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File number:

601903

Proposal/Contract

Recovery and Purification of Arsenic Oxide -

Giant Mine

CANMET

MINERAL



Natural Resources
Canada

Minerals and
Metals Sector

Ressources naturelles
Canada

Secteur des minéraux
Métals Sector

proposal/contract

Canada

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(Signatures are on the last page of the document)

Title

Recovery and Purification of Arsenic Oxide - Giant Mine

Objectives

To study the recovery and production of arsenic oxide (As_2O_3) from the arsenic-rich dust produced and stored at the Giant Mine, Yellowknife.

Background

The Giant Mine of Royal Oak Mines Inc. operates a gold recovery circuit consisting of flotation, concentrate roasting and cyanide leaching. During the roasting operation, arsenic oxide and other compounds are volatilized and recovered in electrostatic precipitator and baghouse systems. During some 50 years of operation, this dust has been stored underground in vaults formed in the rock, and the current inventory amounts to 260,000 tons of dust, containing an average of 76% As_2O_3 and 0.54 opt Au. Royal Oak, in collaboration with the Department of Indian Affairs and Northern Development, is currently considering options to reduce or eliminate the potential environmental impact of the arsenic-rich dust, including the metallurgical reprocessing of the dust to recover a purified arsenic oxide product for the wood preservative industry.

One approach under investigation involves leaching with hot water to dissolve As, removing Sb and other impurities from the resulting solution, and recrystallizing purified As_2O_3 . However, test work carried out by Royal Oak showed that the dissolution of arsenic from the dust was lower than predicted and that Sb and other impurities must be removed from solution prior to crystallization to avoid contamination of the product. Another option being considered involves subjecting the dust to controlled heating in order to promote the vaporization of As_2O_3 . In this context, CANMET has been asked to investigate, in an exploratory manner, the following points: the parameters controlling the solubility of As_2O_3 in water, the mineralogy of the dust and leach residues, the amenability of As_2O_3 to selective vaporization and the removal of Sb and Fe from the leach solutions by ion exchange.

Benefits

Royal Oak will gain useful information about the feasibility of recovering a marketable arsenic oxide product. This in turn may lead to a permanent solution to the arsenic dust problem, thus reducing or eliminating an environmental concern for the inhabitants of the area surrounding the Giant Mine.

Expertise/ Facilities

Scope of Work

CANMET/MMSL personnel have considerable expertise in mineralogy, solution chemistry, ion exchange, vaporization chemistry and extractive metallurgy. The CANMET/MMSL laboratories have all the equipment, such as constant temperature solubility reactors, SEM, image analysis, X-ray diffraction, furnaces, and the analytical facilities to carry out this project.

The work will comprise four parts:

1) Solubility measurements:

The reason for the low dissolution of As_2O_3 from the dust may be related to the presence of two paramorphic forms of As_2O_3 : arsenolite and claudetite. Solubilities will be measured from near 0°C to 100°C , under an air atmosphere. Samples will be taken on heating and cooling to ensure equilibrium. Sampling will be done in $\sim 5^\circ\text{C}$ increments. Four dust samples and two "pure" As_2O_3 products will be used for the solubility work.

2) Dust vaporization:

Antimony oxide boils at 1550°C whereas As_2O_3 sublimates at 465°C . Hence, controlled distillation at various temperatures is one means to up-grade the arsenic-rich dusts. Various atmospheres will be tried at one determined temperature. In all cases, the condensed oxide will be analysed for As, Sb and Fe.

Tests at five constant temperature will be run in slowly-flowing inert gas: 500, 475, 465, 450, 400°C .

Three comparative tests will be run at 475°C using slowly-flowing air, inert gas and hydrogen to assess the influence of the atmosphere on the extent of water dissolution and the purity of the products.

3) Mineralogical characterization:

Two "feed" dust samples, and the corresponding leach residues will be subjected to detailed mineralogical examination. Methods to be used include X-ray diffraction, scanning electron microscopy-energy dispersive X-ray analysis (SEM-EDX) and quantitative electron microprobe analysis. The work will be directed to the identification of the As-, Sb- and Fe-containing phases, rather than a detailed search for "invisible gold".

4) Ion exchange:

Based on the work already carried out by Royal Oak, screening tests will be done using three resins and one activated carbon to be chosen jointly by Royal Oak and CANMET. The screening will be done in batch equilibrium tests at 3 levels of temperature (room, 50°C and 75°C) using a synthetic solution containing concentrations of As(III), Sb(III) and Fe(III) at a level comparable to that found in the leaching experiments. Column breakthrough experiments at room temperature will be done for all four adsorbents. The best adsorbent will be chosen and tested in column experiments using CANMET-produced leach solution at room temperature. Elution experiments will examine the use of only concentrated HCl solutions. No consideration will be given to Sb recovery from the strip solution.

Schedule

It is estimated that the project will take six (6) months to complete. See the project timetable in Appendix A.

Deliverables

A final report detailing the observations and drawing any relevant conclusions will be prepared at the end of the studies. Recommendations for further work will be offered, where such recommendations arise from the studies done.

Project Leader

John Dutrizac will be the project leader, who will direct the solubility tests. Any questions regarding the technical aspects of this project should be addressed to him at (613) 995-4823. Other key personnel will be P.A. Riveros, A. Dubreuil, T.T. Chen and R. Lastra. Their curricula vitae are included in Appendix B.

APPENDIX A

Work Schedule and Detailed Costing

SUMMARY OF ESTIMATED COSTS

Project Activity	Cost (Can\$)
1. Solubility measurements	\$25,541
2. Dust vaporization work	\$ 7,895
3. Mineralogical characterization work	\$ 3,917
4. Ion exchange work	\$14,380
5. Preparation of final report	\$ 2,265
Total estimated Cost	\$54,998

Notes:

The professional and technical staff working on the project will be charged at standard rates scheduled under NRCan policy.

Estimated actual hours at the appropriate rate have been used to prepare the summary of project costs.

MMSL PROJECT PLANNING SHEET

Project Name: Recovery and Purification of Arsenic Oxide - Giant mine
Project Leader: J.E. Dutrizac
Client Name: Royal Oak- DIAND
Project Number: 601903

STEPS	TIME ELAPSED (MONTHS)						Estimated Cost (\$)
	1	2	3	4	5	6	
1 Solubility measurements							26,541
2 Dust vapourization							7,895
3 Mineralogical characterization							3,917
4 Ion exchange							14,380
5 Preparation of final report							2,265
							64,998

APPENDIX B

Curriculum Vitae

- J.E. Dutrizac, Ph. D.
Principal Research Scientist
CANMET - Mining and Mineral Sciences laboratories
Telephone: (613) 995-4823; Fax: (613) 996-9041

More than twenty years experience in extractive metallurgy and mineral chemistry

RESEARCH AND DEVELOPMENT

Extractive metallurgist with experience in both hydrometallurgy and pyrometallurgy as well as a continuing involvement in the field of applied mineralogy. Extensive experience related to copper electrorefining, and in particular, to the characterization of copper anodes, anode slimes and leached anode slimes. The work has focussed on the characterization of selenium-tellurium carriers, as well as the use of the mineralogical information to deduce the reactions of selenium and tellurium which occur during copper electrorefining. Over twenty scientific papers have been published on this aspect of the overall copper refining problem. Expertise in the ferric ion leaching of sulphides such as chalcopyrite, galena and sphalerite, and in the related field of iron precipitation and control. The work has mostly involved jarosite precipitation and hematite formation. Considerable experience in the processing of zinc, and the hydrometallurgical treatment of lead. Considerate involvement in the treatment of metallurgical effluents. In all areas, the processing aspect have been related to the fundamental chemical properties of the systems, and efforts commonly were made to combine chemical and mineralogical techniques.

Expertise in the development of broadly-based research programs, their implementation and monitoring. Experience in the development and monitoring of contracts with industry and universities, and in the evaluation of the results. Considerable experience in coordinating group efforts, organizing meetings and reporting data. Experience and competence in making technical presentations to industry-university working groups and to national and international scientific audiences. Over 175 technical papers and authoritative reviews in the international scientific literature.

PROFESSIONAL SOCIETIES

Member of: Canadian Institute of Mining, Metallurgy and Petroleum (CIM); Chemical Institute of Canada (CIC); and the Minerals, Metals and Materials Society (TMS). Member of the organizing committee for the Copper '91 - Cobre '91, Copper '95 - Cobre '95 and Copper '99 - Cobre '99 series of international conferences on the production and refining of copper.

Patricio A. Riveros, Ph.D.

Research Scientist, Environment Laboratories.
Telephone: (613) 992-0200 Fax: (613) 996-9041
E-Mail: priveros@NRCan.gc.ca

More than 17 years of experience in hydrometallurgy, especially solvent extraction, ion exchange and pollution abatement. Degrees in chemistry (B. Sc.), chemical engineering (M. Sc.) and metallurgical engineering (Ph. D.). Author of several technical publications and reports.

PRACTICAL EXPERIENCE ON:

- Hematite recovery from steel-making wastes.
- Recovery and recycling of cyanide from effluents.
- Purification of phosphoric acid solutions by solvent extraction.
- Removal of iron from zinc electrolytes.
- Ion exchange treatment of acid mine drainage solutions.
- Extraction of gold from cyanide media.
- Extraction of gallium from Bayer liquors
- Recovery of gallium from gallium arsenide scrap.
- Removal of copper from gold pond effluents.
- Removal of ammonia from effluents with zeolites.
- Extraction of molybdenum from alkaline media.
- Recovery of uranium as a by-product of copper leach liquors.

A.A. Dubreuil, Ph.D.

**Research Scientist, Pyrometallurgy Section
CANMET - Mining and Mineral Sciences Laboratories
Telephone: (613) 995-5844; Fax: (613) 996-9041**

Fifteen years of research experience, including cost recovery projects, in government and university in the fields of inorganic and high temperature chemistry.

Experiences:

Broad experience in the research and development of potentiometric sensors for on-line determination of species of interest in pyrometallurgical processing. Experience in development of ceramic synthesis and forming for high temperature applications.

Development of Sensors - Potentiometric probes for the on-line determination of alloying elements in liquid aluminum. Investigations on the real-time measurement of SO_2/SO_3 in gas phases at elevated temperatures.

Synthesis of Ceramics - Investigation of the direct synthesis of various aluminates for solid electrolyte applications and of ceramic plates of titanates for the generation of ozone.

Slip Casing of Ceramics - Fabrication of various shapes of ceramics (oxide, fluoride) for solid electrolyte or containment applications.

T.T. CHEN, Ph.D.

Research Scientist, Mineralogist

Telephone: (613) 995-9490; Fax: (613) 996-9673

Twenty-five years experience in process mineralogy relating to hydrometallurgical research/development, and in materials characterization

RESEARCH AND DEVELOPMENT

- Over twenty years experience with CANMET in process mineralogy relating to extractive metallurgy, materials characterization and general mineralogy. Expertise in characterization of leach residues and in the application of mineralogy and electron microscopy to assess hydrometallurgical processes, particularly the processing of zinc and the disposal of metallurgical wastes. Extensive experience related to copper electrorefining, and in particular, to the characterization of copper anodes, anode slimes and leached anode slimes. The work has focussed on the characterization of selenium-tellurium carriers, as well as the use of the mineralogical information to deduce the reactions of selenium and tellurium which occur during copper electrorefining. Over twenty scientific papers have been published on this aspect of the overall copper refining problem.
- Three years Post-doctorate research with Carleton University on crystallography, crystal chemistry and the synthesis of sodium-zirconium silicates.
- Over 125 publications in scientific journals.

HONOURS

- Recipient of several honours, including the extractive Metallurgy Science Award of the Minerals, Metals and Materials Society of TMS-AIME, and the Best Paper Award of the Metallurgical Society of the CIM on two occasions.

PROFESSIONAL SOCIETIES

- Member of the Process Mineralogy Committee of the Minerals, Metals and Materials Society (TMS), and the Society for Mining, Metallurgy and Exploration (SME).

R. Lastra, PhD

Research Scientist, Process Mineralogy Group
CANMET - Mining and Mineral sciences Laboratories
Telephone: (613) 992-1393; Fax: (613) 996-9673

Fourteen years of experience in extractive metallurgy, mineral processing and process mineralogy.

Government:

Six years of experience, gained working for the government of Canada, performing process mineralogy by image analysis and electron microscopy. Determination of mineral quantities, liberation and association of minerals, in ores to determine the best processing routes, and in process products to improve recovery and reduce costs of concentration plants.

Three years of experience, gained working for the government of México, in mineral processing and extractive metallurgy. Particularly in five industrial research projects involved with leaching of mercury sulphide and cementation of metallic mercury; leaching of manganese ores to produce battery grade manganese dioxide; froth flotation and magnetic concentration of manganese ores; silver recovery from tailing ponds by cyanidation; and recovery of cenospheres, magnetite, and alumina from fly ash of carboelectric power plants.

University:

Five years as professor, of the National Polytechnic Institute (IPN) in México City, lecturing in non-ferrous metallurgy, mineral processing, and physical chemistry in metallurgy. Served as academic co-ordinator, for the Metallurgical Engineering Division.

Protected business information

APPENDIX C

Terms & Conditions

**Terms and
Conditions:**

Royal Oak Mines Inc., of Kirkland, Washington is hereinafter referred to as the "COMPANY".

Estimated Costs:

The estimated cost of this work, Fifty-five thousand Canadian dollars (Can\$55,000), is not a firm price quotation, and should work beyond this amount be required to meet the project objectives, CANMET will seek written authorization from the COMPANY prior to proceeding.

Invoicing and Payment:

This project is being jointly funded by Indian and Northern Affairs Canada (DIAND) and the COMPANY. DIAND will fund Forty-four thousand Canadian dollars (Can\$44,000) of the project cost and the COMPANY will fund Eleven thousand Canadian dollars (Can\$11,000).

DIAND, as a federal government department, will transfer its portion of the funds internally to CANMET after the project commences. CANMET will submit an invoice to the COMPANY for half of their commitment (Can\$5,500) three months after the project commences. A second invoice for the remainder (Can\$5,500) will be submitted after the work in the project has been completed. In both cases payment should be made within thirty (30) days from the date of the invoice.

If payment is not received within the thirty (30) days following the date on the invoice, the debt is considered overdue and interest will accrue starting on the 31st day.

Irrespective of the month, the prescribed rate of interest will be the annual interest rate of the Bank of Canada in effect in the third week of the month prior to the date on which the interest is calculated, plus three percent (3%) per year.

Credit privileges are cancelled when a customer's account is ninety (90) days overdue.

CANMET reserves the right to change the above terms of credit on a customer's overdue account.

Please always refer to our file number 601903 on all documentation associated with this project.

Company's Obligations:

The COMPANY agrees to immediately notify CANMET of any changes to its ownership or other factors which may affect its obligations and responsibilities under this contract.

In addition to paying CANMET for work done under this agreement, the COMPANY shall provide CANMET with all necessary materials data and other information to perform the work. Any unused material will be returned to the COMPANY.

Company's Confidential Information:

The COMPANY acknowledges that it has not disclosed or provided to CANMET any unauthorized confidential information or sample(s) in respect to the work to be done under this agreement.

Confidentiality:

CANMET agrees to keep confidential and not disclose to third parties the information generated during the course of and related to this work, nor any confidential information provided to CANMET by the COMPANY for a period of three (3) years from the effective date of this agreement, except with the written consent of the COMPANY or where the information: (a) is or becomes generally publicly available without the fault of CANMET; (b) is subsequently disclosed to CANMET by any third party not under a secrecy obligation to the COMPANY; (c) is subsequently developed by or for CANMET independent of any information developed under this agreement; (d) or is required by law. At the end of the confidentiality period all documentation and reports will automatically be declassified, unless otherwise specified.

CANMET reserves the right to use the information contained in the deliverables for policy formulation and in-house research purposes, and to publish summary, non-confidential announcements on the project. Such announcements shall not be published without the consent of the COMPANY, which consent shall not be unreasonably withheld.

Should any Intellectual Property arise from the work, CANMET will negotiate in good faith a licence agreement authorizing the COMPANY to use the Intellectual Property on terms and conditions to be mutually agreed upon.

The COMPANY agrees that the information contained in this proposal is confidential and proprietary to CANMET.

The COMPANY agrees that it shall not copy this proposal nor distribute this proposal to other parties except as provided for in the above provisions governing confidential clauses or unless permitted in writing by CANMET.

The COMPANY further agrees that in the event the COMPANY decides not to pursue the proposed work through a contract with CANMET, that it will return this proposal and other information or documentation which has been provided to the COMPANY relating to this proposal.

Warranty and Indemnity:

CANMET shall perform the project as specified in the proposal in a diligent, thorough and workmanlike manner in accordance with good scientific and technical practices. Nonetheless, CANMET makes no representations or warranties respecting Deliverables, either expressed or implied, arising by law or otherwise, including, but not limited to, implied warranties or conditions of merchantability or fitness for a particular purpose.

The COMPANY shall indemnify and save harmless CANMET and its employees and agent(s) from and against any and all claims, damages, losses, costs and expenses, including lawyers fees, actions, suits and proceedings, arising out of or attributable to the use of the Deliverables or any part thereof by the COMPANY, except as the same shall result from CANMET negligence, those of its employees, agents and subcontractors.

Amendment:

This contract may be amended by mutual agreement of both Parties, but no amendment to this agreement shall be effective unless reduced to writing and signed by the authorized representatives of both Parties.

Force Majeure:

Neither party to this Agreement shall be liable to the other for any failure or delay in performance caused by circumstances beyond its control, including but not limited to acts of God, fire, labour difficulties or governmental action.

Governing Law:

This Agreement shall be governed and construed with the Laws of the Province of Ontario and Laws of Canada as applicable, and shall be treated in all respects as an Ontario contract.

Dispute Settlement:

CANMET and the COMPANY shall attempt to resolve any dispute arising out of or pursuant to this Agreement by recourse to the process described in Natural Resource Canada's *Preferred Method of Dispute Resolution - Revenue-Generating Agreements* in order to reduce delays and litigation expenses for both parties.

Termination:

Either party may terminate this Agreement upon thirty (30) days written prior notice to the other party. Upon termination of the Agreement under this clause, the COMPANY shall pay for all charges for the services rendered up to termination and shall reimburse CANMET for expenditures reasonably incurred by CANMET and for which CANMET is obligated to make payment.

Restriction of Benefits:

No member of the House of Commons of Canada shall be admitted to any share or part of this Agreement or to any benefit to arise from it.

Validity:

This proposal remains valid for one (1) month following its submission unless otherwise specified.

Acceptance:

By approval hereof, the undersigned acknowledge and hereby accept the terms and conditions of this agreement.

CANMET

COMPANY

Signature

Harry F. Steyer Jr.

Name

R.N. Hargreaves

Title

Director

Laboratory

CANMET-Mining and Mineral
Sciences Laboratories

Date

September 23, 1998

Signature

Name

Title

Division

Date

Edmund Szol

EDMUND SZOL

COO

ROYAL DAK MINES

October 2, 1998

Please return one signed copy to:

Brenda Moir, Contracts Officer
Business and Administration Services
CANMET - Mining and Mineral Sciences Laboratories
Room 126, 555 Booth Street
Ottawa, Ontario K1A 0G1
Fax: (613) 947-0983