected and assessed for precious metal content. If dirt, dust or plate is found that could potentially contain precious metals, it is mechanically removed, collected and placed into the "Sweeps" bin for processing.

The projects conducted since 2005 were plotted onto a Microsoft Project Schedule in sequence of occurrence with respect to the October 2007 to October 2008 reconciliation period. The schedule is included at the end of this section. The objective was to identify projects that resulted in process equipment changes during this period of time. Projects identified were:

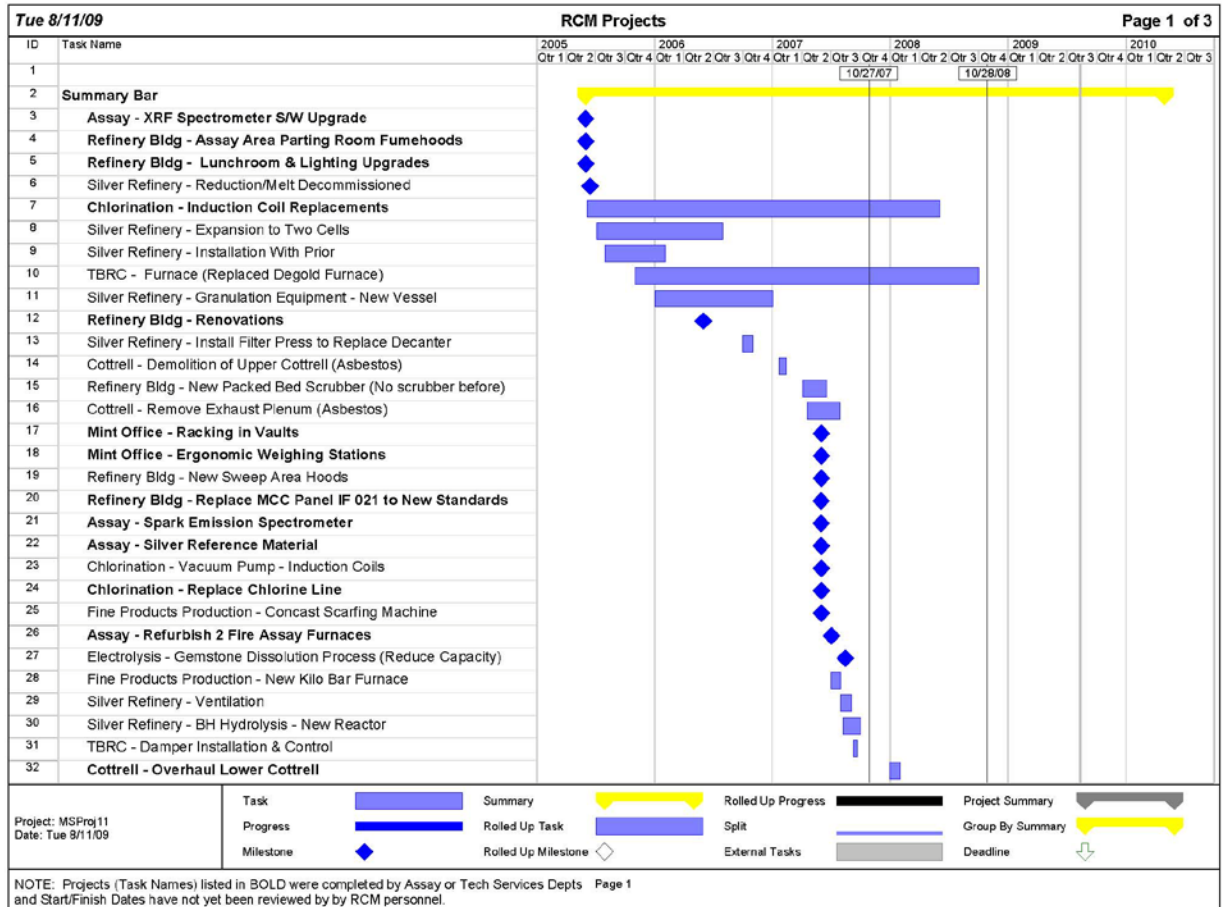
- a) *Cottrell* - Overhauled the Lower *Cottrell* dust collector to replace decayed and rotting components (2008 Q1)
- b) Electrolysis - Replaced Precipitator Reactor vessel (2008 Q1)
- c) Assay – Replace X-Ray Tubes for Spectrometer (2008 Q1)
- d) Chlorination – Replaced Shell & Coils in Furnace (2008 Q2)
- e) Assay – Install new ICP-AES Spectrometer (2008 Q1)
- f) Assay – Change over to pin tube sampling methods (2008 Q1)
- g) Hydromet –Initiated the Slag Granulation process and integrated it with Hydromet chemical treatment (2008 Q3, Q4)
- h) Refinery – Relocated the Premelt Furnace out of its own room into the Chlorination Room and relocated the *Fine gold* Furnace to take the place of the Premelt Furnace. (2008 Q3, Q4)

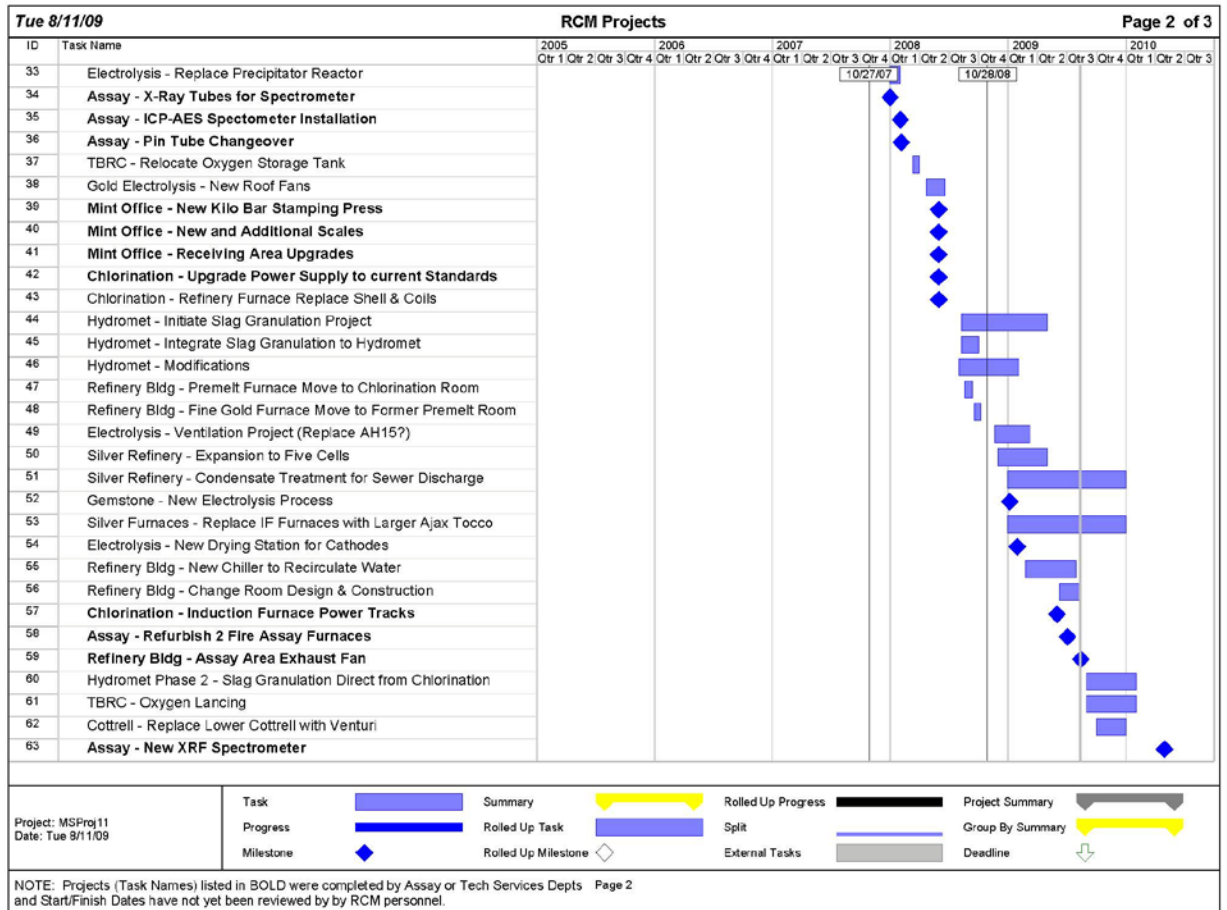
Observations

- a) Projects 1 through 4 were maintenance projects which are completed on a routine basis in the refinery as equipment fails or wears out. Project 5 was a purchase of new piece of equipment used by the RCM Assay Lab and would have been thoroughly checked out upon delivery. No further review was conducted on Projects 1 through 5.
- b) Projects 6 through 8 were changes implemented to improve *assaying* methods and to gain efficiencies in the process and material flow through the refinery. These were examined more closely.
- c) Project 6 was implemented by the RCM after extensive testing to verify that pin tube sampling was providing equivalent results to previous dip sample methods. The pin tube results are verified through third party testing by SGS of several pin tube samples from Premelt in the Section 3.7 of this report.
- d) Project 7 was implemented to reduce process steps between Slag melting, granulation and Hydromet processes. The potential for loss was tested by running a mass balance test across the Hydromet process as reported in Section 3.7 of this report.
- e) Project 8 was implemented so that the *Fine Gold* Furnace was located with other similar equipment, products and methods in one room where most *Fine Gold* products are now poured. This reduced movement of *fine gold* through the chlorination area and provided a direct link by elevator to the electrolytic cells on third floor where *fine gold* is produced.
- f) The *Fine Gold* Furnace took the place of the Premelt Furnace which was moved into the Chlorination Room even though it is preferable to be located in a separated area. Capital renovations should be undertaken by RCM in order to create a separated Premelt Area, perhaps in the building space beside the chlorination room. Project 8 relocations did not affect the process sequence and therefore are not expected to impact process losses.

Project Schedule

The scheduling of the projects is presented below.





7. CONCLUSION

Giffels Associates Limited/IBI Group (GAL/IBI Group) was retained to study refinery operations at the Royal Canadian Mint in Ottawa and determine whether process losses could have contributed to the un-reconciled difference of the physical gold precious metal as of October, 2008. More specifically, the scope of work involved the following:

- a) Undertaking a thorough process review of the refinery operations including observing key processes at different times for a long duration
- b) Identifying potential sources of losses in the refinery operations
- c) Conducting independent testing to determine the extent of losses
- d) Providing a comparative analysis of the independent testing, previous test results, and testing done by RCM
- e) Providing benchmark assessment of RCM losses comparison to industry standards
- f) Estimating loss quantities of key processes
- g) Providing a technical opinion on the un-reconciled difference of precious metal

7.1 Thorough Process Review

GAL/IBI Group assigned a team of engineers, specialty consultants and other professionals with extensive experience in precious metals refining. Expert metallurgists, J. Fairley Associates from United Kingdom, were retained to examine RCM metallurgical processes and methodologies and provide a benchmark assessment of the RCM process against other Precious Metals refining companies in the industry. An independent expert was also dispatched to the External Refiner (ACC), used by RCM, to observe the sampling and *assaying* techniques of chlorinated Slag at their facility.

Through various site visits, of different durations, our team observed all key refinery processes; reviewed RCM's operations and procedures; and reviewed previous studies and reports. We have also visited the facilities of ACC, one of the External Refiners RCM has engaged for processing of by-products. The following are the major processes that were reviewed:

- a) Receiving and PreMelt
- b) Chlorination
- c) Hydromet
- d) Gold Electro-Refining
- e) Fine Gold Casting
- f) High Speed Silver Electrorefining
- g) Gemstone Recovery

INDEPENDENT TESTING

Independent testing is a critical element of any review. For the purposes of this study, we employed the services of SGS, an independent and world renowned testing group. The following is a brief description of the testing completed:

Mass Balance Test

Seven of the significant loss candidates are associated with the Chlorination and the Hydromet process. A Mass Balance Test was conducted by tracking three separate material batches as they

went through the Chlorination and Hydromet equipment. This test was conducted to confirm that the amount of precious metals entering these two key, consecutive processes is being recovered at the discharge points and is not being lost.

Chlorinated Slag Gold Content Test

Two of the significant loss candidates are associated with the chlorination Slag. As part of the mass balance test, the chlorinated Slag from the three material batches was melted and 6 dip samples were drawn from each batch (total of 18 samples) at 4 to 5 minute intervals. These samples were analyzed for gold content in the Slag. This test was to verify that, given enough time, the gold does settle to the bottom of the Slag melt as a recoverable "button" and does not get dumped into Hydromet where it could become an "Unrecoverable Loss".

Independent Sample and Assay

During normal refinery activities, the RCM depends extensively on their ability to obtain a representative sample and an accurate, repeatable assay on the products that are received and on the by-products that are shipped out. As part of testing, a third party international, expert sample and assay firm, Minerals Services division of SGS Canada Inc. from Lakefield, ONT, was retained to supervise the drawing of samples and perform an independent assay on the materials listed above. This was to test whether RCM sampling techniques and assays are giving verifiable results.

7.2 Findings

In each process area, a maximum limit of losses that could be expected was estimated based on "worst case scenario". This is an unreasonable scenario but does serve to identify an upper limit on "unrecoverable losses". The lower and upper limits of potential losses from each process area were also estimated, and these are summarized in Tables 5.3 and 5.4 below:

The RCM refinery is an industrial process and like any other industrial process, is subject to some process losses. RCM has operated the refinery for almost 100 years and the fundamental processes of chlorination and electrorefining haven't changed significantly. However, there are areas where critical processes could impact apparent and unrecoverable losses. The following are our observations on the key processes:

Stack Losses have significantly decreased since 2005, seemingly due to the replacement of the old Cottrell system with the new Siemens scrubber and bag house filters. The system was operating well in 2008 and the maximum losses for that year were unlikely to be more than the 89 oz.

Giveaway Losses for weight and assay are thoroughly documented. The assay results may vary by up to 0.4 oz per 10,000 oz processed. If we assume that the error is biased for the entire year 2008 production of 2,952,000 oz to the client's favour, then the maximum error could be approximately 478 oz. However, this continuous bias is unlikely.

Gold lost to the **Building Fabric** can vary with time. If we assume a two fold increase in retained gold, the retention would increase by approximately 104 oz per year. This is unlikely, but possible, given the age of the facility.

The unrecoverable losses due to **Retention** do not change since the refiner retention is set contractually. Actually, the retention losses in 2008 were high in relation to the gold production due to the large quantity of chlorination sent to external refiners.

In summary, the lower and upper limits of gold potential losses due to the refinery, based on a "Worst Case Scenario", for 2008 are summarized in Tables 5.3 and 5.4.

Table 5-3 – Estimate of RCM Refinery Losses

	Estimated Loss Limits (2008)			
	Lower		Upper	
	Oz	PPTT	Oz	PPTT
Stack	89	0.30	98	0.33
Giveaway Assay	118	0.40	236	0.80
Giveaway Weight	147	0.50	162	0.55
Giveaway in Silver Bars	7	0.02	80	0.27
Physical Loss in Plant	104	0.35	664	2.25
Total	465	1.57	1,240	4.20

Table 5-4 – Estimated Losses of External Refiners

	Estimated Loss Limits (2008)			
	Lower		Upper	
	Oz	PPTT	Oz	PPTT
Retentions (excluding Slag)	297	1.0	326	1.10
By-product Processing (Slag)	0*	0	2976	10.08
By-product Processing (others)	0	0	972	3.29
Total	297	1.0	4,274	14.47

* The gold content in Slag is highly variable due to the manual nature of the Chlorination and Slagging process. As a result of the percent factor assumed, this variation can affect the lower limit to swing between a loss and a gain. Also, often actual gold recovered by third party refiners exceed accrued value. For the purposes of this table, it is assumed that there are neither losses nor gains for the lower limit.

The RCM precious metal refining process has the same characteristics as any other refinery process; losses are inevitable and unavoidable. Process losses are considered to be either "apparent" or "unrecoverable" but are only quantifiable to a certain extent. Losses can no longer be defined when they occur at a rate below the lower accuracy limit of weighing and assaying equipment used for the measurement. An upper limit can be derived for Process Losses by assuming worst case scenarios for significant loss candidate materials.

The SGS sampling and assaying show that RCM sampling and assaying techniques are verifiable for defining amounts of precious metals in Doré or premelt samples. However, there is high variability in the sampling and assaying techniques used for precious metal by-products. This inherent uncertainty can result in increased "unrecoverable losses". RCM sampling and assaying methods for by-product materials should be thoroughly studied and improved in order to increase certainty in these results and improve the settlements for these materials.

GAL/IBI Group team carried out a site visit to External Refiner ACC to observe the Salt Slag processing, sampling and assay methods. In general, the ACC facility was found to be well run and, with the exception of sample preparation, the procedures for receiving, weighing, storing, milling and mixing, and assaying the salt Slag were in the whole satisfactory.

Through this process review, we conclude that the total unrecoverable losses of gold for 2008 would be in the range of 750 oz to 5,500 oz, which represents 2.57 PPTT to 18.67 PPTT respectively.

Given the improvements in the past few years such as those to the exhaust system (Cottrell replacement, new Scrubber, etc..) and the introduction of the Hydromet process, in our opinion these improvements will enhance the refinery efficiency and, as such, the amount of process losses in the future should be lower than those indicated.

As such, in our opinion, the refinery process may have contributed to some additional unreconciled gold losses. However, it is highly unlikely that the gold losses were primarily due to the refinery processes.

8. REFERENCES

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Slag Samples Transfer September 9, 2009