EXPERT OPINION OF PAUL B. QUENEAU AND REBUTTAL OF THE EXPERT OPINION OF J.F. HIGGINSON

PAKOOTAS, ET AL. v. TECK COMINCO METALS ET AL.

May 12, 2011

TABLE OF CONTENTS

I. INTRODUCTION 6

II. QUALIFICATIONS 6
- Employment History
- Books
- Technical Presentations and Journal Publications
- Patents
- Projects That Involved Zinc and Lead Extractive Metallurgy

III. CASES IN WHICH PAUL B. QUENEAU TESTIFIED AS AN EXPERT AT TRIAL OR BY DEPOSITION IN THE PAST FOUR YEARS 14

IV. BASES AND SUPPORTING INFORMATION 14

V. THE PURPOSE OF THIS REPORT 14

VI. EXECUTIVE SUMMARY 16
- A. Lead Blast Furnace (BF) and Fumed Slag Discharges (1920 to 1997)
- B. Non-Slag Discharges (1920 to 2005)

VII. TRAIL OPERATIONS IN ONE PARAGRAPH 18

VIII. OVERVIEW OF METAL AND BYPRODUCT PRODUCTION AT TRAIL 18
- A. Stages of Growth at Trail: 1896 to 1995
  - Overview
  - Location of the Trail smelter
  - Copper ore feedstock and copper matte product
  - Roasting to remove sulfur
  - Production of sulfuric acid from roaster offgas
  - Copper smelting to produce matte product and slag waste

Handling furnace offgas
Production of lead
Acquisition of key mines
Production of electrolytic zinc and copper (1916)
Separation of lead from zinc by flotation (1923)
Fuming of lead blast furnace slag (1930)
Production of fertilizer from Trail byproducts (1931)
Suspension roasting of zinc sulfide concentrates (1936)
Minimizing loss of lead tankhouse electrolyte
Establishing a major source of captive electric power (1942)
Support of World War II efforts
Recovering dust and fume from furnace offgas
Minor metal recovery
The modernization of Trail
B. Calculation of the Weight of Slag Produced at Trail 34
C. Opinions from Section VIII 36

IX. COPPER SMELTING AT TRAIL: 1896 to 1930 52
A. Definition of Copper Smelting; Slag Byproduct Utilization
B. Copper Blast-Furnace Matte Smelting
C. Copper Reverberatory Matte Smelting
D. Roasting or Sintering of BF and RVF Feedstocks
E. Slag Output from Copper Matte Smelting
F. On-Site Conversion of Copper Matte to Refined Copper
G. Opinions from Section IX 62

X. LEAD OPERATIONS AT TRAIL – THE EARLY YEARS: ≈1900 to 1929 63
A. Specifics on the Early Years of Lead Operations
B. Opinions from Section X 67

XI. ZINC OPERATIONS AT TRAIL – THE EARLY YEARS: 1916 to 1929 67
A. Specifics on the Early Years of Zinc Operations
B. Opinions from Section XI 68

XII. LEAD, ZINC & FERTILIZER – THE MIDDLE YEARS: 1930 to 1979 70
A. Fuming of Lead Blast Furnace Slag
B. Suspension Roasting of Zinc Concentrates
C. Sulfuric Acid Output Leads to Fertilizer Production

D. Fertilizer Production Leads to Smelter Process Efficiencies
E. Recovering Dust and Fume from Furnace Offgas
F. Minimizing Loss of Electrolyte in the Betts Process
G. Cadmium Recovery
H. Arsenic Recovery
I. Opinions from Section XII 82

XIII. THE DISPOSITION OF MERCURY AT TRAIL 82
A. Mercury Recovery from Zinc Roaster Offgas
B. Mercury Recovery from Lead Sintering-Plant Offgas
C. The Quicksilver Material Balance for Mercury
D. Opinions from Section XIII 93

XIV. THE MODERNIZATION OF TRAIL: 1981 to 1998 105
A. The Effluent Treatment Plant (1981)
B. Modernization of the Zinc Refinery (1981)
C. Boliden Norzink Process (1981)
D. Electrolyte Purge Recycle (1981)
E. Halide Leach Plant (1982)
F. Copper Products Plant (1989)
G. Thallium Removal Plant (1989)
H. Elimination of the Electrolyte Purge Discharge (1990)
I. Collection and Treatment of Surface Water Runoff (1993)
J. Indirect Heat Exchange (#7 Sewer) in the Lead Smelter (1994)
K. Effluent Treatment Plant Lagoon (1994)
L. TMT Addition for Mercury Precipitation (1995))
M. Eliminating Slag Discharge to the Columbia River (1995 - 1997)
N. Treatment of Copper Matte Granulation Water (1996)
O. Roof Drains and Perimeter Drainage (1997)
P. Start-up of the Kivcet Smelter (1997)
Q. Elimination of Sewer #7 Discharge (1998)
R. Opinions from Section XIV 117

XV. THE SEWERS 118
A. Findings on the 12 Sewers, as Detailed in the B.C. MoE Phase 2 Study
B. Rearrangement of Trail's Sewers in the 1980s
C. Total vs Dissolved Metals, Primarily Discharged to the Columbia River

D. Opinions from Section XV 128

XVI. INPUTS AND DISTRIBUTIONS SPREADSHEETS 131
A. Metal Discharges, Primarily to the Columbia River: 1920 to 2005
B. Sheet 1: Lead Concentrate Analyses
C. Sheet 2: Zinc Concentrate Analyses
D. Sheet 3: Copper, Lead, Zinc and Cadmium Production
E. Sheet 4: Estimated Feedstock Tonnage (1920 to 2005)
F. Sheet 5: Lead Blast Furnace and Fumed Slag Analyses
G. Sheet 6: Estimated Metal Discharges in Slag to the Columbia
H. Sheet 7: Production of Sulfuric Acid (100% Basis)
I. Sheet 8: Summary of Non-Slag Discharges, Primarily to the Columbia River, and Air Emissions
J. Sheet 9: Inventoried and Unaccounted Metals
K. Sheet 10: Metals Emissions to Atmosphere
L. Sheet 11: Metals Outfalls, Primarily to the Columbia River
M. Sheet 12: Arsenic Balance
N. Sheet 13: Cadmium Balance
O. Sheet 14: Lead Balance
P. Sheet 15: Mercury Balance
Q. Sheet 16: Zinc Balance
R. Sheet 17: Inventory of Slag, Sulfide Residue, and ETP Solids
S. Sheet 18: Fertilizer Balance
T. Calculation of Slag Volume
U. Explanation of Spreadsheet Details
V. Opinions from Section XVI 135

XVII. STANDARDS FOR OPINIONS 138

APPENDIX A: A Trail Plant Profile – 1954 138
A. Sintering Lead-BF Feedstocks
B. Lead Blast Furnace Slag
C. Lead Blast Furnace Slag Fuming
D. The Lead Refinery
E. The Silver Refinery
F. Antimony Production
G. The Zinc Department

H. Cadmium Recovery

APPENDIX B: Glossary of Terms 147

APPENDIX C: References Cited, Reviewed, and Considered while Preparing My Expert Opinion and Rebuttal, Including Technical Papers, Books, and Documents (Separate File) 152

APPENDIX D: Inputs and Distributions Spreadsheets, and Explanation of Spreadsheet Details (Separate File) 152

APPENDIX E: Paul B. Queneau – C.V. 152

APPENDIX F: Response to John F. Higginson's (JFH's) Additional Comments Identifying Errors in Mr. Queneau's Historical Review on p 19 in JFH's 30Nov10 Expert Opinion 161

APPENDIX G: Response to JFH's Critique of the "Inputs and Distributions Spreadsheets; see p 19 of JFH's 30Nov10 Expert Opinion 165

APPENDIX H: Response to JFH's Critique of the "Explanation and Spreadsheet Details" 170

APPENDIX I: Response to JFH's Opinion #2: "Constant Properties of Barren slag Put into Columbia River; see p 11 of JFH's 30Nov10 Expert Opinion 171

APPENDIX J: Photographs
See attached file: Photos for PBQ Expert Opinion & Rebuttal" 175

APPENDIX K: Tabulation of Slag Tonnages (Tech 0715785) 175

APPENDIX L: Tabulation of Recorded Spills 176

SIGNATURE PAGE 183

I. INTRODUCTION

My name is Paul B. Queneau. I am President of P. B. Queneau & Associates, Inc. (PBQ & Associates), Principal Metallurgical Engineer at the Bear Group, and an Adjunct Professor in Environmental Science & Engineering at the Colorado School of Mines (CSM).

I was asked to apply my metallurgical education and experience to provide opinions related to known and calculated amounts of effluents from Teck Cominco's Trail smelting complex that entered the Columbia River from 1896 to 2005. These effluents include slag. P. B. Queneau & Associates Inc. (PBQ & Associates) was compensated at a rate of $300 an hour for my time in preparation of this report. PBQ & Associates was also compensated at the rate of $200 an hour for time spent by a member of the Bear Group working under my direction on this project.

II. QUALIFICATIONS

I graduated from Cornell University, Ithaca, New York, with a B. Metallurgical Engineering in 1964, and from the University of Minnesota, Minneapolis, Minnesota with a Ph.D. in Metallurgical Engineering in 1967. A copy of my C.V. is attached in Appendix D.

I am a member of the American Institute of Mining, Metallurgical and Petroleum Engineers, The Metallurgical Society (AIME-TMS), the Mining and Metallurgical Society of America (MMSA), and the Canadian Institute of Mining and Metallurgy (CIM). In 2001, I was presented the AIME-TMS Extraction & Processing Distinguished Lecturer Award. I was elected to membership in Tau Beta Pi, and am a Registered Professional Engineer in Colorado. I am a Past President of the Denver Section, Extractive Metallurgy Division of AIME.

For over 20 years I have presented short courses on recycling metals from industrial waste. Locations have included CSM (up to 100 attendees, from many countries; held annually for 18 years), AIME and CIM annual meetings, the U.S. EPA's Office of Solid Waste in Washington, a DOE site and a waste management facility.

Employment History

1997 – Present	President P.B. Queneau & Associates, Inc., The Bear Group (Principal Metallurgical Engineer) Golden, CO
1990 – Present	Adjunct Professor Colorado School of Mines Golden, CO
1983 – 1997	Principal Metallurgical Engineer Hazen Research, Inc. Golden, CO
1982 – 1983	President/Owner P. B. Queneau Company, Inc. Golden, CO
1972 – 1982	R&D Supervisor AMAX, Inc. Golden, CO
1967 – 1972	Research Engineer Kennecott Copper Corporation Salt Lake City, UT

Books

- Meeting Chairman and Editor, Third International Symposium on Recycling Metals and Engineered Materials, Point Clear, Alabama, The Metallurgical Society of AIME, Warrendale, PA (1995).

- Editor, International Symposium on Residues and Effluents Processing, The Metallurgical Society of AIME, Warrendale, PA (1991).

- Editor, Symposium on Arsenic Metallurgy: Fundamentals and Applications, The Metallurgical Society of AIME, Warrendale, PA (1987).

Technical Presentations and Journal Publications

- Recycling Metal-Rich Industrial Byproducts, Nickelhuette Aue 375th Anniversary Celebration, Aue, Germany (2010).
- Rich Country–Rich Wastes: Meeting Needs and Grasping Opportunities, MiMeR/Boliden Foresight Seminar, Lulea, Sweden (2008).
- Recent Developments: Specialty U.S. Metals Recycling Plants, Recycling Metals from Industrial Waste Short Course, Colorado School of Mines, Golden, CO (2008).
- Recycling Zinc in the United States, The EI Digest Gathering, San Diego, CA (September 2005).
- Hazardous Waste to Valued Byproducts, The EI Digest Gathering, San Diego, CA (September 2004).
- Recycling Non-ferrous Metals from U.S. Industrial Waste, Hydrometallurgy 2003, AIME/TMS, 1543-1553 (2003).
- U.S. Plants Operated Solely to Recycle Metal-Rich Secondaries, Extraction and Processing Distinguished Lecturer, AIME/TMS Annual Meeting (2001).
- Recycling Lead and Zinc in the United States, Zinc and Lead Processing, The Metallurgical Society of CIM, 127-153 (1998).
- Production of Copper Chemicals from Secondary and Byproduct Sources in the United States, Journal of Metals, 34-37, 49 (October 1997).
- Production of Byproduct Mercury, Journal of Metals, 24-28 (October 1995).
- State of the Art in Mercury Recycling, Intl. Symp. on Treatment and Minimization of Heavy-Metal Waste, AIME/TMS Annual Meeting, Las Vegas (Feb. 1995).
- Secondary Zinc Production and Waste Minimization, Pollution Engineering, 42-44 (November 1994).
- U.S. Mercury Recyclers Expand Process Capabilities, Hazmat World, 31-34 (February 1994).

- Recycling Lead and Zinc in the United States, <u>4th Intl. Symp. on Hydrometallurgy</u>, Salt Lake City (1993).

- Waste Minimization: Recycling of Spent Lead-acid Batteries, <u>Hazmat World</u>, 34-37 (August 1993).

- Slag Control in Rotary-kiln Incinerators, <u>Pollution Engineering</u>, 26-32 (January 15, 1992).

- Producing Zn/Fe-Based Micronutrient from Copper Flue Dust, <u>Intl. Sym. on Processing Residues and Effluents</u>, San Diego, TMS/AIME, 239-254 (1992).

- Application of Slag Technology to Recycling of Solid Wastes, <u>Intl. Incineration Conf.</u>, Knoxville (1991).

- Optimizing Matte and Slag Composition in Rotary-Furnace Lead Smelting, <u>Intl. Symp. on Primary and Secondary Lead Processing</u>, 145-178, Halifax (1989).

- Processing Petroleum Coke to Recover Vanadium and Nickel, <u>Hydrometallurgy</u>, vol. 22, 3-24 (1989).

- Germanium Recovery at Lang Bay, <u>CIM Bulletin, 79(886)</u>, 92-97 (February 1986).

- Iron Control during Hydrometallurgical Processing of Nickel Laterite Ores, <u>Iron Control in Hydrometallurgy</u>, The Metallurgical Society of CIM, 76-105 (1986).

- Silica in Hydrometallurgy: An Overview, <u>Canadian Metallurgical Quarterly</u>, 25(3), 201-209 (1986).

- Control of Autoclave Scaling during Acid Pressure Leaching of Nickeliferous Laterite, <u>Metallurgical Transactions B of AIME</u>, 433-440 (1984).

- Control of Silica Deposition during Pressure Let-down of Acidic Leach Slurries, <u>Third International Symposium on Hydrometallurgy</u>, 121-137 (1983).

- Soda Ash Digestion of Scheelite, <u>Extr. Metallurgy of Refractory Metals</u>, AIME/TMS, 237-267 (1981).

- Ion Exchange Purification of Ammonium Molybdate Solutions, Hydrometallurgy, vol. 6, 63-73 (1980).
- Fluid-bed Electrolysis of Nickel, Metallurgical Transactions B, 659-666 (December 1979).
- Leaching of Cu/Ni/Fe Matte, Canadian Metallurgical Quarterly, Met. Soc. of CIM, 18, 145-153 (1979).
- Nickel/Cobalt Separation by Ozonation, CIM Bulletin, 74-81 (October 1978).
- Leaching of Nickeliferous Limonites, Metallurgical Transactions B of AIME, 547-554 (December 1977).
- Processing WO_3/SnO_2 Concentrate for Brannerite Removal, AIME/SME Metallurgical Trans., 218-221 (1975).
- Turbine Mixer Fundamentals and Scaleup at Port Nickel, Metallurgical Trans. B of AIME, 149-157 (1975).
- Atmospheric Leaching of Nickel-Copper Matte at Port Nickel, CIM Bulletin, 74-81 (February 1974).
- Nitric Acid Processing of Copper Concentrates, AIME-SME Metallurgical Transactions, 117-123 (June 1973).
- Acid Bake / Leach / Flotation of Molybdenite, Metallurgical Transactions of AIME, 23-27 (November 1971).
- Sulfation of Copper/Iron Sulfides with Concentrated Sulfuric Acid, Journal of Metals, (December 1970).
- Kinetics of Scheelite Dissolution in Alkaline Solutions, Metallurgical Trans. AIME, 2451-59 (November 1969).

Patents

- Autoclave Control during Pressure Oxidation of Molybdenite: U.S. Patent 6,818,191 (2004).
- Producing Pure MoO_3 from Low-grade Molybdenite Concentrates: U.S. Patent 6,730,279 (2004).

- Pickling of Refractory Metals: U.S. Statutory Invention Registration H2087H (2003).
- Inhibiting Lead Leaching in Water: U.S. Patents 5,544,859, 5,632,285 and 6,013,382 (1996, 1997, 2000).
- Electrolytic Dissolution and Control of NiS Scale, U.S. Patent 4,627,900 (1986).
- Recovery of Alumina Values from Alunite Ore, U.S. Patent 4,618,480 (1986).
- Stripping of Tungsten from Organic Solvents, U.S. Patent 4,450,144 (1984).
- Recovery of Vanadium and Nickel from Petroleum Coke, U.S. Patent 4,443,415 (1984).
- Silica Control during Acid Pressure Leaching of Nickel Laterite Ore, U.S. Patent 4,399,109 (1983).
- Precipitation of Low-sulfur Calcium Tungstate, U.S. Patent 4,397,821 (1983).
- Digestion of Scheelite Concentrates, U.S. Patent 4,351,808 (1982).
- WO_3 Feedback Control when Producing Ammonium Paratungstate, U.S. Patent 4,325,919 (1982).
- Combined Treatment of Wolframite and Scheelite, U.S. Patent 4,320,096 (1982).
- Processing of Refractory Tungsten Concentrates, U.S. Patent 4,320,095 (1982).
- Upgrading of Scheelite Concentrates, U.S. Patent 4,313,914 (1982).
- Separation of SiO_2, P_2O_5 and F from Tungsten Liquors, U.S. Patent 4,311,679 (1982).
- Separation of Molybdenum from Tungsten, U.S. Patent 4,303,623 (1981).
- Processing Concentrates Having a High MoO_3/WO_3 Ratio, U.S. Patent 4,303,622 (1981).
- Electrolytic Cell for Oxidation of $Ni(OH)_2$, U.S. Patent 4,183,792 (1980).
- Ion-exchange Process for Recovery of Copper and Nickel, U.S. Patent 4,100,043 (1978).

- Selective Leaching of Ni/Cu/Fe/S Matte, U.S. Patent 4,094,754 (1978).
- Sulfuric Acid Leaching of Nickeliferous Laterite, U.S. Patent 4,044,096 (1977).
- Separation of Cobalt from Nickel by Ozonation, U.S. Patent 4,034,059 (1977).
- High-temperature Neutralization of Nickel Laterite Ores, U.S. Patent 3,991,159 (1976).
- Atmospheric Leaching of Nickel-Copper-Cobalt Matte Containing Iron, U.S. Patent 3,962,051 (1976).
- Selenium Rejection during Acid Leaching of Nickel-Copper Matte, U.S. Patent 3,959,097 (1976).
- Separating Copper, Lead, and Insol from Molybdenite Concentrates, U.S. Patent 3,834,893 (1974).
- Nitric Acid Processing of Chalcopyrite Concentrates, U.S. Patent 3,793,429 (1972).

Projects That Involved Zinc and Lead Extractive Metallurgy

- Worked with venture capital firms to evaluate the current capabilities and future potential of U.S. zinc smelters.
- At a zinc monohydrate plant, improved leach circuit operation, and the quality of copper and cadmium cementation byproducts, then converted the leady leach residue to a commercial product.
- Prepared a summary of U.S., Canadian and Mexican steel-mill outputs of electric arc furnace (EAF) dust; detailed alternative methods in use for recovering zinc therefrom; and worked with client to implement dust processing improvements.
- Evaluated alternative methods for zinc recovery from a manganese-rich silver ore, including assessing production of electrowon metal vs micronutrient.
- Physical and thermal processing of spent alkaline batteries to recover zinc oxide fume and a iron-manganese calcine.
- Evaluated primary zinc plant (roast/leach/electrowin) as an acquisition candidate for processing sphalerite concentrate output from proposed mine/concentrator.

- Worked with operating management to improve yield at a plant recovering zinc slab, zinc granules, and micronutrient fines from skimmings.
- Developed technical and marketing criteria to profitably recover zinc-iron sulfate micronutrient from secondary copper smelter dust.
- Studied alternative raw materials and technologies for preparing zinc oxide and hydroxide secondaries to be processed by leaching and purification, followed by electrowinning.
- Provided technical support and economic evaluation for a power plant preparing to produce ZnO byproduct recovered from combustion of tires. Worked with a second power plant to improve zinc recovery.
- Worked with EPA contractor to assemble “a guide on recycling low-metal-content wastes for use by decision makers at superfund, RCRA, and other waste sites.”
- Prepared secondary-lead-plant operating criteria for the International Lead Management Center for third-world plant, including a leach circuit for desulfurizing the reverberatory furnace feed.
- Worked with a major U.S. chemical manufacturer and North American secondary lead smelters to process sludge and soil contaminated with tetraethyl lead.
- Assisted a lead-acid battery recycler with blast furnace formulations to maximize slag environmental acceptability without significantly affecting production efficiency.
- Assisted in developing method to minimize lead transfer into tap water. Our modified procedure for manufacturing bronze valves was then implemented by a major water-valve producer.
- Established means to predictably integrate diverse waste byproducts from lead chemical production into a spent lead-acid-battery rotary-furnace operation.
- Developed a slag solidification procedure to minimize concentration of cadmium and lead reporting to the leachate in the EPA’s TCLP procedure.
- Upgraded operating practices of furnaces converting drosses to Sn-Pb solder, resulting in the doubling of furnace output while improving yield by over 20%.

III. CASES IN WHICH PAUL B. QUENEAU TESTIFIED AS AN EXPERT AT TRIAL OR BY DEPOSITION DURING THE PAST FOUR YEARS

During the past four years, Paul B. Queneau has testified as an expert witness at trial or by deposition in one case:

PERINE v. E.I. DUPONT ET AL., 2007: I was asked to apply my metallurgical education and experience to provide opinions related to zinc production at Spelter, WV, between 1911 and when secondary operations ceased in the early 2000s.

IV. BASES AND SUPPORTING INFORMATION

The opinions contained in the report are based on 43 years of experience as a practicing extractive metallurgist, and 20 years as an Adjunct Professor in the Department of Environmental Science and Engineering at the Colorado School of Mines. In addition to my personal experience I have examined, at least briefly, the technical papers, books, and documents listed in Appendix C.

V. ORGANIZATION AND PURPOSE THE PURPOSE OF THIS REPORT

A. Organization

This report combines my original report of September 2010 with my responses to John Higginson's report of November 2010. My intent in combining these two reports is to allow the reader to review my opinions in one document, rather than having to switch between two documents. Any and all new information appearing in this report is set in a different font for ease of reference.

B. Purpose

My first report reviewed the reasonableness of the data that Teck stated Plaintiffs should rely upon, such as the data Teck supplied to the EPA as part of the RI/FS process, Teck's annual reports, and similar documents produced by Teck. A primary criticism of my report by JFH is that I relied upon data provided by Teck to Plaintiffs as part of the discovery process, data that Mr. Higginson believes to be unreliable. Many of his criticisms appear valid, and this report builds upon the new data provided as part of JFH's Expert Report and documents provided. Many of my opinions have been revised as expressed below.

A key issue addressed in this Expert Opinion and Rebuttal is the direct *discharge* of metal-containing effluents from Trail's metallurgical facilities, primarily into the Columbia River. Discharges include liquid and solids, but not gases. Gases, including fume, in this Expert Opinion and Rebuttal are referred to as *emissions*.

Focus is on the evolution of the processes and operations related to lead, zinc, and copper smelting and refining. Included are the following:

- Changes in the processes and operations, particularly relating to the character and quantity of solid and liquid wastes.
- Disposition of Trail unit operation intermediates and outputs, including those from furnaces and kettles, dust and fume treatment, acid plants, zinc leaching and purification, lead and zinc tankhouses, and byproduct recovery.[1]
- Disposal practices over time.
- Discharges resulting from spills (Appendix L only).
- Feedstocks used in the various operations and the resulting variations in solid and liquid wastes; plus the impact, if any, of changes to feedstocks used in various processes on the character and quantity of wastes.
- Types, origins, compositions, and quantities of solid and liquid wastes discharged by Trail metallurgical operations and the Warfield fertilizer plant to the Columbia River over time.
- Air emissions from Trail operations were addressed in order to calculate year-by-year material balances, specifically for lead, zinc, arsenic, cadmium, and mercury.

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[1] A Glossary of Terms can be found in Appendix B.

- This Expert Opinion and Rebuttal incorporates my review and analysis of the 1,800-plus new documents provided to me on or about January 14, 2011, and relied upon by Mr. Higginson in his November 30, 2010 ("30Nov10") Expert Opinion. These new documents were not made available to Plaintiffs by Teck until after JFH issued his 30 Nov10 Opinion.
- In addition, this Expert Opinion and Rebuttal includes my response to Mr. Higginson's Opinion 2, Constant Properties of Barren Slag Put into Columbia River.
- In addition to responding to JFH's November 2010 report, this report also contains a portion of Plaintiffs' response to the reports submitted by Teck's experts regarding the divisibility of this site, and the volume of metals loaded into the Upper Columbia River. In response to those reports, I have included additional analysis and calculations regarding mercury, spills, and discharges from Teck's fertilizer plant.

VI. EXECUTIVE SUMMARY

Slag is a byproduct of high-temperature recovery of metals. In the context of this report, slag is a glass-like material consisting primarily of silica, lime and iron (oxide and metallic), as well as small amounts of base metals, including zinc, lead, copper, arsenic, and cadmium. Processing sintered lead-rich feedstocks at Trail in blast furnaces prior to 1930 produced *lead blast-furnace slag* waste. In 1930, Trail began *fuming* this lead-BF slag to economically recover additional metal values as condensed fume. Fuming lead-BF slag generated *fumed slag*, which was a waste.

Details on direct slag and metal discharges, primarily to the Columbia River, are tabulated in Tables 2 and 3, Section XVI – *Inputs and Distributions Spreadsheets*. These details include findings and works cited by JFH in his 30Nov10 Expert Opinion. Estimates are provided of the weight of Pb, Zn, As, Cd and Hg originating from Trail's metallurgical operations from 1923 to 2005 that discharged directly either into the

Columbia River or into Stoney Creek. Limited findings are provided on copper discharges.

These discharge totals, as calculated in the Spreadsheets, do not include all of the Pb, Zn, As, Cd, and Hg discharged into the Columbia and Stoney Creek from Trail operations, specifically not:

- Spills of process fluids and slurries, which are included separately in Appendix L.
- Storm water drainage (Cominco, 2007, 005877), and contaminated effluent from groundwater, e.g., seepage along the banks of Stoney Creek and other plant properties (Cominco, 2007, 005877).
- The contribution of Pb, Zn, As, Cd, and Hg from atmospheric discharges from Trail that found a path to the Columbia River.
- Emissions from coal burning.

Thus, estimates provided of the metals discharged directly into either the Columbia River or into Stoney Creek are minimum values. I reserve the right to modify my report if additional information becomes available.

A. Lead-BF Slag and Fumed Slag Discharges (1920 to 1997)

- Quantity of slag discharged to the Columbia: 10,127,000 tons[2]
- Zinc in slag discharged to the Columbia: 389,900 tons
- Copper in slag discharged to the Columbia: 29,000
- Lead in slag discharged to the Columbia: 14,800 tons
- Arsenic in slag discharged to the Columbia: 2,090 tons
- Cadmium in slag discharged to the Columbia: 130 tons
- Mercury in slag discharged to the Columbia: Nil

B. Non-Slag Discharges (1923 to 2005; does not include air emissions)

- Non-slag zinc to the Columbia: 177,000 tons
- Non-slag lead to the Columbia: 14,800 tons

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[2] This report uses short tons (2000 lb), unless specified otherwise.

- Non-slag cadmium to the Columbia: 1,790 tons
- Non-slag arsenic to the Columbia: 376 tons
- Non-slag mercury, primarily to the Columbia: 223 tons

VII. TRAIL OPERATIONS IN ONE PARAGRAPH

The Trail metal and fertilizer production facilities are located approximately 10 river miles upstream from the U.S.-Canada border in Trail, B.C., Canada. Smelter operations have been underway in Trail since 1896. The smelter was owned by a company which became known as Consolidated Mining and Smelting Company of Canada, Ltd., in 1906, was officially renamed Cominco in 1966, and merged with Teck Ltd. to become Teck Cominco Metals, Ltd., in 2001. The facility primarily produced precious metals, copper, lead, and silver during the first decade of operation. Zinc production was initiated in 1916. Plants for production of nitrogen- and phosphorus-based fertilizers began operations in 1930. Although the smelter was originally built to process materials from local mines, it currently processes ore concentrates obtained from mining operations throughout the world. In addition to lead, zinc, cadmium, silver, gold, bismuth, antimony, indium, germanium, arsenic, and mercury, Trail also produces sulfuric acid, liquid sulfur dioxide, and elemental sulfur.

VIII. OVERVIEW OF METAL AND BYPRODUCT PRODUCTION AT TRAIL

To quantify smelter- and refinery-derived effluents that subsequently discharged primarily to the Columbia River via Trail's sewers, it is helpful to understand the processes that created these discharges. This write-up therefore describes the various hydrometallurgical and pyrometallurgical steps that evolved at Trail over 109 years of operation.

A century provides ample opportunity for production, innovation, and change. Change at Trail was particularly rapid between 1896 and 1936, and between 1980 and 2000. Focus was on production of base and precious metals. Byproduct fertilizer operations productively utilized important portions of smelter and refinery effluents; aspects of this nearby facility are also detailed.

A. Stages of Growth at Trail: 1896 to 1995

Briefly tabulated below are key steps in the growth of Trail operations from a 19th Century tent camp to one of the 21st Century's major metal producers.

Overview: The Teck Cominco smelter was originally built by Fritz August Heinze on a bluff above the Columbia River in British Columbia, Canada. He was the driving force behind construction and start-up of the copper smelter in 1895-6 (Fish / Cominco, p 92, 1997). Mr. Heinze had been head of the smelting works in Butte, Montana, and thus brought the expertise to treat the Rossland copper-gold ores. Most of the ores' dollar value was in the gold. It was Heinze who obtained a land grant at Trail from the Dominion Government, founding the British Columbia Smelting & Refining Company.

Location of the Trail smelter: In 1896, Heinze sited his smelter about 120 feet above the Columbia. A later reference (Turnbull, 1907, p 421) states that the smelter was located on the edge of a flat sand bench that rose about 200 feet directly above the Columbia at the junction of Trail Creek. See Figure 1.

In 1898, Heinze sold his holdings to the Canadian Pacific Railroad, which renamed the facility Canadian Smelting Works. The new owners immediately enlarged plant capacity. By 1901, management had created a lead smelting department.

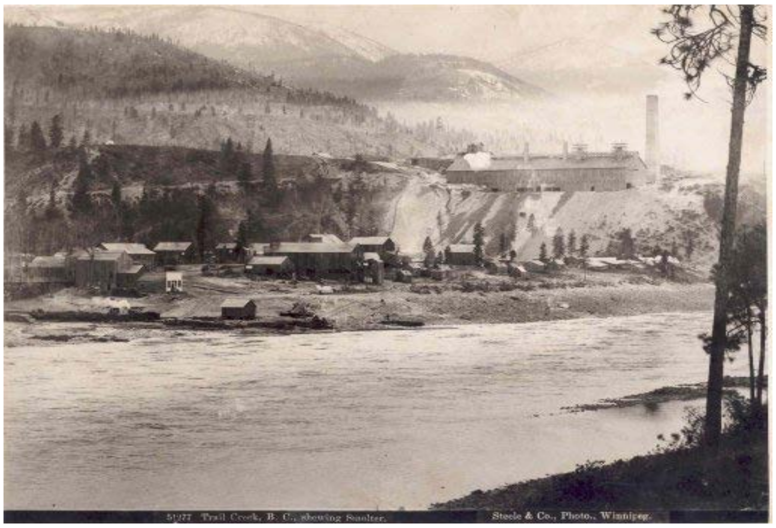


Figure 1. Trail Creek in 1896 – Rails and ties are being unloaded from the Columbia and Western Railway work train (Trail Historical Society – Photo # 1829)

When establishing a location for a smelter, where to put the slag is an important consideration. One attempts to anticipate what the future will bring. J.E. Johnson, a prominent engineer and author in the field of iron blast-furnace construction and practice, observed in 1917 that: *It is not always easy to find a place in which to dispose of the slag without a long chance that one will later on be exceedingly sorry for having put it there* (pp 351-352). Johnson then describes ongoing use of slag granulation at Iron Gate, Virginia, followed by flushing the slag granules into the James River to be carried away by the current.

In regard to slag waste, substantial savings can be derived by water granulation of the molten slag, then using water to sweep slag to its dumping location. This procedure is substantially more economic than mechanically transporting the slag. Additional savings can be attained by discarding the slag into a river, rather than preparing and maintaining a slag dumping ground (Surface Arrangements, Textbook, 1902, pp 42-44).

By 1926, it was clear to Donald M. Liddell (Managing Editor of *The Engineering and Mining Journal*; Secretary of the Mining and Metallurgical Society of America) that an important smelter siting consideration involved anticipating the path of toxic liquid and solid wastes dispersed downstream / downwind from the plant (Vol 1, p 603).

Unless means were implemented to avoid the associated damage, lawsuits could result.

> *Plants which have a waste disposal containing cyanide or other harmful or poisonous ingredients must consider the people and livestock on the downstream side of the mill, or suits may arise involving damage and riparian rights. Plants which emit obnoxious fumes must guard against smoke suits. This can be done either by installing expensive mechanical and chemical means of rendering the gases innocuous, or by constructing the plant of such type and in such localities that the fumes will be so diluted and disseminated before they reach any land capable of producing crops that the danger of smoke suits may be eliminated.*

During the 1930s and 1940s, there was a Trail Smelter Arbitration. This arbitration addressed complaints from American farmers located downwind.

In 1936, S.W Griffin and E.F. Potter completed a study for the Bureau of Chemistry and Soils at the U.S. Department of Agriculture: *Undissolved Mineral Matter, Natural and Extraneous, in the Columbia River in Northern Stevens County, Washington: Slag Pollution.* The final paragraph (p 98) of this report reads:

> *It is recommended that all smelter wastes be excluded from the Columbia River – and in particular it is suggested that officials of the Trail Smelter be asked to cause the abatement, at their plant, of the nuisance of slag-pollution of the river.*

In 1943, Trail management gave considerable thought to building a new smelter at a new site. However, key process operations already in place were relatively modern. The transfer of materials to and from other departments by pipeline also influenced the decision to rebuild within the existing boundaries. These legacy operations were thus *effective anchors to the old site* (Anonymous, Canadian Mining Journal, 1954, p 234).

Trail also completed a detailed study (about 1975) of the possibility of making a large investment in another site in Canada. The company determined that the advantages at Trail far outweighed disadvantages. The roasters, acid plants, lead refinery, the electrical power supply, shops and services, and the community infrastructure at Trail were all deciding factors in maintaining a complete smelting operation at Trail (Fish / Cominco, 1981, p 48).

Copper ore feedstock and copper matte product: The Columbia and Western Railroad delivered most of the smelter's ore from Rossland, an eleven-mile trip with switchbacks to overcome the 2100-

foot drop in elevation. About seven tons/day (tons per day; tpd) of low-grade copper matte product were shipped to Butte, Montana. Matte is a mixture of metallic sulfides. In copper smelting, it is a mixture of copper (Cu) and iron sulfide. In subsequent years, Trail roasted (burnt) this matte, then smelted (melted and processed) the roasted output to produce high-grade matte (40% Cu). Copper matte was later converted to metal (cathode) from 1916 to 1930. *Since 1989 copper matte has been processed to produce copper sulfate and to better manage arsenic by recovering it as copper arsenate* (JFH, Expert Opinion, 30Nov10, p 19). Additional information on production of copper sulfate and copper arsenate from matte and high-arsenic flue dust at Trail since 1989 appears in Section XIV-F: *Copper Products Plant – 1989*.

Roasting to remove sulfur: Roasting (or calcining) of the ore rejected sulfur as sulfur dioxide gas (SO_2). The calcine contained most of the metal oxides. Sufficient sulfide remained in the calcine to permit formation of copper-iron matte during subsequent smelting. In the beginning, *copper-gold ores* and limestone were piled up along with wood and set on fire (Fish, 1997, p 92; Cominco, 2007, TECK 0058560). In less than a year, the heaps were replaced by more efficient mechanical roasters (Carlyle, Provincial Geologist, 1896, p 18).

Production of sulfuric acid from roaster offgas: Beginning in 1916-17, Trail produced 30 tpd of sulfuric acid from zinc roaster gas (which contains SO_2) in two small chamber plants. Outside sources of acid were both unreliable and expensive. A third acid plant, this one using a modified Grillo process, came on line in 1929 (35 tpd). In 1931, three additional units came on line, each rated at 112 tpd acid (King / Cominco, 1950, p 2243). Over a third of the SO_2 released by roasting was then being captured for production and utilization of sulfuric acid.

In 1936, a portion of the roaster offgas was diverted to produce 100% SO_2, which was used to enrich dilute lead sinter-plant offgas. The SO_2 generated during sintering was then captured. In 1938, two additional sulfuric acid plants came on line, which increased Trail's rated capacity of installed units to 600 tons sulfuric acid per day (100% H_2SO_4 basis). Acid production required thorough scrubbing of sinter-plant and roaster offgas. This scrubbing captured metal values that now became available for disposal to the Columbia River (King / Cominco, 1950, p 2243).

JFH in his Expert Opinion (p 19) takes exception to the above phrase … *captured metal values that now became available for disposal to the Columbia River*. He states:

> *This statement ignores the use of settling ponds, called the Glover Tower ponds, to remove much of the suspended particulate and hence most of the metal values in the scrubber effluent. When errors in metallurgical accounting for effluents were being diagnosed by such engineers as Beley (31), the Glover Tower pond overflow was used, not the total from the process.* {Beley prepared a Metallurgical Loss Survey in 1972.}

In response to JFH, *To become available for disposal to the Columbia River* means just that – *available*. Had the metal values not been captured from the roaster offgas, they would have vented to atmosphere, and would thus have been unavailable. Captured metal values were indeed typically returned to a Trail facility for additional treatment, put into inventory, or disposed of on land. Because there remained the possibility that at least a portion of the captured metals would find their way to the Columbia via the sewers, typically during subsequent processing, this material is considered *available*.

The underlying point is that metallurgical processing facilities need to purge feedstock constituents that have no economic home. For example, at Trail, *a portion of the spent acid from the fume section {was} discarded continuously to control the bulk and provide a purge for soluble impurities, such as chlorine, fluorine, and magnesium sulfate* (Anonymous, Cominco Feature, Canadian Mining Journal, 1954, p 278). Fumed slag is a second example of a means to purge unwanted constituents from Trail operations. To the extent that constituents are no longer purged to atmosphere, these constituents need to be purged by other means.

Furthermore, JFH refers to *the use of settling ponds*, which are a source of uncertainty. How well were these ponds maintained and sealed? Were there overflow events? How secure were the solids harvested from the ponds?

Copper smelting to produce matte product and slag waste: Good roasting practice minimizes formation of liquid phases. In contrast, smelting produces liquid phases, e.g., a heavy matte and a lighter (less dense) fluid slag that floats on top of the matte. Slag is predominantly a mixture of metal oxides that have a relatively low affinity for sulfur. Slag and matte are tapped (removed from the furnace) separately. Slag produced during copper smelting is rich in the silicates of oxygen-loving elements, such as iron (Fe), calcium (Ca), magnesium (Mg), and aluminum (Al). The slag's copper content is relatively low, because copper prefers to be associated with sulfur rather than oxygen. Precious metals dissolve in the matte.

In 1896, Trail operated one blast furnace (BF: a vertical smelting furnace) and four reverberatory furnaces (RVFs: horizontal smelting furnaces). By 1898, three 600-ton per day blast furnaces and 48 enclosed roasters had been installed. Fuel and reductant were principally wood (sourced locally), coal, and coke (coal that has been heated to remove volatile constituents). Coal from the U.S. Rocky Mountains was imported via rail to the Columbia River, then sent downstream to Trail in scows. Coke was imported from Fairhaven, Washington. Reductants are substances that can remove oxygen, in this case to assist in formation of Cu_2S-FeS matte product for shipment to Butte.

Trail's early slags from copper production assayed 42 to 46% silica (SiO_2), 12 to 19% FeO, 14 to 19% alumina (Al_2O_3), and 4 to 6% magnesia (MgO) and other metal constituents; see Carlyle, 1896, p 19. This slag was tapped from the furnaces into gutters and slag pots, from which the slag was discharged down the side of the bluff above the Columbia River. The bluff slopes were thus protected against erosion.

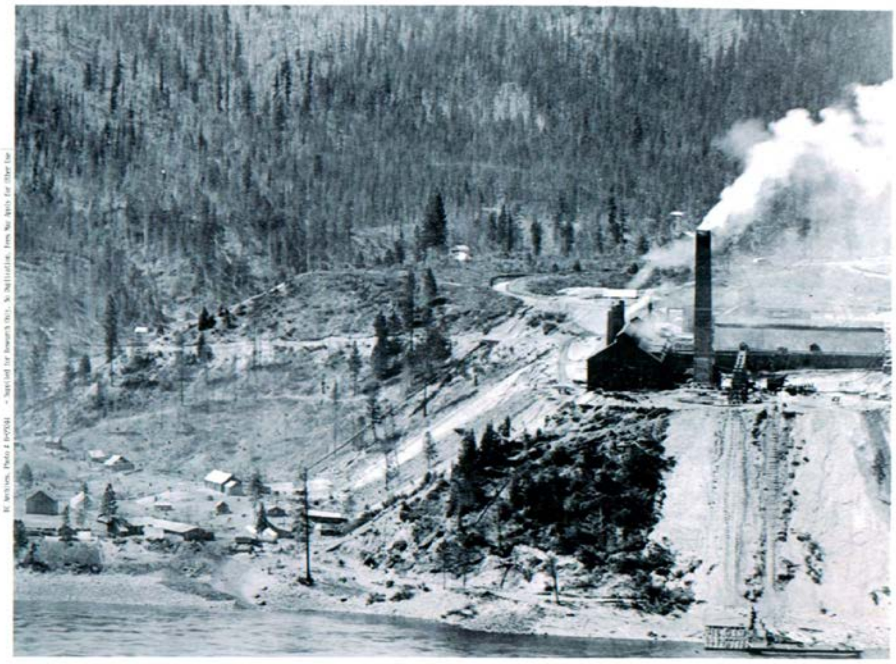
> *The bluff on which the smelter stands is sand, but the top and face of the dump, 120 feet high,* are *being covered with slag that flows in sand gutters from the reverberatories, or is wheeled out in the usual slag-pots from the blast furnace.*

Plans called for granulating the slag, then sweeping it out to the dump (Carlyle, 1896, p 19). As time passed, the bluff gradually extended outward with *a mixture of granulated slag, gravel, ashes, and general refuse* (Murray / CM&S, 1933, p 85). By 1907, slag generated during copper smelting was being water granulated (Turnbull, 1907, p 424).

Two lead blast furnaces were also in operation (Turnbull, 1907, p 421). Trail's slag output during this period would thus have been from both lead and copper smelting. The slag generated during lead smelting was most likely also granulated.

Figure 2 shows the Trail smelter in 1896, with the embankment below extending to near the Columbia River's edge (B.C. Archives). A riverbank retaining wall was built in 1921, then extended in 1922, to hold slag from copper and lead smelting in place. This wall was 37 to 50 feet high (Murray / CM&S, 1933, p 87).

Figure 3, a photo taken in about 1930 during construction of the slag fuming plant, shows this wall. Note that the buildings below the bluff to the left in Figure 2 are also shown in Figure 1.[3]



1896

Figure 2. View of the Trail copper smelter in 1896, showing the close proximity to the Columbia River (B.C. Archives)

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[3] See Opinion #4 (Revisited)

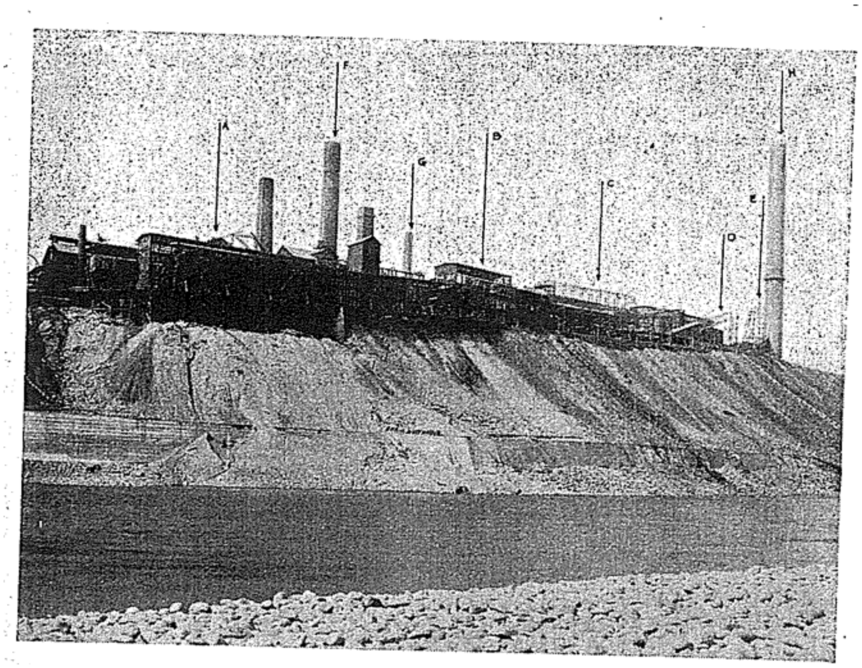

Figure 3. View of Trail's BF-slag fuming plant under construction in about 1930; shown is a retaining wall below the plant along the Columbia that held back slag, gravel, ashes, and general refuse (Murray / CM&S, 1933, p 85)

Handling furnace offgas: Until the installation of hot Cottrell electrostatic precipitators in 1914, smoke from the furnaces was cooled, then passed through dust settling chambers that fed a chimney. Fine dust swept up the stack was likely enriched in arsenic (As) and cadmium (Cd). The basis for this conclusion is as follows:

- Arsenic and Cd – and their oxides and chlorides – are easily volatilized.
- A significant portion of the As and Cd condenses on dust surfaces.
- Most of this surface is associated with the finer dust fractions.
- Fine dust settles slowly, and thus more readily passes through settling chambers into the stack, then to the atmosphere.

A portion of the As and Cd, as well as most of the mercury (Hg), does not condense. This uncondensed fraction is swept up the stack as fume.

Production of lead: Trail operations roasted and smelted lead sulfide ores and concentrates beginning in 1899 (McNab, 1909, p 424). A second historical account states that the decision to include lead smelting at Trail was made in 1901 (Cominco, 2007, TECK 0058560). Roasted feedstocks were smelted in a blast furnace (BF) to produce lead bullion product. A blast furnace is a shaft down which agglomerated lead-rich oxides are reduced to lead using carbon (coke) to produce liquid lead bullion, slag, plus offgas carrying dust, carbon monoxide, and fume. Small quantities of speiss (e.g., iron-rich arsenide) and matte are also formed. Precious metals transfer into the lead bullion.

By 1902, Trail commissioned the world's first electrolytic lead plant; see Figure 4 (Fish, 1997, p 93). This operation, the Betts electrolytic process, refined (purified) blast-furnace lead (Pb). Betts electrorefining continues, expanded and modernized, at Trail as of the date of this report.

Acquisition of key mines: Mines purchased by Trail in 1905-06 included the Rossland and St. Eugene. To reflect this expansion, the company was renamed *The Consolidated Mining and Smelting Company of Canada Limited* (CM&S). This name remained until it was changed to *Cominco* in 1966.

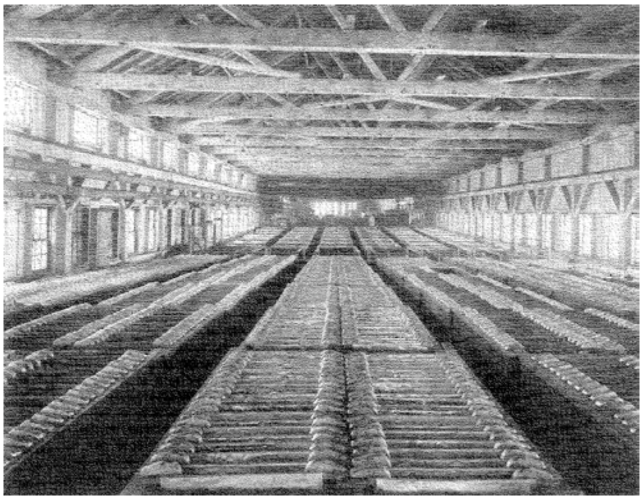

Figure 4. Interior view of the early Betts electrolytic refinery showing the arrangement of the cells (Fish, 1997, p 93)

Most important to Trail's future was purchase of the Sullivan Mine in 1913. By 1914, the Sullivan became the largest lead producer in Canada. After commercialization of sulfide flotation to separate zinc

(Zn) sulfide from lead (Pb) sulfide, this mine also became a world-class zinc producer. Output was high-grade lead concentrate, and high-grade zinc concentrate. After 92 years of operation, the Sullivan mine was closed in 2001. Ore mined from the Sullivan contained approximately 9 million tons of lead, 8 million tons of zinc, and 285 million ounces of silver (Horswill, Northern Miner, Nov 5, 2001).

In addition to the Sullivan, the Pine Point and Red Dog mines were / are the principal source of zinc and lead concentrates fed to Trail's metallurgical operations. The Pine Point mine (Northwest Territories in Canada; owned by Cominco) produced lead and zinc concentrates from 1964 to 1988; the zinc concentrate was consumed at Trail. This concentrate contained minimal amounts of detrimental impurities (Giroux, 2001, p 21). The Red Dog mine (Alaska; owned by Teck Metals) began production in December 1989. A major portion of both Red Dog's zinc and lead concentrate output are shipped to Trail.

Our best estimates of the metal content of typical Sullivan, Pine Point, and Red Dog concentrates consumed at Trail appear in Table I. See the attached *Inputs and Distributions* spreadsheets for details on the sources from which these assays were obtained.

TABLE 1. *TYPICAL* TRAIL FEED CONCENTRATE ANALYSES[4]

	Lead, %	Zinc, %	Cd, %	Arsenic, %	Cu, %	Hg, ppm
Lead Concentrate						
Sullivan	59.0–71.2	2.3 – 9.6	0.017–0.020	0.023–0.133	0.12	2.3–3.3
Red Dog	52.6–56.3	11.2 –14.3	0.08 – 0.10	0.03 – 0.06	0.06	18
Zinc Concentrate						
Sullivan	1.0 – 9.0	38.4–54.0	0.08 – 0.20	0.01 – 0.02	0.15	37–60
Pine Point	1.2 – 3.9	53.6–60.2	0.09 – 0.12	0.01	0.03	0.5–1.0
Red Dog	2.0 – 3.3	53.3–56.1	0.26 – 0.32	0.011–0.020	0.14	91–94

Production of electrolytic zinc and copper (1916): Trail's electrolytic zinc and copper refineries came on line in 1916 (Fish, 1997, p 94). Incentives included war-time need for cartridge brass (an alloy of Cu and

Zn), as well as minimizing product shipping and refining cost. Copper smelting and refining at Trail ceased in 1930 due to a shortage of economic feedstocks. Electrolytic zinc output in 1916 was 30 short tons/day, which had increased to 325 stpd by 1930, and to 450 stpd by 1948. Expanded and modernized zinc tankhouse operation continues at Trail to this day. Refined zinc output from Trail in 2006 was 725 stpd.

Separation of lead from zinc by flotation (1923): Key to large-scale production of zinc by electrolysis was Trail's development of sulfide flotation to produce separate lead and zinc concentrates. Hand sorting (Figure 5) was displaced by flotation (Figure 6). The Sullivan Concentrator at Kimberly using differential flotation commenced operation in August, 1923.

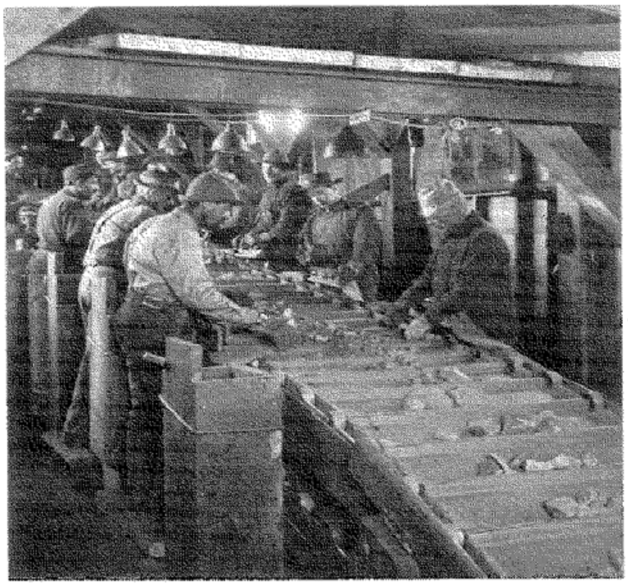

Figure 5. Hand sorting to separate lead and zinc minerals at the Sullivan mine (Fish, 1997, p 94)

Selective flotation also minimized subsequent interference from zinc in the lead smelter. Sullivan lead flotation concentrate was relatively low in zinc content, e.g., 66% Pb and 6% Zn. Conversely, Sullivan zinc flotation concentrate was relatively low in lead content, e.g., 44% Zn and 5.3% Pb. Calcining and leaching this zinc concentrate generated zinc-rich solution, plus lead-rich zinc-poor leach residue. This residue

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[4] The thallium content of Sullivan lead concentrate is about 340 ppm (NRC assay, 2008, p 2).

was blended with lead-rich feedstock in preparation for sintering prior to blast-furnace reduction.

Figure 6. Early wooden flotation cells used to produce separate lead and zinc sulfide concentrates (Fish, 1997, p 94)

Fuming of lead blast furnace slag (1930): Prior to development of the Sullivan mine, Trail's lead-BF slags were reasonably low in zinc content, i.e., 7 to 12% Zn (McNab, 1909, p 431). Once Sullivan output became significant, so did the zinc content of the lead-BF slag. By 1920, Trail had began accumulating lead-BF slag (15 to 20% Zn) in large stockpiles in anticipation of inventing a means to recover this zinc (Yurko / Cominco, 1970, p 331). Zinc built up rapidly in the lead-BF slag; flotation separation of lead from zinc had not yet been commercialized. In 1924, the Staff of CM&S wrote that *a considerable tonnage of this slag* [high iron and zinc] *has been stored with a view to recovering the zinc* (p 455).

Even after lead-zinc flotation separation came on line, the zinc content of lead-BF slag remained high. The operators simply fed more lead to the BF until the 15 to 20% Zn slag limitation was met. Zinc-rich lead-BF slag inventory thus accumulated during the 1920s. Meanwhile, Trail's research staff worked to develop an economic process to recover this zinc.

Research succeeded in 1929. The installation of lead-BF slag fuming in 1930 enabled about 85% of the zinc, and almost all of the residual lead, to be recovered from the zinc-rich lead-BF slag. Blowing air and coal fines into the molten lead-BF slag fumed (volatilized) the zinc, residual lead, and a substantial portion of the cadmium, arsenic, and indium. Product fume was then oxidized and condensed as flue dust, which was captured in baghouses for recovery of metal values. Granulating and discarding the fumed slag into the Columbia River (typically <0.1% Pb and <5% Zn) completed the process.

Analysis of the fumed slag remained steady at about 2.5% Zn and 0.1% Pb; iron, silica, lime, and copper content were 31%, 30%, 17%, and 0.3%, respectively (Fish, 1981, p 55). Cominco subsequently provided this assay as typical for fumed slag (Cominco, 1985, TECK 0617708, p 37). Discharge of fumed slag into the Columbia River continued until 1995.

<u>Production of fertilizer from Trail byproducts (1931)</u>: In 1930, CM&S constructed a chemical complex to manufacture fertilizer at Warfield Flats, a terrace located above the smelter. The company built this plant in anticipation of receiving a key raw material – sulfuric acid – from Trail.

Beginning in 1931, about 38% of the sulfur that had been released to the atmosphere at Trail was converted to sulfuric acid. This acid, derived from the sulfur dioxide gas (SO_2) produced when roasting zinc sulfide concentrates, was in turn converted to commercial fertilizer products. By 1948, 90% of the sulfur in Trail feedstocks was being converted to sulfuric acid.

There was substantial synergy between smelter and fertilizer operations:

- <u>Steam</u> generated during roasting of zinc concentrate was utilized during evaporation of fertilizer solution.
- <u>Oxygen</u> byproduct from fertilizer production was consumed when used to improve smelting and roasting efficiency.
- <u>Ammonia solution</u> from fertilizer production was used to scrub dilute smelter offgases, which in turn produced additional fertilizer.
- <u>Zinc micronutrient fertilizer</u> was later produced from a portion of the zinc sulfate electrolyte purged from the tankhouse.
- <u>Fluosilicic acid</u> byproduct from leaching phosphate rock was captured for use as an electrolyte additive in lead electrolytic

refining; it was therefore no longer necessary to react sulfuric acid with calcium fluoride to produce hydrofluosilicic acid.

Suspension roasting of zinc sulfide concentrates (1936): Offgas from roasting and sintering (agglomerating) lead-BF feedstock was too dilute to economically produce sulfuric acid. In contrast, offgas from roasting zinc sulfide (ZnS) concentrate contained higher and more controllable concentrations of SO_2.

Therefore in 1936 Trail targeted its ZnS roasting process to maximize sulfuric acid output and economics. The company provided additional space between roaster hearths to facilitate sulfide particle combustion while in free fall. A portion of the nitrogen in the furnace combustion air was then replaced with oxygen delivered from Trail's uphill fertilizer operation. The result was output of 6 to 8% SO_2 roaster offgas from which sulfuric acid was efficiently manufactured.

Upgrading zinc concentrate roaster operations opened the door for additional economic recovery of sulfuric acid.

Minimizing loss of lead tankhouse electroyte: In the early years, loss of lead fluosilicate electrolyte solution provided sufficient purge from the lead tankhouse to control impurity concentration. However, by the mid-1930s tankhouse operation had become so efficient that it became necessary to withdraw electrolyte from the system. This purge was treated to recover a substantial portion of its lead and fluosilicic acid content (Fingland,1930, p 190).

Establishing a major source of captive electric power (1942): To meet ever-increasing needs for power, CM&S in 1942 put the Brilliant Dam into operation on the Kootenay River. By 1948, more power was consumed in Trail than in all of the rest of British Columbia.

Support of World War II efforts: Trail's fertilizer plant commenced production of explosive-grade ammonium nitrate at Warfield (2 miles west of downtown Trail) and Calgary, at the request of the Canadian government. This facility was operated on a no-fee basis. CM&S also worked with the American government to build a secret heavy-water plant at Warfield to support early experiments in nuclear fusion (Figure

7); this plant operated from 1944 to 1955 (Cominco, 2007, TECK 0058563).

Figure 7. The secret heavy water plant at Trail, one of Cominco's many war-time contributions (Fish, 1997, p 95)

Recovering dust and fume from furnace offgas: Until 1914, the primary means to minimize dust and fume (volatilized metals) loss to atmosphere was by cooling and settling. In 1914-15, Cottrell electrostatic precipitators were installed to substantially improve fume and dust recovery from lead blast roasting (to agglomerate the BF feed), the lead blast furnaces, and copper converting (Hofman, pp 457-458, 1918). By 1931, hot Cottrells were in service for the sintering machines, zinc roasters, acid plant, and silver refinery.

More complete dust collection was later attained by installing baghouses following slag fuming (1930), the silver refinery (1939), lead blast furnace smelting (1951), the antimonial lead plant, and zinc roasting (1962). Cadmium-rich dust collected in the lead-BF baghouse was pneumatically pumped to the slag fuming operation. Fuming of this dust provided the major purge of cadmium from the smelter (Fish, 1981, p 57). A portion of the arsenic was also purged.

Minor metal recovery: A key to minimizing metal outfall is maximizing recovery. The years in which recovery of key minor metals began are as follows: cadmium (1927), bismuth metal (1929), antimony (1938), indium (1941), arsenic as lead-arsenic-antimony alloy (by 1973), high-purity arsenic metal (1974), mercury (1981), and copper arsenate

(1989). Gold and silver were recovered from the beginning (1896), not only because of their value, but also because these noble elements follow copper and lead during smelting.

<u>The modernization of Trail</u>: The major modernization of Trail began in 1979-89 with installation of continuous drossing of the lead bullion, construction of a modern lead-smelter feed plant, and upgrading of the roaster oxide leach plant. Numerous other upgrades followed, the primary focus of which was improving plant economics. The environment was not neglected in this modernization. Metallurgical modernization projects that achieved major effluent reductions, and the metals targeted, included:

- Effluent Treatment Plant in 1981: All metals
- Modernization of the zinc plant in 1981: Zinc, cadmium
- Boliden Norzink process in 1981: Mercury
- Electrolyte purge recycle in 1981: Zinc
- Halide Leach Plant in 1982: Zinc
- Copper Products Plant in 1989: Copper, arsenic
- Thallium Removal (1993 – 1998): Thallium
- Elimination of the electrolyte purge discharge in 1990: Zinc
- Collection and treatment of surface water runoff in 1993: All metals
- Indirect heat exchange for #7 sewer in lead smelter in 1994: Mercury and arsenic
- Effluent treatment plant (ETP) lagoon in 1994: All metals
- TMT addition for Hg precipitation in 1995: Mercury
- Eliminating slag discharge to the Columbia River in 1995 - 1997: Zinc, copper, and lead
- Treatment of copper matte granulation water in 1996: Cadmium
- Roof drains and perimeter drainage in 1997: All metals
- Start-up of the Kivcet smelter in 1997: All metals
- Elimination of Sewer #7 discharge in 1998: All metals

B. Calculation of the Weight of Slag Produced at Trail

It was not practical to weigh slag waste at Trail. A quick method to estimate slag weight was to ratio its tonnage based on lead production. Toward this end, Cominco's D.D. Logan estimated the weight of fumed slag by multiplying lead production by 1.4 (quantity of BF slag produced) X 0.85 (to convert BF slag to fumed slag); see Cominco Memo, November 28, 1990 by D.D. Logan. The Logan formula was used as a quick means to estimate the weight of slag produced at Trail during a given year. Knowing both the slag's approximate weight and the variation of its assay for a particular metal, one could then quickly estimate a minimum and maximum loss of that metal to slag.

Comparison of slag weights from the Logan formula with that from metallurgical balances (1978 to 1995) showed an average difference of -0.25%. However, four of these 17 years differed from the material balance by over ±20% (Exhibit 257; TECK 715786(1).xls, 2010, Table 2).

For Trail's annual lead BF slag, fumed slag, and refined lead production, I relied in my original report on the values that Teck provided. See TECK 0715785, which appears in Appendix K. Slag outputs were calculated by Cominco from 1910 through 1997. To check these numbers, I relied on smelter data provided in Trail's published technical articles. Using these inputs, slag tonnages were calculated for ten individual years between 1913 and 1990 (i.e., due diligence, picking years for which there were sufficient data). Slag tonnage outputs from these calculations were reasonably consistent with those provided by Teck. Furthermore, Cominco's calculated slag tonnages are reasonably close to those appearing in the company's technical articles.

In the Teck 0715785 tabulation of annual quantity of slag discharged to the Columbia River, no slag is shown going into the river from 1910 to 1920. Furthermore, the quantity of slag shown going to the Columbia from 1920 to 1929 (Teck 0715785) appears to be much higher than it should be.

In his rebuttal report, JFH calculates year-by-year slag tonnage using the Iron-in-Feed method (M3). Details on this *M3 method* appear in his 30Nov10 Expert Opinion, pp 9 - 11. M3 calculations include the following steps:

- Determine the amount of iron entering the smelter from all feeds.

- Calculate the weight of the slag. This calculation is straightforward, because we know with reasonable accuracy 1) the weight of iron in all feeds, 2) the iron assay of the slag, and 3) that all of the iron ends up in the slag.
- Adjust this result for changes in the quantity of iron in stockpiled inventory, e.g., Fe residues, Effluent Treatment Plant solids, BF slag, and pot shell.

JFH developed the M3 method to provide litigants with a more accurate means to determine slag weight than was attained via the Logan formula, or via the M2 metallurgical balance calculations used at Trail. Comparison of total slag weights from JFH's M3 calculations (fumed slag only) with 65-year total from Cominco's metallurgical balances (1930 to 1995) showed a difference of -2.3%. However, comparing the M3 slag for a given year with that derived from the plant's metallurgical balance (M2) fares poorly. The plant M2 balance did not take iron-in-inventory into account.

Furthermore, many rules-of-thumb appear to have been applied in the M2 plant metallurgical balance. For example, the M2 slag output remains the same from 1939 to 1948 (136,799 tons) and from 1951 to 1959 (232,419 tons). Over the 65 years, deviations from between M2 and M3 slag tonnages vary from -72% (1930; M3 is 123,00 tons, vs 34,733 from M2 Metallurgical Accounting) to + 90% (1950).

I accept JFH's improved M3 method for calculating Trail's slag tonnages over the decades. His diligence developed a supportable and more accurate method, M3, of estimating slag tonnage. M3 nevertheless includes its own set of shortcomings, in that the method relies upon:

- The accuracy of Trail's historical annual-feed-tonnage discoverable by JFH; JFH's estimates of tonnages that were not discovered; and the accuracy of occasional estimates made by others decades ago.
- The accuracy of the iron assays of Trail's feedstocks; JFH's estimates of iron analyses that were not discovered; and the accuracy of occasional estimates of iron analyses made by others decades ago.

- JFH's skill in adjusting his calculations for changes in the iron in stockpiled inventory, e.g., Fe residues, Effluent Treatment Plant solids, BF slag, and pot shell, which includes estimating annual through-puts to Trail's fuming furnaces over the decades.

JFH chose not to use his vast data base to prepare similar calculations for lead BF slag of concern (1920 – 1929). I have therefore relied on the tonnages for this slag reported by W. Duncan, as calculated using the Logan formula (Appendix K; and TECK 715786(1).xls, Table 1, Exhibit 257, 2010). Totaling slag tonnage over a ten-year period averages out much of the error of the Duncan method, i.e., not accounting for year-to-year changes in 1) Pb:Fe ratio in feedstocks, and 2) inventory tonnage.

C. Opinions from Section VIII

Opinion #1 (Contested): A variety of factors likely contributed to Mr. Heinze's decision to locate his smelter at Trail:

- Proximity to Rossland ore
- Proximity to rail and river transport for raw materials and products
- Access to fuel, flux (slag additives), and reductant (coal, coke, wood)
- Access to a reliable skilled work force
- Proximity to the Kootenay River for hydroelectric power
- Proximity of clean creek water at suitable head
- A reasonably isolated location for release of smoke
- Proximity to the Columbia River for solid and liquid waste

JFH's *Expert Opinion* (30Nov10, p 13) included the following critique of Opinion #1 above: *Opinion is speculative; there is not supporting data.*

Opinion #1 is not speculative because it tabulates practical, rather than theoretical, factors that likely contributed to Mr. Heinze's decision to locate his smelter at Trail. My reasoning is neither abstract, nor theoretical. Supporting data for the eight components of this opinion are as follows:

- **Proximity to Rossland ore**: Fritz Heinze's B.C. Smelting and Refining Company smelter at Trail Creek Landing *was originally built to smelt* *the copper and gold ores from nearby Rossland mines* (Cominco, Fish, 1997, p 92). *He* {Heinze} *justified his business decision on the strength of a ready supply of copper-gold ore from the burgeoning new mining camp of Rossland, 10 km to the west* (The Northern Miner newspaper, Whiteway, 1996, p 10).

- **Proximity to rail and river transport for raw materials and products**: In 1896, when Mr. Heinze decided to invest in a copper smelter, Rossland ore was being hauled by road to Trail Creek Landing. The ore was then transferred to stern-wheelers or barges for shipping down the Columbia to American smelters (Whiteway, 1996, p 10).

  The mountains in this Trail Creek region were for the most part rounded, so that a railroad could be put through, and nearly any mine would not be difficult to access (Provincial Geologist for British Columbia, Carlyle, 1896, p 14). Heinze fortuitously brought with him from the States the remnants of Brigham Young's narrow-gauge railway, which was laid up the hill to Rossland and renamed Trail Creek Tramway (Rossland Historical Mining Museum). As former head of the smelting works in Butte, Montana, Heinze thus recognized practical river and rail aspects of siting his smelter at Trail (Rossland Historical Mining Museum).

- **Access to fuel, flux, reductant, power, and water**: As former head of the smelting works in Butte, Montana, Heinze was well versed in practical aspects of siting a smelter such that it had economic means to obtain fuel, flux, reductant, power, and water.

  In 1896 in the Trail Creek Mining district, the cost of timber, lumber, wood, and other supplies was very reasonable. Nevertheless, when Mr. Heinze erected his smelter *with great rapidity in spite of inclement winter weather*, he had *great difficulty in securing supplies of building material and importing the plant and machinery*. Work began in October 1895, and was complete in February 1896.

  On a tributary of the Columbia, not far from Trail, a very large water power {was} *secured by Mr. Heinze, who propose*{d} *the installation of an electric plant for the distant transmission of electrical energy…* (Carlyle, 1896, pp 18, 19, and 32).

- **Access to a reliable skilled work force**: In 1896, the chief mining center in the Trail Creek mining district had about 4,000 people, including a water works, an electric light plant, churches, good hotels, two banks, a post office, and three newspaper offices.

From 175 to 200 men were employed at Trail in 1896. *The cost of labor was then about the same as found in other mining centers of the West.* Ore was routinely shipped to American smelters at Tacoma and Everett, Washington, and Great Falls, West Helena, and Butte, Montana, i.e., sources of labor skilled in non-ferrous smelting practice (Carlyle, 1896, pp 13, 17, 19, and 32).

- **Proximity to the Kootenay River for hydroelectric power**: In 1896, West Kootenay Power and Light Company was incorporated to supply the mines with energy to be developed on the Kootenay River (Rossland Historical Mining Museum).
- **Issues associated with liquid waste, solid waste, and smoke**: Fritz Heinze's practical operating and management experience at Butte resulted in his being familiar with a smelter's need to deal with smelter waste.

  The efficiency of rivers for sweeping away liquid waste had been established millennia earlier. In regard to slag and other solid wastes, Heinze almost certainly understood the substantial savings derived by using water to sweep slag to its dumping location. He also likely understood cost savings achieved by discarding slag and solid waste over a river bluff, rather than preparing and maintaining a dumping ground. Water sweeping of slag was substantially more economic than transporting it mechanically. See Surface Arrangements, Textbook, 1902, pp 42-44.

  In regard to smoke, Mr. Heinze was certainly aware of the advantages of siting his smelter such that fumes would be sufficiently diluted and disseminated before reaching land capable of producing crops. However, matters related to smoke damage likely did not head Mr. Heinze's list of key criteria for siting his smelter at Trail Creek Landing.

Opinion #2 (Contested): When comparing Figure 1 to Figure 2, it appears that the direction of slag discharge from the Trail smelter was likely down the bluff toward the Columbia River, rather than down the bluff toward the buildings.

JFH's *Expert Opinion* (30Nov10, p 13) included the following critique of Opinion #2 above:

> *Disagree. This opinion is incorrect. Mr. Queneau's Figure 1 shows slag was being discharged down the hill toward the town site and not towards the Columbia River which is in the foreground and at right angles to this hill. Whatever appears on the river bank in Figure 2 is not slag because we know from the layout of the plant shown in Figures 3 and 4 in Murray 1933 (12) and CM&S plant drawings (29) that there was no ability to move the slag pots in this direction, only toward the bluff toward the buildings.*

In response to JFH's findings on Opinion #2, I have revisited this issue using an expanded collection of smelter slag photos collected from the Trail Historical Society (THS) from the Royal British Columbia (RBC) archives. Also included is JFH's 1920 photograph from p 13 of his 30Nov10 Expert Opinion. See the attached electronic file (Appendix J): *Dated Photographs of Areas Below the Trail Smelter*. These photos viewed sequentially clearly show that prior to 1930, slag was discharged on the buildings side of the smelter, i.e., on the Victoria-Street side of the smelter. Maps showing the location of Victoria Street in 1910 and in 2010 (it has not moved) are included in the *Dated Photographs* attachment, which include TECK 1547095.

Opinion #2 (Revisited): Study of *Dated Photographs of Areas Below the Trail Smelter*, and of JFH's findings related to my Sept 15 Opinion #2, indicates the following: Slag output from the Trail smelter in 1896 was down the bluff to the slag dump on the Victoria-Street side of the smelter, rather than down the bluff that bordered the Columbia River. See Figures 1 and 2.

Opinion #3 (Contested): Based on examination of Figure 2, it appears that if slag had not already reached the Columbia River in 1896, it is likely that slag would have done so by the end of the century, four years later.

JFH's *Expert Opinion* (30Nov10, p 13) included the following critique of Opinion #3 above:

> *Disagree. This opinion is incorrect. It is clear from Figure 2.2 in this report that the slag was being granulated quite early on (no visible poured slag on bank) and this picture in 1910 contradicts the supposition that it would have reached the river by the end of the century.*

In response to JFH's findings on Opinion #3, I continued my study of the attached *Dated Photographs of Areas Below the Trail Smelter*.

Slag was indeed being granulated *quite early*. In 1896, copper reverberatory furnace slag was discharged directly into sand gutters. Copper-BF slag was wheeled out in slag-pots for dumping (Carlyle, 1896, p 19). Carlyle then states that:

> *…but in a short time all the slag will run from the furnaces into water troughs, be granulated, and then swept out to the dump, which will be protected from scouring out by the slag covering.*

A review of the photos attached in Appendix J shows that slag was still being discharged toward Victoria Street to the slag dump in 1910. In 1910, the city of Trail… *attached to the smelter slag launder… a continuation of said launder for the purpose of conveying water and furnace slag in order that certain public and private land may be leveled with said slag to the grade of the surrounding property…* (1910, TECK 1547094). Today the five-block slag-filled area centered on three blocks of Bay Avenue (TECK 1547095 – 1547096) remains an integral part of the city of Trail.

Dated photos in Appendix J are particularly instructive and reveal the following:

- **1900**: *Canadian Smelting Works* (Trail Historical Society, i.e., THS). Note the large pile of black slag granules in the slag dump, located between the smelter and the buildings.
- **1904**: *Trail & Smelter* (THS). The slag pile in the slag dump now extends into the river. Delivering the slag to the river by launder took advantage of the river's current to sweep away slag discharged from the launder.
- **1907**: *Smelter & Bay Avenue bridge*. The slag pile remains extended into the river (THS).
- **1910a**: *Slag pile at left was used to fill in Trail Creek gully* (THS). The portion of the slag pile that extended into the river is gone. This slag was likely consumed filling Trail Creek gully (after insertion of a culvert) from Cedar Avenue along Bay Avenue to the river during the land leveling process. See the map in TECK 1547095.
- **1910b**: *Slag filling in Bay Avenue* (THS). Note the slag launder flushing slag to the site.
- **1910c**: *Here the town is dwarfed by the Heinze Smelter, and a mountain of black slag* (p 13 of JFH's 30Nov10 Expert Opinion).

  Note the size and shape of the slag pile, as compared to the 1900, 1904, and 1907 photos. Compare the height of the slag pile with the top of the bluff upon which the smelter rests. The quantity of slag in

Trail's slag dump appears to have changed little between 1904 and 1910, other than the temporary disturbance in 1910 from filling in the gully.

- **1924**: *Bay & Cedar Avenue from the smelter* (THS). Note the slag launder flushing slag to the site. The slag pile is lower left in this photo.
- **1927a**: *Trail Smelter* (Royal BC Museum). Note the size, shape, and height of the slag pile (lower right), as compared to earlier photos.
- **1927b**: *Trail Smelter* (Royal BC Museum). Apparent discharge of copper smelter and lead-BF slag into the Columbia River. See the two launders in the lower left.
- **ND**: Downtown, west Trail and smelter (THS). This undated photo shows two slag launders in a very similar setting to those that appear in 1927b, but from a different angle.

  The photo was taken after 1910; compare its skyline with the skyline shown in 1910a and 1910c.
- **1930**: *Trail Smelter and Pine Avenue* (THS). Note the size and shape of the slag pile as compared to the earlier photos. Compare the height of the slag pile with the top of the bluff.

Opinion #3 (Revisited): Based on examination of the ten photos described immediately above (1900 to 1930), it appears that slag during this period was deposited in at least three locations:

- Into the slag dump via launders. The slag dump was located between the smelter and the buildings on the smelter side of Victoria Street.
- Into Trail Creek gully via launder to level this location for the city of Trail.
- Into the Columbia River via launders.

Opinion #4 (Contested): Based on Figure 3, I conclude that slag discarded toward the Columbia River would have passed over the wall and entered the river prior to 1930. This slag must have been generated from both copper and lead smelting.

JFH's *Expert Opinion* (30Nov10, p 13) included the following critique of Opinion #4 above:

> *Disagree. This opinion is incorrect. It is clear from the layout of the plant discussed above under*

> *Opinion #2 that slag cannot be discarded in this direction, toward the river. From George Murray's 1933 description (12) on page 85 it is clear that the ground we're looking at under the #1SFF* {Slag Fuming Furnace} *is "…a mixture of granulated slag, gravel, ashes, and general refuse." One of three boreholes sunk in August 2007 show that this fill was in layers with at least 6m of slag in one area at 13 to 19 m depth. Above that was a mixture of sand and slag and gravel. When this ground was "…made outward…" as Murray says, they were not careful to not spill any into the river and that is what I see in the Figure 3 that Mr. Queneau presents. Below in another photo of the #1 SFF as it was completed in 1930 and I think what we're seeing is gravel, sand, and maybe some ash that poured over the wall as the land was made up to provide the foundation for #1SFF. It has nothing to do with slag being discarded into the river.*

In addition to the above critique, JFH provided addition comments (Item #9 on p 22 of his Expert Opinion):

> *Slag discharged on Sheet 6 Rows 7 to 16 shows all lead BF slag produced as being discharged to Columbia rather than any to stockpile in spite of the comments in the first 2 paragraphs on page 27 of the "Expert Opinion" report (2). I agree with the latter comments; I think they should be reflected in the spreadsheet.*

My findings related to the contested Opinion #4 are as follows:

- Based on JFH's findings and my Revisited Opinions #2 and #3, I agree that no substantial quantity of fumed lead-BF slag was discarded over *the wall* prior to Murray's 1933 publication. The wall is shown in JFH's *another photo* in his 30Nov10 Expert Opinion (p 14), and in my Figure 3.
- The final page (Appendix 1, p 28) of JFH's Expert Opinion provides three simplified figures that differentiate the three major flowsheets used at Trail from 1916 to date. A surprise for me was that the first flow diagram shows lead-BF slag going to *Landfill or Stock Piles* (1916 – 1929), omitting the third destination: discharge to the river. This figure has therefore been updated to show discharge of lead BF slag to the river. The term *Barren Slag* has been replaced by *Fumed Slag*. See Figure 19.
- Revisited Opinions #2 and #3 state that slag prior to 1930 exited the smelter from the portion of the bluff located above Victoria Street. A portion of this slag went to the slag dump. The smelter was also equipped to deliver slag-water slurry to the river via slag launders. Launder design and routing is illustrated in the lower left corner of Figure 24 (dated 1927) in my Expert Opinion.

  During the 1920s, Trail generated about 1 million tons of granulated lead-BF slag and well over 2 million tons of granulated copper-smelter slag. There would not have been sufficient room in the slag dump (≈170,000 sq ft) to store all of this slag. Stacking two million tons of this slag vertically, ignoring the angle of repose, results in a slag pile over 200 feet tall.[5] The smelter rests on a bluff on the order of 120 feet above the base of the dump. It appears that much of the copper-smelter slag was discarded into the Columbia. In the Spreadsheets, I did not attempt to quantify or analyze matters related to copper slag.

- Yurko stated that: *The history of slag fuming at Trail began in 1920 when a comprehensive program was initiated to develop an economical process for recovering zinc from lead furnace slag that was accumulating in large stockpiles* (1970, p 331). Mason reported that *…some 500,000 tons of old slag, running about 20% Zn, has been accumulated* (Mason, 1929, p 342), i.e., about half of the lead-BF slag from 1920 through 1929. This high-zinc slag would likely have been stored and segregated on the bluff near the smelter to be readily available for future processing.
- Figure 3 in JFH's Expert Opinion shows on the order of 100,000 tons of *Equivalent Slag* in inventory in 1930, a portion of which was slag.[6]

  Question: What happened to the residual 400,000+ tons of inventoried lead-BF slag that was taken out of inventory between 1929 and 1930? Answer: It was likely disposed of as landfill, rather than being delivered to the slag dump or the river.
- The 400,000+ tons of slag, if delivered to the slag dump, would likely have increased the height of this dump by at least 40 feet. However, the slag-pile profile and height in the 1927 slag-dump photo appears quite similar to that in the 1930 photo, indicating that the slag did not report to the dump. Nor is it likely that this slag was sent to the river, in that a nearby landfill or fill procedure would almost certainly have required less effort.

  Half of the approximately one million tons of granulated lead-BF slag generated from 1920 through 1929 can be accounted for via inventory, fill, or landfill. The remaining 500,000 tons were discharged to the Columbia River based on the following observations:

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[5] The base of the slag dump appears to be about 620 ft long and 270 ft wide. The density of the granulated BF slag is about 117 lb/ cu ft; assume the same for the copper slag.

[6] I was unable to discover whether JFH provided a definition of *Equivalent Slag* in his Expert Opinion. Based on his discussion, Equivalent Slag during a given period may not be slag at all, but instead plant residue containing an equivalent quantity of iron to that in BF slag.

- If this slag had been sent to the slag dump, the added volume should have been readily apparent when comparing the 1927 and 1930 photos of the slag dump.
- The lower left-hand corner of Figure 24 shows two launders discharging into the Columbia River in 1927, both originating from the Victoria-Street side of the smelter. Presumably one flushed the granulated copper-smelter slag, and the other the granulated lead-BF slag.
- Mason (1929) states that the quantity of lead-BF slag stored for future processing was about 500,000 tons, i.e., about half of the approximately one million tons of zinc-rich lead-BF slag produced.
- A letter dated September 15, 1921, written by F.H. Laws (Manager, Northport Smelting & Refining Co.) discussing tailings and slag that had collected in and near the river upstream of the Northport Smelter.
- Finally, in regard to JFH's statement *as Murray says, they were not careful to not spill any into the river and that is what I see in the Figure 3*, "spills" apparently did occur, despite the human propensity to be careful not to spill. See Appendix L.

Opinion #4 (Revisited): Based on a) my findings above related to Opinion #4, b) study of JFH's 30Nov10 Expert Opinion, c) Figures 3, 24, and 25 in my Expert Opinion; and d) the attached dated photographs, I conclude that:

1. From 1920 through 1929, about 500,000 tons of granulated lead-BF slag was discharged via launder from the Victoria-Street side of the Trail smelter into the Columbia River.
2. During this same period, about 500,000 tons of granulated lead-BF slag was stockpiled for future processing, i.e., was placed in inventory.
3. Between 1929 and 1930, 400,000+ tons of this stockpiled slag were removed from inventory, then used as fill or sent to landfill. Up to 100,000 tons of the stockpiled slag remained in inventory.

Opinion #5 (Not contested): Early copper BF and reverb slags at Trail were air-cooled, rather than granulated in water. These slags would likely therefore be found in larger chunks, i.e., substantially coarser than the relatively fine water-granulated slag. By 1907, the slag from copper smelting was being granulated.

Opinion #6 (Not contested): At Trail, when slag from copper smelting was granulated, similar granulation practice was also in place for slag produced from lead smelting.

Opinion #7 (Contested): Relying on open burning – rather than furnaces equipped with means to collect a portion of the evolved dust and fume – resulted in a greater portion of the feedstocks' heavy metals exiting into the atmosphere. Therefore a lesser portion of the metals in Trail's feedstocks was available during this short period for disposal to the Columbia River.

JFH's *Expert Opinion* (p 14) included the following critique of Opinion #7 above:

> *Disagree. This opinion is misleading because open burning was only practiced briefly, as Mr. Queneau says on the bottom of page 18. Such burning was only applied to gold/copper ores. Pb was not treated until 1898 in a converted Cu blast furnace, then a Bruckner roaster was installed with stack and flues completed in 1899 (7).*

I agree that open burning was only applied to Trail's *gold/copper ores*:

Opinion #7 (Requested phrase inserted): Relying on open burning of *gold/copper ores* – rather than furnaces equipped with means to collect a portion of the evolved dust and fume – resulted in a greater portion of the feedstocks' heavy metals exiting into the atmosphere. Therefore a lesser portion of the metals in Trail's feedstocks was available during this short period for disposal to the Columbia River.

Opinion #8 (Contested): Installation of roasters equipped with means to collect a portion of the dust and condensed fume resulted in a greater portion of the metals in Trail's metallurgical feedstocks being available for disposal to the Columbia River.

JFH's *Expert Opinion* (30Nov10, p 14) included the following critique of Opinion #8 above:

> *Disagree. This opinion is incomplete. Collecting a portion of the dust and condensed fume resulted in a greater portion of the metals being captured and recycled.*

Opinion #8 (Provides requested clarification): Installation of roasters equipped with means to collect a portion of the dust and condensed fume resulted in a greater portion of the metals in Trail's metallurgical feedstocks being available for recovery, inventory, landfill, and/or disposal to the river.

Opinion #9 (Not contested, but expanded to address JFH's concerns): Acid production required thorough scrubbing of sinter-plant and roaster offgas.

This scrubbing captured metal values that were now available for recovery, inventory, landfill, and/or disposal to the Columbia River, rather than possible release to the atmosphere.

Opinion #10 (Not contested): Fine dust swept up the stack was likely enriched in arsenic (As) and cadmium (Cd). The basis for this conclusion is as follows:

- Arsenic and cadmium – and their oxides and chlorides – are easily volatilized.
- A significant portion of the As and Cd condenses on dust surfaces.
- Most of this surface is associated with the finer dust fractions.
- Fine dust settles slowly, and thus more readily passes through settling chambers into the stack, then to the atmosphere.

A portion of the As and Cd, as well as most of the mercury (Hg), does not condense. This uncondensed fraction is swept up the stack as fume.

Opinion #11 (Contested): Relying on settling chambers to capture dust and condensed fume resulted in the release of substantial portions of arsenic and cadmium, and most of the mercury, in Trail's metallurgical feedstocks to the atmosphere. The greater the loss of these metals to the atmosphere from Trail's metallurgical dust settling chambers, the lower was the portion of these elements in Trail's feedstocks that could report directly to the Columbia River.

JFH's *Expert Opinion* (30Nov10, p 15) included the following critique of Opinion #11 above:

> *Disagree. This opinion is incomplete. Collecting a portion of the dust and condensed fume resulted in a greater portion of the metals being captured and recycled. Significant amounts of arsenic dusts were subsequently disposed of on land.*

Opinion #11 (Provides requested clarification): Relying on settling chambers to capture dust and condensed fume resulted in the release of substantial portions of arsenic and cadmium, and most of the mercury, in Trail's metallurgical feedstocks to the atmosphere. The greater the loss of these metals to the atmosphere from Trail's metallurgical dust settling chambers, the lower was the portion of these elements in Trail's feedstocks that could report directly to the Columbia River.

Collecting a portion of the dust and condensed fume resulted in a greater portion of the metals being captured and recycled. Significant amounts of arsenic dusts were subsequently disposed of on land.

Opinion #12 (Contested): Addition of hot Cottrell precipitators in 1914 decreased the quantity of arsenic and cadmium escaping into the atmosphere. This decrease resulted in a greater fraction of these metal inputs becoming available for discharge into the Columbia River.

JFH's *Expert Opinion* (30Nov10, p 15) included the following critique of Opinion #12 above:

> *Disagree. This opinion is misleading. The "hot Cottrell precipitators" again resulted in more arsenic and cadmium being recycled and then disposed of on land. Over the years, significant stockpiles of arsenic were created on the property, notably on Duncan Flats above Stoney Creek.*

Opinion #12 (Provides requested clarification): Addition of hot Cottrell precipitators in 1914 decreased the quantity of arsenic and cadmium escaping into the atmosphere. This decrease resulted in a greater fraction of these metal inputs becoming available for discharge into the Columbia River.

Use of Cottrells resulted not only in a greater fraction of the As and Cd becoming available for discharge into the Columbia, but also in more As and Cd being reprocessed. Recovery of cadmium at Trail began in 1927. Much of the arsenic was disposed of on land. Over the years, significant stockpiles of arsenic were created on the property, notably on Duncan Flats above Stoney Creek.

Opinion #13 (Not contested): Trail's Cottrell precipitators collected dust from humidified gas. Unless sufficient moisture was injected to form a liquid phase, direct discharge of the collected dust to the Columbia River was unlikely.

Opinion #14 (Not contested): Recovered flue dust typically contains metals that have significant economic value. Trail would therefore have made substantial effort to economically recover, rather than discard, these values.

Opinion #15 (Contested): Lead blast furnace slag containing at least 15% zinc had substantial commercial value – if an efficient slag fuming process could be implemented. Slags having lower zinc content did not contain sufficient metal values to pay for the cost of fuming, and to provide a margin for profit.

JFH's *Expert Opinion* (30Nov10, p 15) included the following critique of Opinion #15 above:

> *Disagree. This opinion is incorrect. The cutoff grade depends on price of zinc and the combination of Cd, In, Ge when these are being recovered. In the last 10 years metals are being economically recovered from feeds as low as 4% Zn.*

My Opinion #15 remains as written. This opinion refers to when CM&S was determining *if an efficient fuming process could be implemented*, i.e., prior to 1930. Note the past tense: *had commercial value*.

In further response, indium and germanium were not being recovered during this period. Cadmium recovery did begin near the end of this period (1927), but the lead-BF slag contained only a small portion of the cadmium fed to Trail operations. Therefore, the contained metal value of Trail's BF slag at this time was indeed almost totally in its zinc content, not in In, Ge, and Cd. Recall that Murray stated the cutoff-grade criteria in 1933 succinctly: *Slags should contain 15 per cent zinc at least* (1933, p 75).

Opinion #16 (Not contested): When Trail fumed its lead-BF slag, the slag's arsenic, cadmium, lead, and zinc content was substantially lowered. Mercury is so highly volatile that its concentration in both lead BF and fumed slag would be very low.

Opinion #17 (Contested): Annual blast furnace and fumed-slag production tonnages provided by Teck (TECK 0715785) appear to be reasonable. This conclusion is based on using data from Trail's published technical articles to calculate ten yearly slag tonnages in the period from 1913 to 1990.

JFH's *Expert Opinion* (30Nov10, p 15) included the following critique of Opinion #17 above:

> *Disagree. This opinion is incorrect. Refer to my opinion #1 above.*

I agree that JFH's iron-in-feed method (Method #3; M3) can provide a more accurate estimate of BF and fumed slag tonnage, than does application of the Logan Formula.[7] Slag tonnage as calculated by JFH's method #3 have therefore been incorporated into the Inputs and Distributions Spreadsheets.

Opinion #17 (Includes JFH findings): When estimating fumed slag tonnage, JFH's iron-in-feed method (Method #3; M3) appears to give more accurate than tonnages generated by the Logan formula.[8] Slag tonnage as calculated by JFH's method #3 has therefore been incorporated into the Inputs and

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[7] Note that M3 includes its own set of shortcomings, as detailed in Section VIII-C.

[8] Note that M3 includes its own set of shortcomings, as detailed in Section VIII-C.

Distributions Spreadsheets.

Opinion #18 (Not contested): From about 1920 until 1930, Trail stored substantial tonnages of its zinc-rich lead-BF slag (15 to 20% Zn) from lead-BF production in anticipation of developing a process to recover this zinc. It therefore appears that Teck may have overestimated the quantity of lead-BF slag that CM&S discharged to the Columbia River from 1920 to 1930 (TECK 0715785).[9]

Opinion #19 (Not contested): Lead blast-furnace slag generated prior to about 1918 was relatively low in zinc content (7 to 12%), and therefore was discarded. Teck shows no lead-BF slag going to the Columbia River prior to 1920 (TECK 0715785, as provided by Teck).

Opinion #20 (Contested): It appears that granulated lead-BF slag produced at Trail between about 1901 and about 1918 was discarded into the Columbia River.

JFH's *Expert Opinion* (30Nov10, p 15) included the following critique of Opinion #20 above:

> *Disagree. This opinion is incorrect. The following photo, similar to that under Opinion #3 above but from a different angle, shows the BF slag pile in 1910 far from the river.*

See the 1904 and 1907 Trail Historical Society photos from my discussion of Opinion #3 above, which are graphic illustrations of slag that was deposited into the Columbia River, presumably between 1904 and 1907:

- **1904**: The slag pile in the slag dump extended into the river.
- **1907**: The slag pile remains extended into the river.

Opinion #20 (Revisited): Photographs of Trail's slag dump, which was located between the smelter and Victoria Street, show that slag was discarded into the Columbia River in 1904 and 1907.

Opinion #21 (Not contested): Production of sulfuric acid required efficient cleaning of the dust- and fume-laden furnace gases. This cleaning included efficient aqueous scrubbing of the gas, which collected as an aqueous slurry most of the remaining As, Cd, Pb, and Zn, plus a substantial portion of the Hg.

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[9] But note that not all of the slag was stored during this period; see Figure 14.

Opinion #22 (Contested): The efficient gas scrubbing prior to the acid plants substantially decreased loss of arsenic, cadmium, lead, zinc, and mercury to the atmosphere. Efficient scrubbing of gas fed to the acid plants resulted in a greater portion of arsenic, cadmium, lead, zinc, and mercury in Trail's feedstocks being available for discharge to the Columbia River.

JFH's *Expert Opinion* (p 15) included the following critique of Opinion #22 above:

> *Disagree. This opinion is misleading. There were neutralization and settling ponds in use from at least 1950 until 1993 even though they saw much less use after startup of the Effluent Treatment Plant in 1981. These were the Glover Tower ponds and ammonium hydroxide was used to neutralize the scrubber solutions flowing to them. It is evident from the Tadanac Metallurgical Statements (30) and shown by other analyses at the time, such as Beley (31), that this settling removed hundreds of tons of suspended solids from the scrubber solutions before they became effluents. Some of these solids were recycled through the old smelter but the majority of them became part of the Effluent Treatment Plant Residue stockpile which is slowly being recycled through KIVCET.*

Opinion #22 (Includes JFH findings): The efficient gas scrubbing prior to the acid plants substantially decreased loss of arsenic, cadmium, lead, zinc, and mercury to the atmosphere. Efficient scrubbing of gas fed to the acid plants resulted in a greater portion of arsenic, cadmium, lead, zinc, and mercury in Trail's feedstocks being available for discharge to the Columbia River.

In regard to the metals captured by efficient gas scrubbing prior to the acid plants:

- Beginning in the 1950s, a substantial portion of metals collected during gas scrubbing was recovered by neutralization and settling ponds. Some of these solids were recycled within the old smelter.
- Start-up of the effluent treatment plant (ETP) in 1981 resulted in the majority of these solids reporting to the ETP residue stockpile. This stockpile is currently being slowly recycled through the Kivcet furnace.
- A portion of the metal values captured by scrubbing and/or neutralization ended up in the Columbia River. Had these metals not been captured by scrubbing, most of these metals would have discharged to atmosphere.

Opinion #23 (Contested): The upper limit of the amount of zinc tankhouse electrolyte purge that could be consumed in Trail's fertilizer operation was the amount of zinc micronutrient that could be marketed. The amount of zinc that could be marketed as micronutrient was usually substantially less than the amount of zinc purged.

JFH's *Expert Opinion* (p 16) included the following critique of Opinion #23 above:

> *Disagree. This opinion is incomplete. From 1947-1964 a simpler version of the process was operating (7) in which Zn and ammonium sulphate were recovered from stripping acid with the precipitate returned to the roaster, a process limited by Zn economics not a fertilizer demand. This process was converted in 1964 to the ZnMnS fertilizer production referred to and operated until 1989. After that, the purge was piped to the Phosphate plant where it was also not limited by fertilizer demand.*

Opinion #23 (Includes JFH findings): Prior to 1947, the upper limit of the amount of zinc tankhouse electrolyte purge that could be consumed in Trail's fertilizer operation was the amount of zinc micronutrient that could be marketed. The amount of zinc that could be marketed as micronutrient was usually substantially less than the amount of zinc purged.

From 1947-1964, at least a portion of the Zn and ammonium sulphate was recovered from stripping acid by precipitation of zinc ammonium sulfite. The precipitated zinc returned to the roaster, a process limited by Zn economics rather than by fertilizer demand. This process was converted in 1964 to a ZnMnS precipitation process, which was operated until 1989 to convert at least a portion of the purged stripping acid to fertilizer micronutrient. After 1989, at least a portion of the purge was piped directly to the phosphate plant to utilize its zinc and acid content.

Opinion #24 (Not contested): Controlled removal of impure lead tankhouse electrolyte permitted processing of the electrolyte, prior to its disposal to the Columbia River, to recover a substantial portion of its lead and fluosilicic acid values. Thus, the greater the ratio of controlled electrolyte removal to electrolyte loss, the less lead and acid reported to the river.

Opinion #25 (Not contested): Until baghouses were installed in 1951 to more efficiently recover dust and condensed fume from lead blast-furnace offgas, a greater portion of the cadmium and arsenic in Trail's feedstocks had been exhausted to atmosphere. To the extent that less cadmium and arsenic exhausted to atmosphere after baghouse installation on the lead BFs in 1951, more Cd and As were available for discharge to the Columbia River.

Opinion #26 (Contested): To the extent that minor metals such as arsenic, cadmium, copper, and mercury were recovered as byproducts, less of these metals were available for discharge to the Columbia River.

JFH's *Expert Opinion* (p 16) included the following critique of Opinion #26 above:

> *Disagree. This opinion is incomplete. Substantial amounts of these metals were stockpiled in Fe residues.*

Opinion #26 (Includes JFH findings): To the extent that minor metals such as arsenic, cadmium, copper, and mercury were recovered as byproducts, less of these metals were available for discharge to the Columbia River. *Substantial amounts of these minor metals were stockpiled in Fe residues for eventual recycling to the lead blast furnace.*

IX. COPPER SMELTING AT TRAIL: 1896 to 1930

The descriptions below of CM&S copper processing practices introduce vocabulary essential for understanding Trail's subsequent lead and zinc smelting and refining metallurgy. Similar equipment was used in subsequent decades, albeit modified and improved. Copper ore and concentrate smelting at Trail ceased in 1930 due to a scarcity of feedstocks.

A. Definition of Copper Smelting; Slag Byproduct Utilization

Copper smelting is based upon the strong affinity of copper (Cu) for sulfur (S), and copper's weak affinity for oxygen (O) in comparison with iron (Fe) and other base metals. During smelting, a portion of the solids fed to the furnace vents as dust, fume, and gases. Most of the balance exits as matte, metallics, and slag.

A slag is not necessarily a waste. Slag may contain significant metal values: e.g., copper, zinc, iron, antimony, tin, indium, and/or germanium. A slag could therefore be economically processed immediately for additional values, ideally before solidification. Or the slag could be inventoried for such time as suitable equipment, and/or financing, becomes available. Slag can also be sold for use as aggregate, ballast (base for railroad tracks), cement-kiln or concrete additive, or for other applications.

Key is that the slag meets physical, chemical, and environmental specifications for the particular application.

B. Copper Blast-Furnace Matte Smelting

Blast furnaces (see Figures 8 and 9) provided an important means for smelting Trail's copper feedstocks, and for processing lead concentrates. Thermal pretreatment (roasting/sintering) was often necessary to adjust feedstock sulfur content, and/or to agglomerate feedstock fines. These pretreatments will be described in a subsequent section of this report.

A blast furnace (BF) consists of two major parts, the *shaft* and *crucible*. The shaft is fed ore, coke, and flux from the top, where the venting gases are also withdrawn. As feedstocks descend down the shaft, hot gases rise up through the charge. Efficient BF operation thus requires that the feed be relatively coarse to permit gases to escape.

Figure 8. A water-jacketed blast furnace
(Queneau, CSM class slide)

At the bottom of the shaft (the *bosh*, where the shaft funnels inward) are *tuyeres*. *Tuyeres* are pipes through which air is forced into the base of that shaft to provide oxygen. Oxygen supports combustion of the coke, and oxidizes a portion of the sulfide sulfur to sulfur dioxide.

The BF crucible extends downward from the tuyere level. This crucible holds the matte and slag; slag floats on top of the matte. The two phases are *tapped* (removed from the crucible) separately and at different levels through tap holes. In later years, these liquid outputs were collected in an external basin (*settler*), which improved gravity separation of the matte from the slag.

The principal slag additives (fluxes) at Trail were *limestone* (calcium carbonate), iron oxide, and silica. These additives were adjusted such that the BF slag had an appropriately low liquidus temperature. The fused BF slag was formulated to be sufficiently fluid to permit its separation by gravity from the much denser (but highly fluid) matte.

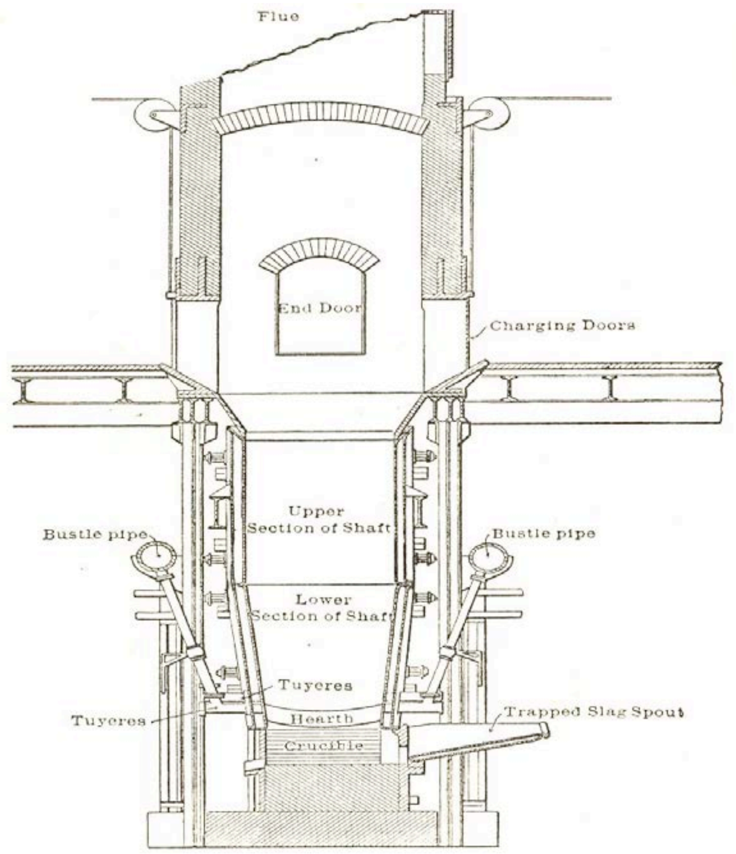

Figure 9. Blast furnace – a section view (Levy, 1912, p 138)

Gaseous products from BF smelting carried a considerable load of dust and fume. Typical dust load from the copper blast furnace was at least 2% of the charge; 5% was more typical, and even larger quantities were often produced. Dust was usually higher in copper content than the original charge due to the brittleness of the copper sulfide minerals. There was therefore substantial economic incentive to recover this dust.

Chambers of enormous capacity were required to provide the fine solid particles an opportunity to settle by decreasing velocity and cooling. Unsettled fines exhausted out of the stack. This means of offgas handling was standard practice not only at Trail, but worldwide.

Gaseous metal, i.e., fume, was carried with furnace exit gas. As the gas cooled, a large portion of the fume condensed. Metal-rich solids appeared both as difficult-to-collect extreme fines, and as coatings on dust particles. In fact, fume could be so difficult to collect that a baghouse was needed. The description below further describes fume behavior in a smelter (Levy, Univ. of Birmingham, 1912, p 168):

> [Values] *in the form of volatilized metallic products are also conveyed by the gases, particularly when lead, zinc, arsenic, etc., are present in the furnace charge, and these are carried forward in the form of fume. They tend to solidify as the temperature of the gases becomes lower, although their settling is very greatly impeded owing to the exceeding minuteness of their particles and also to their dilution; the problem of separating and collecting them is in consequence attended with great difficulty*….
>
> *Where large quantities of lead, etc., are present some bag-house system of fume filtration is necessary, especially if silver be present, since this metal tends to be carried over in the leady fume. At the majority of copper smelters such extreme requirements are rarely necessary, although modern legislative requirements make severe demands on the managements for the freedom of the gases from injurious constituents*.

The settled and collected BF dust could be smelted with roaster calcine in a RVF (reverberatory furnace), or returned to the BF if the dust was first briquetted. Trail had briquetting machines. The role of *baghouses* and electrostatic precipitators (Cottrells) for offgas treatment will be discussed in a subsequent section of this report. A Cottrell and an electrostatic precipitator are the same thing.

No Cottrell was used to collect dust from gases evolved from the copper blast furnace. Dust was collected in balloon flues by settling.

C. Copper Reverberatory Matte Smelting

Although the blast furnace was the most economic means to smelt lumps and coarse particles of copper-bearing ores, this furnace was not acceptable for fines. Blow-out of fine dusty ore from the BF could be as high as 10%. Briquetting fine feed, along with the recycled dust, was a significant cost. Fine ores and concentrates were often therefore more economically processed in reverberatory furnaces (RVFs).

A RVF was (and still is) an elongated brick structure enclosing an essentially horizontal space with a *hearth* (floor) upon which ore or concentrate was placed. See Figure 10. The charge would have best been free from lumps, finely divided, and roasted (detailed later) so that sulfur content would be limited to that needed to generate the matte.

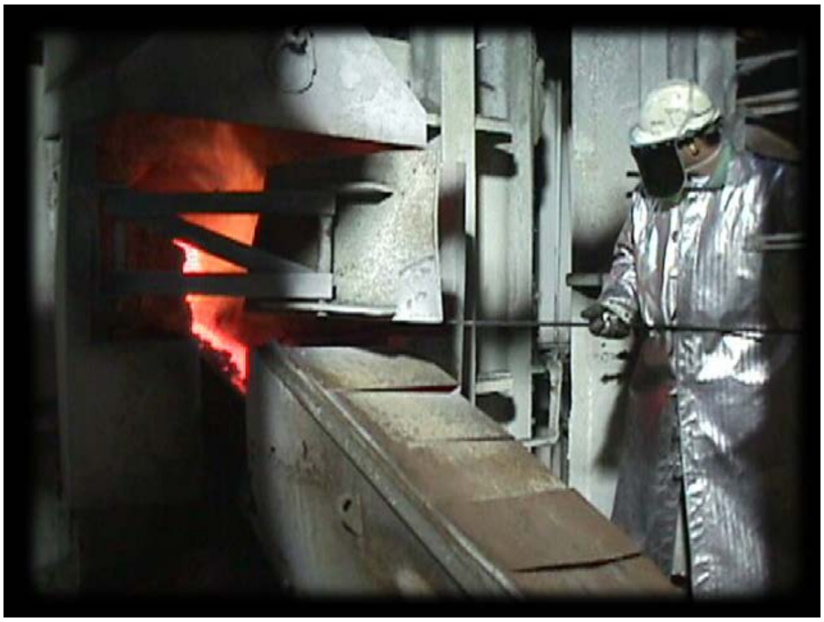

Figure 10. Tapping a reverberatory furnace (Queneau, CSM class slide)

A fire box heated the RVF from one end using highly bituminous coal (resinous wood was sometimes also added) to produce a long flame. Doors on the side of the furnace provided access to skim off reverberatory furnace slag. Matte product was tapped from the back end of the hearth close to hearth level. Smoke vented into the flue leading to the smokestack. The smoke consisted of dust, fume (vaporized metals), and gas (nitrogen, steam, carbon monoxide and dioxide, excess oxygen, etc.). Larger dust particles settled from the smoke prior to exiting the stack.

D. Roasting or Sintering of BF and RVF Feedstocks

The objective of roasting sulfide copper ore prior to smelting was to oxidize a portion of the sulfur and iron, and to remove volatile impurities such as arsenic (As), antimony (Sb), and bismuth (Bi). Sixty to 97% of the arsenic and 20 to 85% of the antimony were volatilized from copper sulfide ore via roasting (Hofman, 1914, p 65). The roasted ore could then be efficiently smelted to matte having high copper concentration and relatively low As, Sb, and Bi impurity.

The Herreshoff roaster shown in Figure 11 was a brick-lined vertical cylinder. An air-cooled central shaft supported arms that raked six hearths. Solids descended from hearth to hearth. At Trail the Herreshoffs were mounted above the RVF, thus providing direct feeding to hot calcine (Carlyle, 1896, p 18). Calcine discharged from the roasters needed to be *sintered* (agglomerated) prior to smelting in the blast furnace. Circular pot calciners served this purpose – and also removed additional sulfur.

The quantity of ore roasted per unit of hearth area increased dramatically between 1896 and 1916. Heap roasting at the turn of the century processed 5 to 20 lb ore/ft^2 of hearth per day. By 1925, D&L sintering achieved 2000 to 3000 lb ore/ft^2 of hearth per day (Liddell, Vol 1, 1926, p 303).

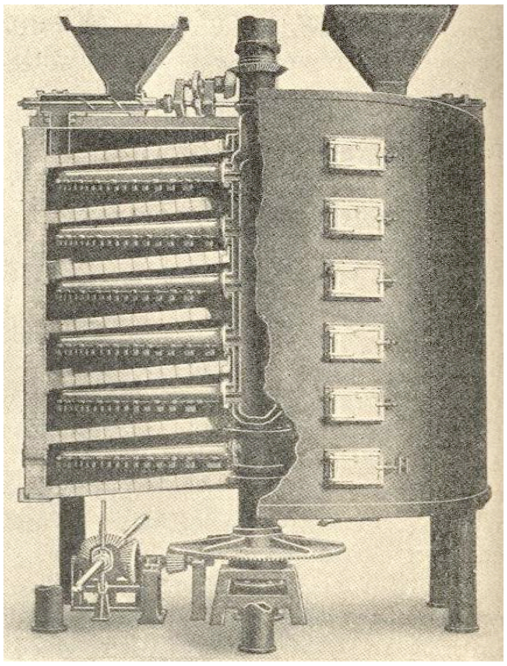

Figure 11. Herreshoff multiple-hearth roaster (Levy, 1912, p 74)

Dwight & Lloyd (*D&L*) continuous sintering displaced both roasting and earlier methods of thermal agglomeration. The first D&L unit was brought on line in 1910. Trail had installed a D&L machine for its copper concentrates (1% Cu and 1 oz Au/ton) by 1913 (Hayward, 1924, p 107). A 1950s model of this key piece of equipment at Trail, in this case for sintering lead concentrates, is shown in Figure 12. D&L sintering is a continuous rather than a batch process. This machine produces better sinter, consumes less labor, requires less floor space, and thus incurs a substantially lower operating cost.

Agglomerated fluxed ore and coke mixture was placed on pallets (grates) that had been pre-coated with limestone to minimize sticking. The sulfide fraction was then ignited. As the ignited mixture passed over the suction box, air was drawn through the mix to complete sintering and to oxidize most of the sulfide sulfur. The sinter then cooled, and was discharged from the pallets. The grates continued in the loop to accept fresh feedstock.

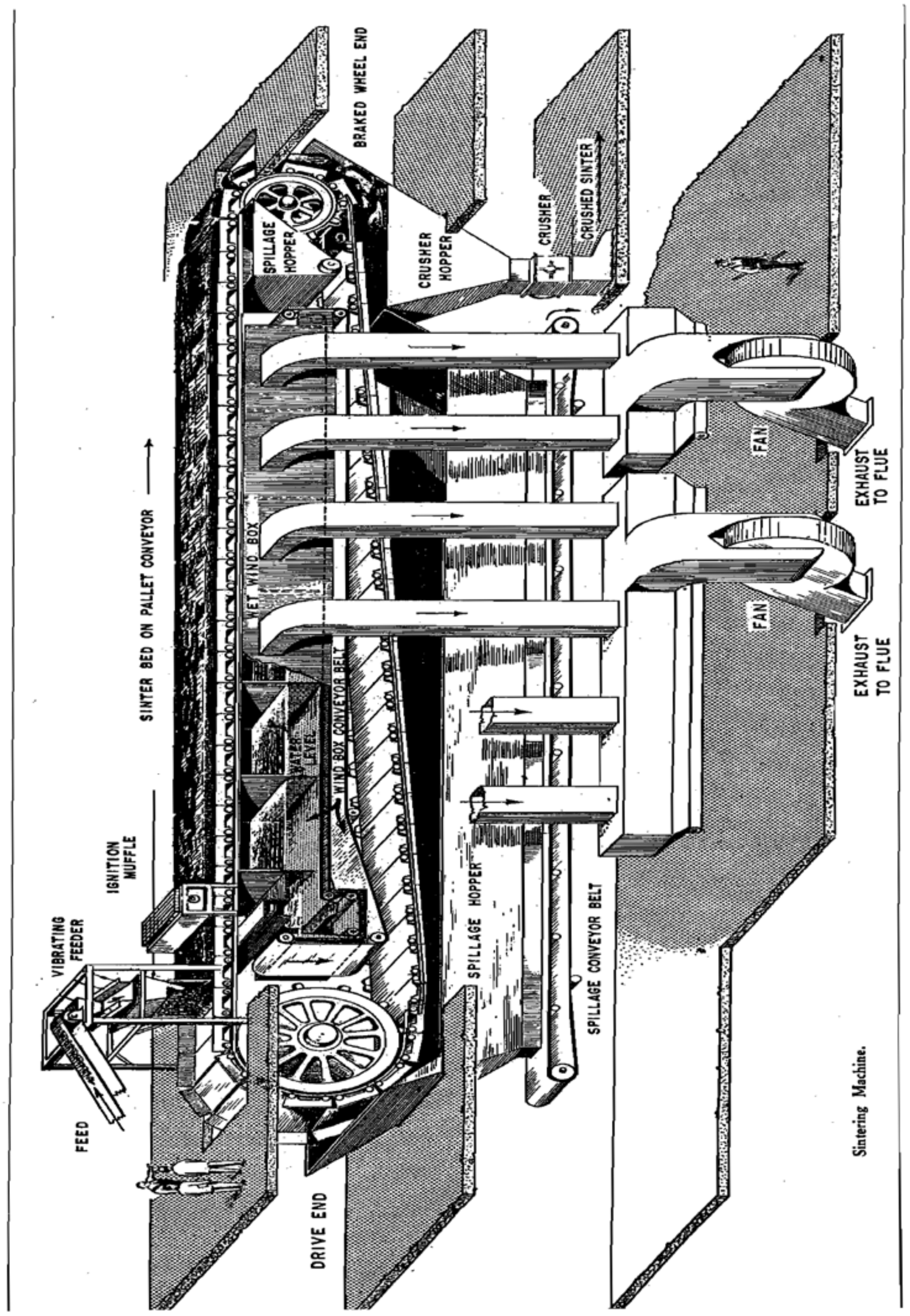

Figure 12. Dwight & Lloyd (*D&L*) continuous sintering machine (Anonymous, 1954, p 239)

E. Slag Output from Copper Matte Smelting

The primary fused outputs from copper matte smelting were matte and slag. Slag from copper smelting at Trail was "granulated and carried away by streams of water very conveniently and cheaply" (Turnbull, Canadian Mining Journal, 1907, p 424). Hofman (1914, pp 174) describes slag from copper smelting being granulated by a jet of water followed by disposal in a dump or into a river at the Mond Nickel Works in Ontario. Austin describes the slag granulation process at an unspecified location as follows (1909, pp 325-326):

> *A cast-iron launder is arranged to receive the slag as it falls from the spout of the fore-hearth. The launder has a grade of 1 inch to the foot, and through it water is made to flow constantly. In addition, a horizontal flattened jet of water strikes the falling slag, instantly cooling and breaking it into granules of various sizes averaging one-sixteenth of an inch diameter. The flow of water carries the slag to the dump.*

The quantity of slag generated during matte smelting depended on the factors listed below.

- Ore gangue content: The quantity of SiO_2, Fe(Mn)O, Ca(Mg)O, Al_2O_3, and ZnO in the ore. Silicon, iron, calcium and aluminum are more comfortable as oxides rather than metals.

- Flux addition: The quantity of flux that must be added to the furnace to produce a suitable slag. Trail smelter operations eventually were able to blend diverse feedstocks such that need for flux became minimal, i.e., essentially just limestone was used.

- Copper content of ore and matte: The grade (copper content) of the matte, and the copper content of the feed. The lower the Cu:Fe ratio in the matte, and the higher the copper content of the furnace feed, the greater the portion of feed iron that reported to the slag.

- Fuel ash content: The ash content of coke and other fuels that ended up in the smelting portion of the furnace transferred to the slag. The BF coke typically contained at least 10 to 12% ash, most of which reported to the slag. Early reverberatory furnaces burned coal in a firebox, thus permitting separate recovery of the ash.

F. On-Site Conversion of Copper Matte to Refined Copper

For copper at Trail, 1916 was a key date. The plant installed the converting and refining capacity to produce electrorefined copper from its matte. The metallurgical steps for this plant upgrade are summarized below (Young, Eng. & Mining Journal, 1923, pp 141-44; Anonymous, 1925, p A 258).

- Converting matte to blister copper: Matte was blown with air in two Great Falls converters to blister copper (about 95% Cu), impurity-rich slag, and dusty SO_2 offgas. See Figure 13. Siliceous ores, plant scrap / cleanups, and recycled converter flue dust were converted along with the matte. Copper-rich converter slag returned to the three blast furnaces used to produce the matte.

- Gas cleaning: Electrostatic precipitators (Cottrells) collected the converter dust. In a Cottrell, the air carrying the dust was ionized. Air conductivity was enhanced by its SO_2 content. Dust particles in this media gathered sufficient electric charge to move under the force of the electric field, and to thus be collected.

- Production of electrorefined copper: The blister copper was further purified and its oxygen content adjusted (in a separate furnace) to produce flat anodes. The anodes were then electrolytically refined to produce high-purity copper cathodes.

  Copper tankhouses used electricity to dissolve copper from the impure anode, then selectively plated the copper to produce a pure cathode. Gold and silver were recovered from the anode slimes. Copper tankhouse technology has many similarities to that used for Betts electrolytic lead refining (to be described later in this report); refer back to Figure 4.

  Trail purged arsenic (As) and antimony (Sb) from the copper refinery by returning black copper containing the rejected As and Sb to the copper blast furnace, where arsenic and antimony were eliminated by venting up the stack (Young, 1923, p 144).

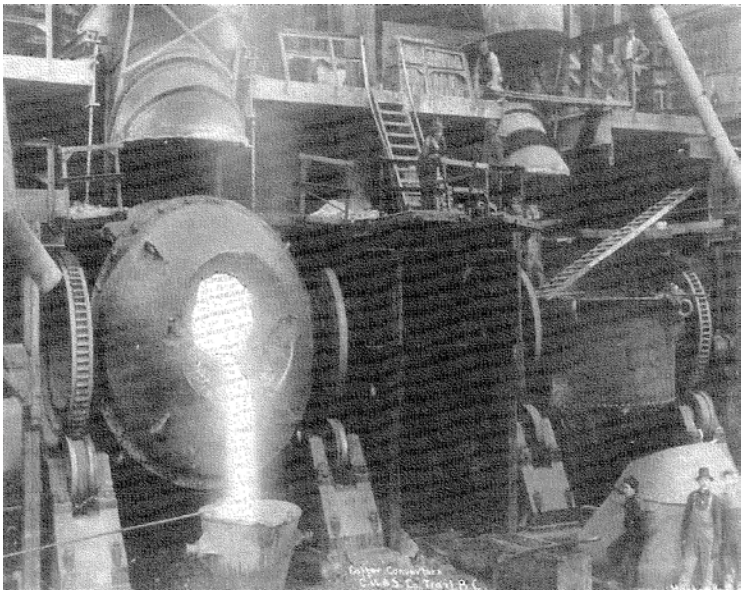

Figure 13. Early copper converters at use in the Trail smelter (Fish, 1997, p 92)

G. Opinions from Section IX

Opinion #27 (Not contested): Slag is not necessarily a waste. Economic value can include the slag's contained metals, or its use as aggregate, ballast (base for railroad tracks), cement-kiln additive, and/or concrete additive.

Opinion #28 (Not contested): Trail slag from copper operations contained substantial concentrations of silica, iron oxide, and calcium oxide, as well as small quantities of copper matte.

Opinion #29 (Not contested): Smelter flue dust at Trail typically contained sufficient metal values to provide economic incentive for its recovery.

Opinion #30 (Not contested): Relying on settling to collect furnace dust and fume – rather than its collection by Cottrells, baghouses, and/or scrubbing – resulted in a greater portion of feedstock heavy metals exiting via the stacks. Therefore, prior to more efficient dust and fume collection at Trail, a lesser portion of metallurgical feedstock heavy metals was available to report to the Columbia River.

Opinion #31 (Not contested): Granulated slag from copper smelting produced in the early 1900s appeared to be about one-sixteenth of an inch diameter. My more recent experience with granulated slags is that little has changed: the bulk of the slag's weight is on the order of one-sixteenth of an inch diameter.

Opinion #32 (Not contested): Most of the arsenic in the feedstocks fed to Trail's copper smelter between 1896 (initiation of copper smelting) and 1930 (cessation of copper smelting) was vented to atmosphere.

X. LEAD OPERATIONS AT TRAIL – THE EARLY YEARS: About 1900 to 1929

When lead production at Trail began between 1899 and 1901, its metallurgical practice was standard for the time. Ore was roasted in ten hand-rabbled RVFs and six Bruckner furnaces, followed by reduction in three blast furnaces. The Bruckner was a rotary furnace, i.e., a horizontal rotating brick-lined cylinder fired along its central axis. Blast-furnace bullion output, with its substantial silver values, was shipped to San Francisco for refining.

A. Specifics on the Early Years of Lead Operations

- Lead ores came to Trail mainly from the East Kootenay, Slocan and Lardeau (B.C.) districts. Ore suppliers included the St. Eugene Mine and the Snowshoe Mine at Phoenix, B.C. The former provided 75% of the smelter's lead output. Trail also purchased additional lead bullion and mill products from other smelters.

- Prior to ramping up of the Sullivan mine (1915), diversity in ore gangue content minimized need for flux. Efficient ore smelting was attained using limestone, plus minor quantities of iron oxide and silica for trim.

- After initiating Betts electrolytic lead refining in 1902, Trail marketed its lead output directly. Precious metals, which concentrated in the tankhouse slimes, were sold separately. Trail lead-production capacity increased from 10 stpd (1902) to 20 stpd (1904) to 50 stpd (1905) to 75 stpd (1906). The silver refinery was started up in 1908, as was a plant to manufacture fluosilicic acid for the Betts electrolyte (from calcium fluoride and silica).

- By 1908, eight Huntington & Heberlein (H&H) circular roasters and 24 H&H pot calciners replaced ten hand-rabbled roasting furnaces. Two briquetting presses, each equipped with a pug mill, agglomerated the fines. Roasting was carried out in Wedge multiple-hearth furnaces.

- Ample water from three creeks flowed to the smelter at 100-ft head via five miles of wood pipe. Good quality high-ash coke and coal arrived from Fernie and Michel, B.C., about 240 miles east of Trail. Up to 200 stpd of limestone flux (50% CaO) was shipped in from Fife, B.C. Target lead-BF slag composition was 31 to 33% SiO_2, 24 to 30% Fe(Mn)O, 18 to 20% Ca(Mg)O, 8 to 16% Al_2O_3, 7 to 12% Zn, and 1% Pb (McNab, 1909a, p 431). This lead-BF slag was discarded.

- By 1917, Trail was using two stages of Dwight-Lloyd sintering to prepare its BF feed. This upgrade eliminated the need for Wedge roasters and pot calciners. The lead BF-slag assayed 32% SiO_2, 29% Fe(Mn)O, 20.5% Ca(Mg)O, 6.5% Al_2O_3, 10% Zn, and 1.5% Pb (Hofman, 1918, p 221). The BF slag was still relatively low in zinc content (10%). It was only when the majority of the lead-zinc feedstock came from the Sullivan mine (shortly before 1920) that the zinc content of lead-BF slag became sufficiently high to be of economic interest.

- An average lead-BF slag analysis in 1922 was 15.8% SiO_2, 33% Fe, 6% CaO, 17 to 21% Zn, and 2.4% Pb (Buchanan, 1922, pp 532-533). Young in 1923 (p 141) provided the following lead-BF slag composition: 18% SiO_2, 31% Fe, 9% CaO, 3% Al_2O_3, 18% Zn, and 1.7% Pb. Note the relatively high zinc and iron content, and the relatively low silica and lime content, as compared to the lead-BF slags generated in 1917.

- By 1925, most of Trail's lead feed was Sullivan concentrate having a typical assay of 66% Pb, 6.3% Zn, 18.8% S, 7.5% Fe, and 1% silica (Anonymous, B.C. Minister of Mines, 1925, p A254). Also fed to the lead blast furnace was zinc leach plant residue, e.g., 10.9% Pb, 19.1% Zn, 3.5% S, 37% Fe, and 1% silica. See Figure 14 for the overall flow diagram of the lead smelter.

Comments to provide an understanding of Figure 14 are as follows:

- Recycling zinc plant residues to the lead BF required that BF feed be iron-rich and sulfur-poor. Smooth BF operation could then be maintained, outputting BF slag assaying 16 to 17% Zn. *Before the introduction of slag fuming at Trail, the slag was granulated and stored* *awaiting the development of a process for the recovery of its zinc and lead* (Murray, Cominco, 1936, p 67).

- Figure 14, which was published in 1925, shows lead-BF slag going to "*Waste*". The associated text in this paper reads: *The slag is granulated and conveyed to the slag-dump by launder*. This BF slag reportedly assayed 16 to 17% Zn.

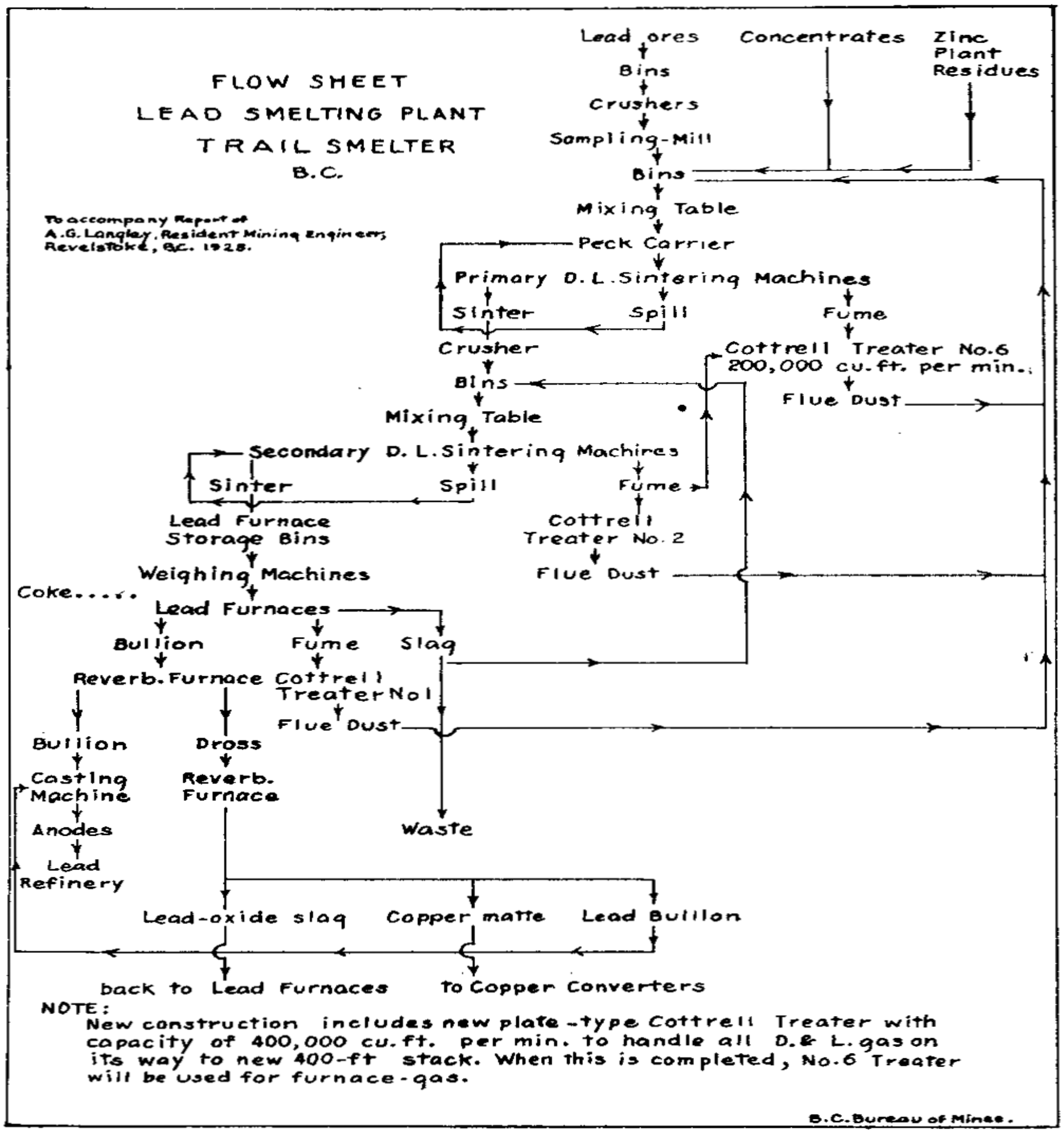

Figure 14. Lead smelter flow (Anonymous, B.C. Minister of Mines, 1925, pp A255)

- There nevertheless is ample evidence that substantial quantities of high-zinc lead-BF slag were inventoried by CM&S for later economic recovery of contained metal values, e.g., *…some 500,000 tons of old slag, running about 20% Zn, has been accumulated* (Mason / Cominco, 1929, p 342).

- Research at Trail initiated in 1920 ultimately developed an economical process (slag fuming, commercial by 1930) for recovering contained values from lead-BF slag. During the interim, BF slag was relegated to large stockpiles (Yurko, 1970, p 331). Beginning in 1930, lead-BF slag was withdrawn from inventory and fumed, along with current production, to recover residual lead and zinc values.

- Cottrells were first installed in 1914-15 to process dust- and fume-laden gases from blast roasting, smelting, and converting. The Cottrell-treated gas vented into two balloon flues, thence into a single flue leading to the stack. By 1933, eleven Cottrells had been erected for dust removal from various gases (Hofman, 1918, pp 457-458; Murray / CM&S, 1933, p 81).

- A problem was the disparity between the output of zinc plant residue and the capacity of the lead smelter to treat it. Over the years the residue stockpile grew.

- Offgas, fume, and dust from sintering and BF operations passed through Cottrells prior to discharge to the balloon flues. The dust was briquetted, then returned to the BF via the sintering machines.

- Copper matte byproduct produced from drossing the BF bullion went to the copper converters (refer back to Figure 13).

- The drossed lead bullion was cast into Betts anodes. These anodes were then hung in tanks alternately with thin cathode starting sheets of refined lead for electrorefining; refer back to Figure 4. After eight days in a fluosilicic acid electrolyte, most of the lead in the anodes had transferred to the cathode starting sheets. Precious metals and impurities in the anodes remained as a black slime in the tanks, for subsequent recovery.

B. Opinions from Section X

Opinion #33 (Not *contested*): Efficiently blending feedstocks purchased from a wide variety of sources not only minimized flux consumption, but also substantially decreased the quantity of waste slag generated per ton of metal produced.

XI. ZINC OPERATIONS AT TRAIL – THE EARLY YEARS: 1916 to 1929

In 1912, Trail began researching methods to recover zinc by electrolyzing purified zinc sulfate solution. Meanwhile, selective mining and hand sorting of zinc-rich mineralization at the Sullivan mine produced concentrates assaying 25 to 35% Zn. By 1916, production of electrolytic zinc had begun.

Trail's electrolytic zinc plant was profitable, due principally to the high zinc prices associated with metal needs during World War I. Lead exited the process (along with residual zinc) as insoluble sulfate – a suitable feed for the lead BF.

A. Specifics on the Early Years of Zinc Operations

- Sullivan zinc concentrates were dried, then passed through six multiple-hearth Wedge roasters to reject sulfur as SO_2. Roaster output was primarily ZnO calcine. Offgas passed through Cottrells to a 200-ft stack. Acid plants built in 1916-17 provided the sulfuric acid needed for *leaching* the roaster calcine (TECK 0279510).
- *Leaching* involves mixing calcine with sulfuric acid to dissolve zinc oxide, generating zinc sulfate ($ZnSO_4$) electrolyte. Impurities, including copper and cadmium, are subsequently precipitated from this electrolyte by addition of zinc dust. The purified zinc-rich electrolyte (on the order of 150 gpl Zn) goes to a tankhouse for electrowinning (EW) of zinc cathodes. I am using the present tense, because this process continues at Trail to the day that this Expert Opinion is dated.
- As zinc sulfate reduces to zinc metal in the tankhouse, the associated sulfate ion remains behind as sulfuric acid. This sulfuric acid (including on the order of 50 gpl zinc) is returned to leaching to dissolve additional

zinc. However, a portion of this electrolyte must be purged to control impurities.

- The purged portion of the zinc tankhouse electrolyte was *stripped* and discarded daily to control both the volume and purity of the retained electrolyte. Stripping the 50-gpl zinc-electrolyte purge involved a second electrolysis process that reduced its zinc content to 8.6 gpl to 20 gpl. A portion of this stripped solution was discarded to the Columbia River.

- The residue produced by leaching zinc concentrates contained most of the lead fed to the zinc roasters. A substantial portion of this leady residue, along with unleached zinc ferrite, was therefore returned to the lead blast furnaces. Often the BFs had insufficient capacity for this residue; the excess was inventoried until additional BF capacity became available.

- Sullivan mine zinc output continued to increase, resulting in increased output and inventory of zinc-rich lead-BF slags. An economic means was therefore needed to recover rather than to lose this zinc and associated lead in the discard lead-BF slag – a worthy target for corporate research. An important secondary benefit of developing a BF-slag treatment process would be removing a key BF operating constraint: the need to target production of BF slag assaying <2% Pb.

- Trail's roast-leach-EW process for zinc provided important opportunities to recover minor metals, e.g., cadmium, the recovery of which began in 1927 (TECK 0279511). These minor-metal recovery processes minimized loss of metals to the environment.

- Zinc concentrate roasting also provided means to economically recover sulfuric acid. Acid recovery opened the door to economic production of fertilizer. Fertilizer production led to economic production of major quantities of tonnage oxygen to improve efficiencies in Trail's lead, zinc and acid production operations.

B. Opinions from Section XI

Opinion #34 (Not contested): When Trail implemented a wet process in 1916 to recover zinc, i.e., leaching and electrowinning, aqueous zinc and associated impurities were at that time available for discharge into the Columbia River.

Opinion #35 (Contested): Substantial quantities of stripped spent zinc electrolyte (15 to 18 gpl Zn) were purged for discharge into the Columbia River or Stoney Creek from 1916 to 1990.

JFH's *Expert Opinion* (p 16) included the following critique of Opinion #35 above:

> Disagree. This opinion is incorrect. There are four things incorrect in this opinion –
>
> 1. the concentration was much less than the 15-18 g/L Zn in strip solution in the original cascade cells. The excerpt below from a 1937 Zn plant annual report (6) gives annual averages ranging 8.6 to 11.8 g/L which will result in a far lower total Zn in effluents. The total Zn tonnage is also calculated here giving a total Zn in outfall for 1936 of 403 tons (strip only) compared with PBQ's estimate of 2,392 tons (total)
> 2. the 15-18 g/L Zn in strip solution only became the norm in 1968-69 as a) treatment of Pine Point Zn concentrate with its high magnesium content and b) corroding cooling coils in the aging tankrooms required more stripping volume to be treated and beyond the ability of the strippers to remove Zn to its former lower concentrations.
> 3. Discharge volumes of stripped electrolyte slowed in 1981-82 and stopped in 1983 as new cell houses came on line with new technology which reduced stripping requirements. The ZnMnS circuit had sufficient capacity to treat all this stripped solution, none was discharged to sewer after this time. The few times when stripping needs exceeded ZnMnS capacity, some stripped solution and some electrolyte was discharged to the Glover Tower ponds. The resulting effluents are known because, by this time, all sewers were routinely monitored.
> 4. Stripping acid was never sent to Stoney Creek.

My response to JFH's findings on Opinion #35 are as follows:

1. Based on zinc assays discovered in the 1800+ documents provided by JFH, the zinc content of stripped spent electrolyte sewered to the Columbia between 1916 and 1990 ranged from 8.6 to 20 gpl. These documents also provide the weight of the zinc included in the stripped spent electrolyte. The basis of stripped spent electrolyte losses, as included in the documents provided by JFH, therefore now use the weight of zinc sewered in the Inputs and Distributions Spreadsheets.

By using Trail's measured SSE zinc tonnage, rather than estimated grams per liter zinc, incorrect zinc SSE outfall values can be minimized, e.g., such as the 1936 values cited by JFH above.

2. I have included the text of JFH's item #2 above in Section XIV-H of my Expert Opinion and Rebuttal.
3. Where Trail's measured annual sewer discharges values have been discovered, typically for operations beginning in the early 1980s, these values are and have been relied upon in the updated Inputs and Distributions Spreadsheets.
4. The reference to SSE being discarded in Stoney Creek has been eliminated from Opinion #35.

Opinion #35 (Revisited): Substantial quantities of stripped spent zinc electrolyte (8.6 to 20 gpl Zn) were purged for discharge into the Columbia River from 1916 to 1990.

XII. LEAD, ZINC & FERTILIZER – THE MIDDLE YEARS: 1930 to 1979

By the *Middle Years* is meant the half century beginning in about 1930, when slag fuming, flash roasting, and fertilizer production began. (A major modernization began in 1979, culminating with conversion to Kivcet smelting in 1997.) Events of particular significance during these middle years include the following:

A. Fuming of Lead Blast Furnace Slag

In 1930, injecting molten lead-BF slag with air and coal began. This fuming process volatilized, oxidized, then collected condensed lead, zinc, and minor-metal values from the BF slag in a baghouse. A baghouse captures dust by passing the gas through supported cloth socks. The dust is periodically released from the socks either by shaking, or with a puff of air.

Slag fuming volatilized about 85% of the zinc, plus nearly all of the lead. Addition of excess air oxidized the Zn^o- and PbS-rich fume to ZnO and PbO / $PbSO_4$, which were collected as dust. Lead in the BF slag was thus reduced from <3% to ≈0.1%;[10] zinc content was reduced from ≈18% to ≈2.6%. Non-volatile metals remained in the fumed slag, e.g., copper assayed about 0.5%.

A variety of minor metals also fumed from the slag. For example, cadmium (Cd), arsenic (As), tin, indium, germanium, and silver compounds have appreciable vapor pressure at Pb-Zn fuming temperatures; these impurities were thus mostly driven into the ZnO-rich fume product. Cadmium content of BF slag was decreased from ≈0.01% to ≈0.001%; arsenic content was reduced from ≈0.15% to ≈0.01% (TECK 0099157).

In 1931, Trail's fuming furnace processed 150,000 tons of lead-BF slag. The fumed slag output went to waste. Figures 15 and 16 illustrate Trail's slag fuming practice.

- It was no longer necessary to produce BF slag having low lead content. Five percent lead (rather than targeting <2%) in BF slag was now acceptable, because the fuming furnace volatilized almost all of the remaining lead. The BF therefore became much easier to operate; both coke consumption and flux cost decreased.

  > *Possibly the most notable feature in connection with the slag-fuming plant at Trail is the effect it has had on blast-furnace smelting practice for lead. It…marks the most important development in Trail lead-metallurgy since the introduction of sintering* (Murray / CM&S, 1933, p 100).

- The ZnO-rich fume was leached with acidic sulfate solution to recover zinc and minor metals. The lead-sulfate-rich leach residue recycled back to the sintering and the BF.

- A problem was the disparity between the output of zinc plant residue and the capacity of the lead smelter to treat it. By the end of World War II, the pile had reached *the formidable total of half a million tons* (Mitchell / Cominco, 1957, pp 361). Residue processing capacity was substantially expanded in 1955-56 when sinter-plant equipment was upgraded, including wet-mix drying (360 F exhaust temperature) of the feed.

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[10] The "≈" symbol in front of a number shows that the number is an approximate value.

- In addition to BF slag and flue dust, the fuming furnace processed zinc dross, cadmium residues, furnace and ladle skulls, and miscellaneous plant reverts.

B. Suspension Roasting of Zinc Concentrates

By the late 1920s, the need to capture rather than vent SO_2 emissions became a major priority. In 1928, some 9,600 tons of sulfur per month were discharged to atmosphere in the form of sulfur dioxide gas (Anonymous, Canadian Mining Journal, 1954, p 308). Young (1931c, p 416) describes the technical barrier to economic capture of the sulfur dioxide, i.e., SO_2 concentration in the gas too dilute to be economically captured.

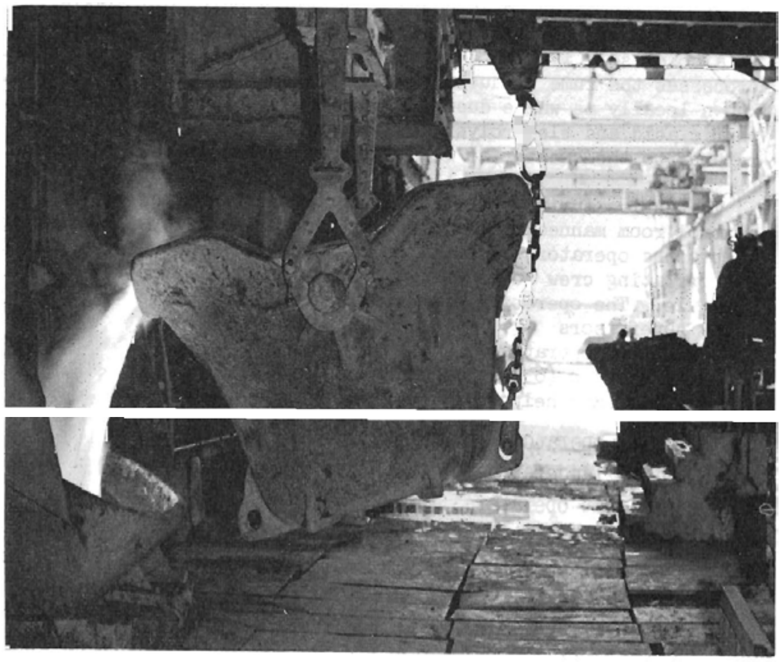


Figure 15. Charging a lead-BF slag fuming furnace at Trail (Yurko / Cominco, 1970, p 340)

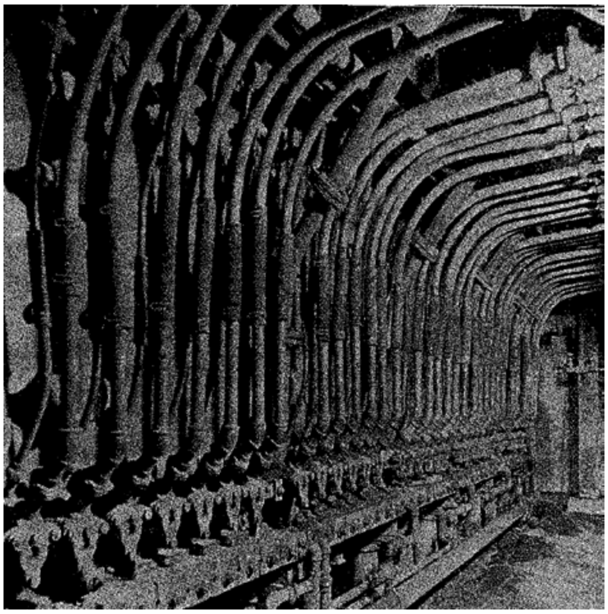


Figure 16. Trail's water-jacketed fuming furnace with 35 tuyeres (McNaughton / CM&S, 1936, p 723)

Young then alludes to what later became the basis for an economic solution: implementation of flash roasting to generate strong (6 to 8%) SO_2. An additional benefit of the new process is additional capture of Cd, Bi and Sb. Young's description is as follows:

> *Gases from the lead blast furnaces and the sintering furnaces are so dilute that it is impracticable to do more than is being done with them – to remove fume and dust suspensions. On the other hand, the gases from zinc roasting contain higher and more controllable amounts of sulphur dioxide. Roasting practice is being studied, and a new method of roasting is being experimented with. The objective is….a gaseous product containing about eight per cent of sulphur dioxide. This product will be handled in sulphuric acid plants now under construction. In addition to the utilization of this gas, other byproducts are produced – cadmium, bismuth, and antimony.*

The new method that soon led to economic sulfuric acid production was *suspension roasting*. By 1936 the Wedge multiple-hearth roasters had been converted over to this new technology. See Figure 17. Removing the middle hearths of the roasters extended the time that the ignited sulfide particles spent in free fall. Capacity was tripled. A decade later others would develop similar technology for *flash roasting* copper and nickel sulfides.

- Conversion to suspension roasting not only increased roaster capacity, but also improved process control, eliminated secondary roasting for final sulfur removal, attained higher zinc solubility, permitted more efficient dust collection, attained additional heat recovery, and generated higher SO_2 concentration. The increased SO_2 concentration substantially improved the economics of acid production. This increased concentration soon made it economic to convert over 90% of the plant's sulfur input to sulfuric acid.

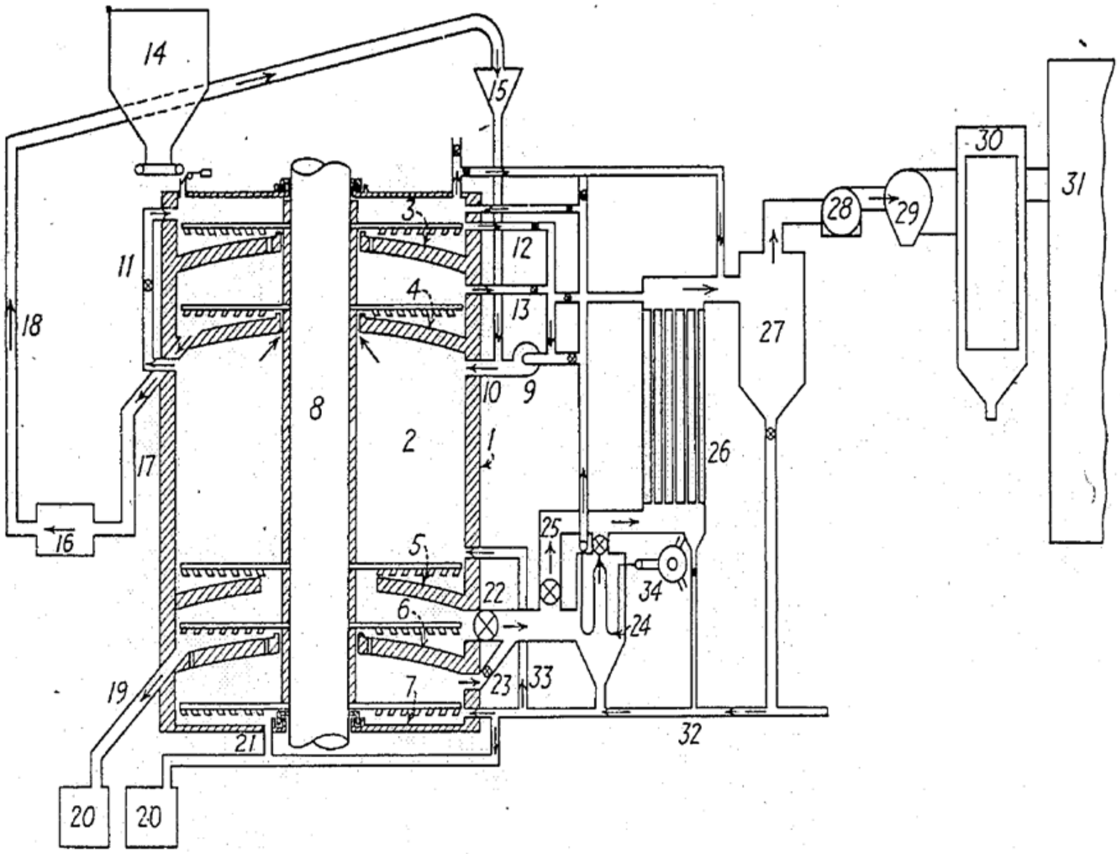


Figure 17. A suspension multiple-hearth roaster with boiler (26), cyclone dust collector (27), balloon flue (29), Cottrell (30), and acid plant (31), from Stimmel, 1936, pp 542

- Gas exiting the roaster carried about 40% of the furnace charge. About 20% of this dust settled in the waste heat boiler; this 20% of the dust was sent to zinc leaching. Cyclone separators recovered 90 to 95% of the remaining dust for additional roasting. About 95% of what dust remained was then collected by Cottrell electrostatic precipitation; this latter dust also went to leaching. The SO_2-laden gas, containing on the order of 0.2% of roaster feed, then continued on for extensive additional cleaning prior to conversion to sulfuric acid.

Highly volatile minor metals, e.g., Cd, As, and Hg, reported to roaster offgas. A significant portion of these metals reported to the 0.2% of the roaster dust that passed through the Cottrells.

Because catalysts used in manufacturing sulfuric acid are easily damaged (poisoned), the acid-plant feed must be thoroughly cleaned to remove as much of these metals (and other contaminants) as possible (Davenport, Univ. of Arizona, 2006, pp 31-45). This gas scrubbing generates slurry discharge that provides opportunities for additional minor-metal recovery.

C. Sulfuric Acid Output Leads to Fertilizer Production

In 1931, CM&S expanded its Trail operations to include manufacturing of ammonium sulfate and ammonium phosphate fertilizer. Warfield Flats is a high terrace overlooking Trail's metallurgical plant. It was here in 1930 that CM&S initiated construction of a 65-acre fertilizer production facility to utilize byproduct acid and energy output from the smelter. Steam generated from waste-heat boilers at the slag fuming plant was transferred in a well-insulated 12-inch pipe about a mile to Warfield Flats. This steam concentrated fertilizer solutions derived from the smelter's sulfuric acid output.

Markets within reasonable shipping distance from Trail initially could not absorb all the sulfuric acid potentially available (King, 1950, p 2243). It took until 1944 for fertilizer markets to consume this substantial acid output (Kirkpatrick, 1949, p 972). Figure 18 is a simplified representation of the relationship between the zinc plant and the fertilizer plant. This figure appears to depict Trail after 1980 (when pressure leaching of zinc concentrates began), but before 1981 (start-up of the effluent treatment plant).

Operations at Warfield Flats included manufacturing of sulfuric acid, pure sulfur dioxide, oxygen, nitrogen, hydrogen, ammonia, phosphoric acid, ammonium phosphate, ammonium sulfate, nitric acid, ammonium nitrate, and hydrofluosilicic acid. Aqueous effluents from the fertilizer plant included mercury and zinc.

Acidification of phosphate rock produced not only phosphoric acid, but also gypsum (hydrated calcium sulfate) precipitate and silicon tetrafluoride gas. The phosphoric acid was reacted with ammonia to produce ammonium phosphate fertilizer. A small quantity of the gypsum was sold into agriculture. The balance went to waste.

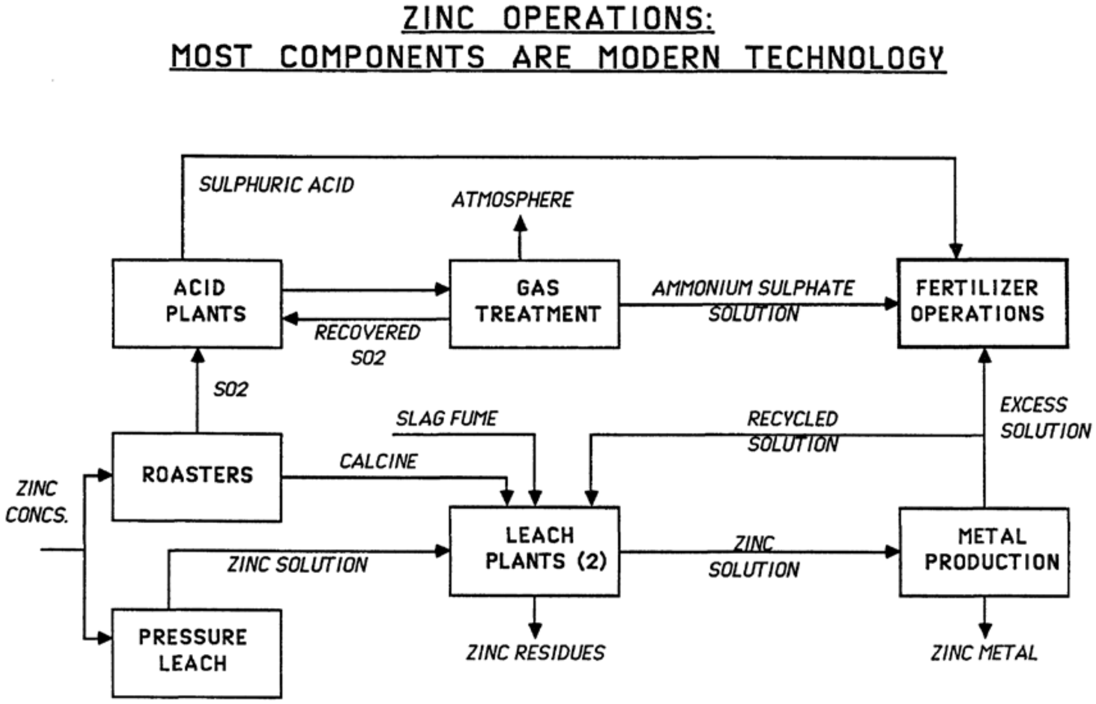


Figure 18. A simplified Trail zinc-processing diagram, including fertilizer operations (TECK 0099142; ca. 1980)

Water scrubbing of the fluoride-rich byproduct gas (evolved when manufacturing phosphoric acid) produced hydrofluosilicic acid. This acid served as electrolyte make-up in the lead refinery. Kirkpatrick stated in 1949 that several tons of this acid were consumed daily (p 975):

> [Lead refining requires] *several tons each day of hydro-fluosilicic acid to maintain the proper acid balance in the cells. Until a few years ago all or part of the hydro-fluosilicic acid required for the refinery was made from fluorspar, sulfuric acid, and silica. Now… there is an adequate supply of hydro-fluosilicic acid as a chemical plant byproduct.*

D. Fertilizer Production Leads to Smelter Process Efficiencies

To produce ammonia, a key raw material for producing sulfate- and phosphate-based fertilizers, one inputs tonnage nitrogen and hydrogen. Trail produced its nitrogen by liquefaction and low-temperature fractionation of air; the byproduct was tonnage oxygen. The plant produced its hydrogen by electrolysis of water via its inexpensive hydroelectric power. The byproduct was additional tonnage oxygen.

Trail used oxygen produced in its fertilizer operation to improve smelter process efficiencies:

- Air fed to the BFs was enriched with oxygen. Furnace output improved, coke consumption decreased, and the furnace ran more smoothly. Offgas volume also decreased, enhancing offgas treatment capacity and/or efficiency.

- Trail also used oxygen to enrich the air fed to the suspension roasters. The result was improved roaster operation, throughput, and heat recovery. Use of oxygen also improved the efficiency and capacity of its sulfuric acid plants by generating higher SO_2 concentration in the roaster offgas. Roaster offgas went to acid plants.

- A further use of oxygen at Trail was to improve slag fuming. Oxygen enrichment improved both furnace output and zinc recovery, resulting in lower zinc content in the discard fumed slag.

- Ammonia produced in Trail's fertilizer plant was also useful in the sinter plant. Sinter-plant offgas (in the lead smelter) contained only 0.5 to 1% SO_2. The contact sulfuric acid plants needed at least 5% SO_2 for satisfactory SO_2 recovery and economics. To bypass this limitation, the sinter-plant Cottrell offgas was scrubbed with aqueous ammonia. Scrubbing captured the SO_2, producing ammonium bisulfite.

- Adding sulfuric acid and oxygen to the ammonium bisulfite solution liberated concentrated SO_2. This SO_2 was used both to enrich acid-plant feed gas, and for production of elemental sulfur. The product was ammonium sulfate feedstock for the evaporators at Warfield Flats. Ammonia was also used to scrub acid-plant tail (exhaust) gas to facilitate meeting SO_2 smelter environmental discharge standards.

Figure 19 provides three simplified flow diagrams of Trail's Pb-Zn smelting processes from 1916 to 1929, 1930 to 1995, and 1996 to 2010.

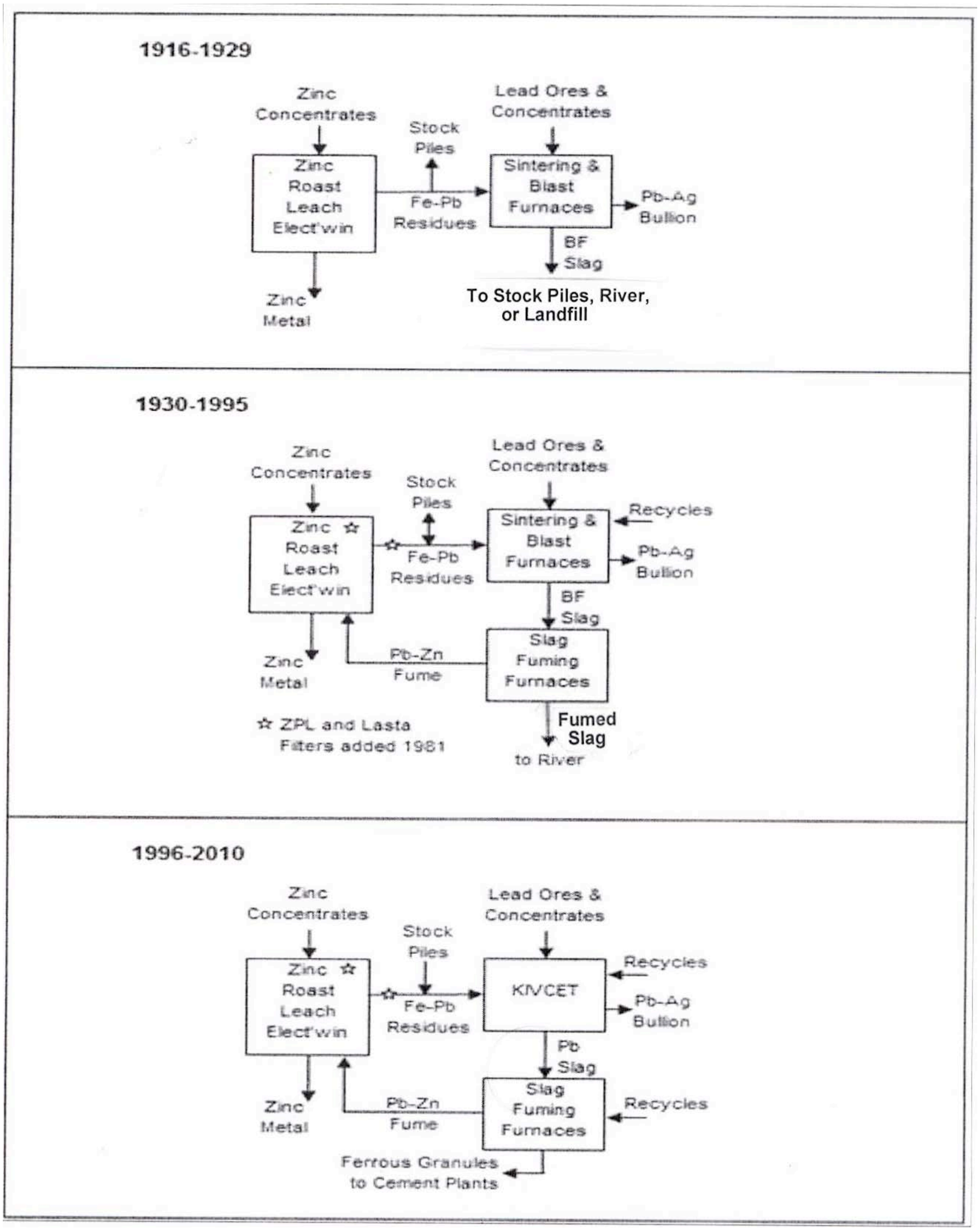


Figure 19. Simplified History of Trail's Lead-Zinc Smelting Processes (Edited from JFH's Expert Opinion, 30Nov10, p 28)

E. Recovering Dust and Fume from Furnace Offgas

In 1931, hot Cottrells were in use to clean offgas from Trail's sinter machines, blast furnaces, zinc roasters, and for the silver refinery (arsenic and antimony fume). Cottrells also rejected dust, fume, and mist prior to production of sulfuric acid. Weight of dust captured was substantial (Young, 1931d, pp 507-508):

- Sintering furnace circuit: 15 to 20 tons/day
- Blast furnace circuit: About 40 tons/day
- Zinc roasters: About 60 tons/day
- Silver refinery: 2 to 3 tons/day
- Acid-plant Cottrells: 1 to 1.5 tons of dust/day

Hargrave provided the following tabulation of dust and fume collection equipment in use at Trail in 1959 (p 367):

- Lead sinter-plant driers: 3 Doyle wet scrubbers
- Lead sintering: 5 Cottrells
- Blast furnaces: 20 baghouses
- Slag fuming: 16 baghouses
- Zinc roasting: 15 cyclones and 4 Cottrells
- Silver refineries: 4 baghouses
- Antimonial lead plant: 2 baghouses

Where particularly efficient gas scrubbing was required, Trail relied on its Doyle wet scrubbers. When processing vent gases from wet-mix drying prior to lead sintering (1953), these units collected 98% of the dust. The Doyle scrubbers also processed large volumes of air ventilating the conveyers at the discharge of the sinter machines.

In 1962, Trail began adding halide (lead chloride) to its sinter-plant feed, probably to accelerate the fuming off of impurities, e.g., arsenic, cadmium, and thallium (Cominco, 1962, TECK 0279518).

Cottrell treatment of humidified BF flue gas attained over 95% dust collection efficiency. When the BFs were equipped with baghouses in 1951, dust collection efficiency exceeded 99%.

The major part of the sulfuric acid produced at Trail was made from zinc roaster offgas. To protect the acid-plant catalyst, this gas had to be thoroughly cleaned as follows (Cobleigh, 1932, pp 719-20):

- Cyclones first removed coarse dust.
- Most of the remaining dust was then collected in hot Cottrells.
- Scrubbing with dilute sulfuric acid followed.
- Next came water washing, followed by mist removal in a Cottrell.
- Final cleaning entailed gas drying in 80 to 93% sulfuric acid, followed by removal of entrained acid in a box filter filled with coke.

F. Minimizing Loss of Electrolyte in the Betts Process

The Betts process for lead electrolytically refines (rejects most impurities from) lead. It is similar to electrolytic refining of copper. Betts electrolyte in 1938 contained 67 gpl lead and 142 gpl total hydrofluosilicic acid; free silicic acid was 95 gpl (Huttl, 1938a, p 38). Gelatinous organic addition agents (*glue*) facilitated production of solid competent cathodes.

Of particular concern at Trail was decomposition of glue additive to amino acetic acids, which had no outlet from the system. High mechanical losses of lead electrolyte in the early years at Trail provided the purge from the Betts tankhouse. The Betts electroyte in 1924 contained 11 to 13% total H_2SiF_6 and 6 to 9% Pb. Electrolyte loss was 4 to 5 lb of H_2SiF_6 per short ton of pig lead (CM&S Staff, 1924, p 457). In later years, dilution of the electrolyte that accompanied plant expansion offset losses. By the mid-1930s it became necessary to withdraw electrolyte from the system.

Lead was recovered from Betts electrolyte purge by addition of sulfuric acid to precipitate lead sulfate. About 75% of the residual acid was then recovered from the lead-stripped liquor. Work was initiated to substitute *Goulac* for a portion of the glue to minimize need for this electrolyte purge (Fingland / CM&S,1930, pp 184 and 190; pp 198-199; McIntyre, 1936, pp 280-81).

G. Cadmium Recovery

Cadmium recovery at Trail began in 1927. Most of the cadmium fed to Trail arrived in the zinc concentrate. During roasting, cadmium split between calcine, dust and fume. The roaster calcine and a portion of the flue dust were leached to generate electrolyte for zinc electrowinning. Dissolved cadmium was then cemented as *sponge* on zinc dust to generate the primary feed to the cadmium plant.

In the cadmium plant, the sponge was leached with sulfuric acid. Electrowinning the purified Cd-rich solution produced cadmium cathodes, which were melted, then cast into balls or slab (Anonymous, 1954, pp 280-81).

The calcine leach residue contained not only residual cadmium, but also zinc and lead. This residue returned to the lead smelter, where cadmium concentrated in the blast furnace dust. Prior to installation of BF baghouses (1951), cadmium was allowed to build up in the BF dust, which was periodically purged to the zinc roaster. Build-up was limited to 3.5% Cd to avoid excessive loss of cadmium to the atmosphere:

> *Experience had shown that if the cadmium content was allowed to exceed 3.5%, loss of cadmium through the treaters* (Cottrells) *to the stacks became excessive* (Bainbridge, 1952, p 1306).

After the BF baghouses were installed in 1951, the Cd-rich BF dust was sent to the fuming furnace for concentration prior to leaching. Cadmium and its compounds are sufficiently volatile that slag fuming efficiently rejects this impurity.

H. Arsenic Recovery

Significant quantities of arsenic arrive at Trail in both the lead and zinc concentrates. Trail consumed a portion of it as an alloying element in lead, and as a raw material to produce copper arsenate for wood treatment. Arsenic is a particularly difficult impurity to work with because:

- Arsenic is toxic.
- The market for arsenic and its compounds is insufficient to economically consume Trail's output.

- Arsenic oxide volatilizes easily, but not so easily that a clean separation is made between gas and solids.
- A substantial portion of the arsenic follows lead into the lead refinery, and ultimately into the silver refinery.

The result is that much of Trail's arsenic input ultimately accumulated on site as arsenic-rich flue dust in stockpiles. In the early years, much of the arsenic exited via the stacks. By the 1930s, dust collection became more efficient. Furthermore, excellent cleaning of fume-laden offgas was necessary prior to its use to produce sulfuric acid.

Arsenic and its compounds are sufficiently volatile that slag fuming efficiently rejects this impurity.

I. Opinions from Section XII

Opinion #36 (Not contested): By producing ammonia- and phosphate-based fertilizers, Trail provided tonnage oxygen, ammonia, and hydrofluosilicic acid to its metallurgical operations. The result was being able to economically 1) scrub dilute sinter-plant offgas, 2) improve the efficiency of its furnace operations, 3) lower the zinc content of its fumed slag, 4) increase the capacity of its furnace-offgas processing plants, and 5) have the ammonia needed to precipitate zinc from its zinc tankhouse purge electrolyte.

Opinion #37 (Not contested): Wet scrubbing of cadmium-rich vent gases from wet-mix drying prior to lead sintering increased the potential for cadmium to be discharged to the Columbia River, as did scrubbing of air ventilating the conveyers at the discharge of the sinter machines.

Opinion #38 (Not contested): Electrolyte containing a high concentration of soluble lead was lost or purged from Trail's lead refinery prior to 1930. As a result, about 2 lb of lead per ton of Pb cathode output (4.5X67/142) was likely flushed into the Columbia River between 1902 and 1930.

XIII. THE DISPOSITION OF MERCURY AT TRAIL

Mercury is a liquid metal that evaporates at a relatively low temperature. The operating temperatures of Trail's hot cyclones, Cottrells, and baghouses were too high to efficiently collect mercury from its vapor.

To collect a substantial portion of the mercury from a flue gas, one needs to cool the gas to a reasonably low temperature, e.g., below 105 F (40 C). Scrubbing the gas with an aqueous solution provides this cooling. Much of the mercury captured at Trail was via cooling and cleaning flue gases in preparation for producing sulfuric acid. This preparation involved scrubbing with acidic solution, followed by mist elimination.

A. Mercury Recovery from Zinc Roaster Offgas

Zinc roaster offgas is the combination of gas, dust, and fume that results from combustion of Trail's zinc-sulfide-rich roaster feedstocks. Zinc roaster offgas at Trail carried with it a substantial quantity of mercury and dust. Coarser dust was collected by first spinning the offgas in hot cyclone separators (550 F; 290 C). Over 95% of the remaining dust was then collected electrostatically in hot Cottrells (300 F; 150 C), for an overall dust collection efficiency of 99.5%. In 1962, Trail installed a baghouse (212 F; 100 C) to capture roaster flue dust, collecting 99.5% of dust exiting the cyclones.

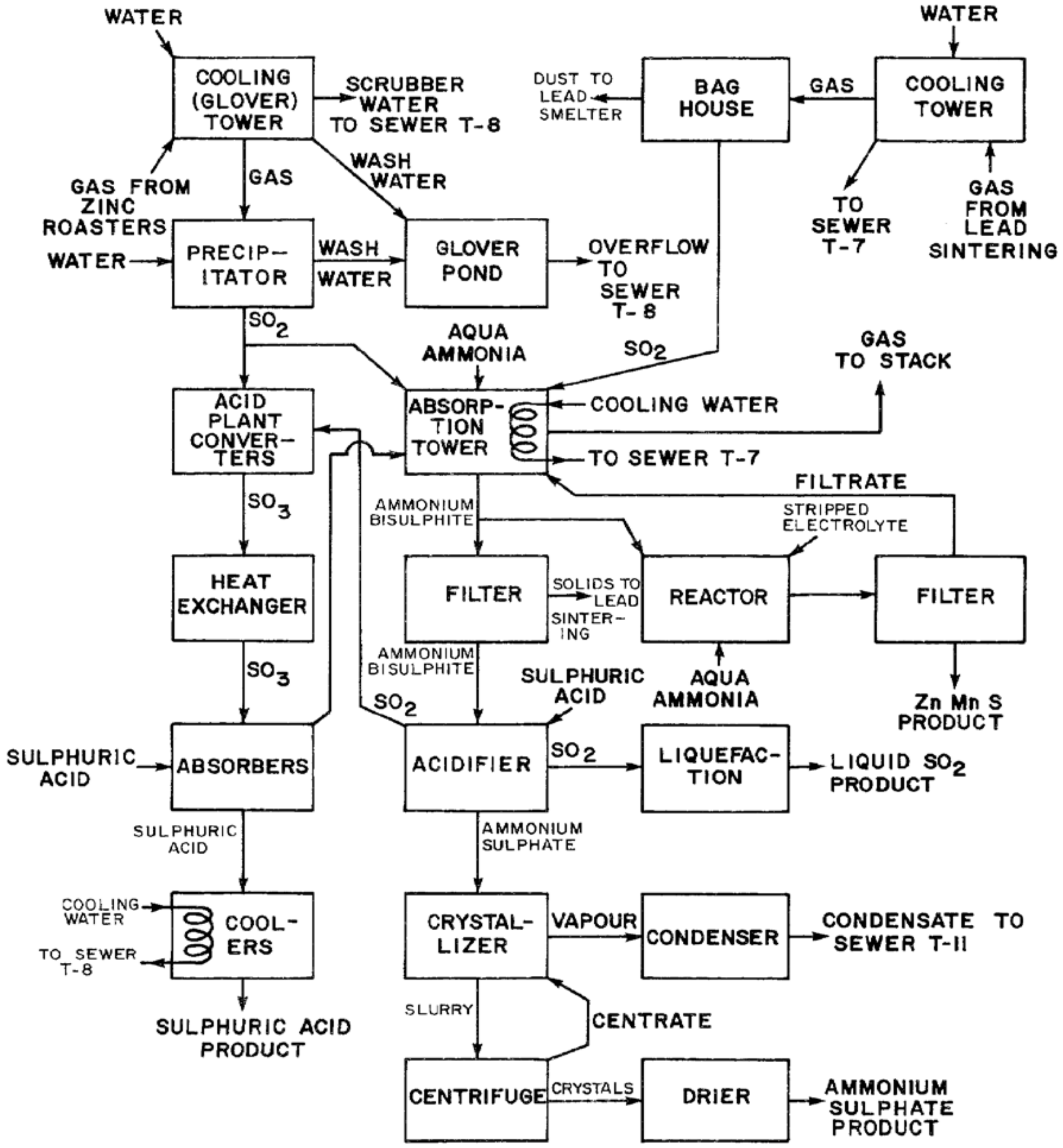
Production of sulfuric acid at Trail began in 1916. By 1931, CM&S was scrubbing substantial volumes of its zinc roaster offgas, sufficient to convert over one-third of Trail's sulfur input to sulfuric acid. The purpose of scrubbing was to prepare the gas for production of sulfuric acid (Cobleigh, 1932, p 719). The cool scrubber environment, followed by mist elimination, likely captured at least 60% of the mercury prior to the acid plant (Steintveit, 1980, p 87; Dutrizac, 1979, p 207).

Hot Cottrell exit gas from the zinc roasters was split between four scrubbers (Glover Towers) that used weak sulfuric acid to collect residual dust and metals as mud. Trail began to purge this mud into at least one pond, called Glover Pond(s), in the 1950s. In 1932, Cobleigh states that the acidic scrubber purge solution was consumed leaching zinc oxide (p 720). This practice appears to have been abandoned by 1934, when Hannay established the importance of avoiding the addition of volatile impurities, particularly fluoride, to the zinc tankhouse electrolyte (Hannay, p 150).

Glover Tower exit gas was further scrubbed with water, then passed through a second Cottrell to eliminate mist. Both steps resulted in additional mercury collection. The gas was now sufficiently free from impurities for drying in preparation for producing sulfuric acid. The mercury-rich mud was captured by settling (Cobleigh, 1932, p 719; Anonymous, 1954, p 290). In 1977, the scrubber and mist eliminator solids were flushed into Glover Pond, as crudely shown in the upper left portion of Figure 20. The two wash water streams feeding Glover Pond in this figure carried the mud.

Figure 20 <ECY3-00000507>

COMINCO LTD., TRAIL
SIMPLIFIED FLOW DIAGRAM OF THE
SULPHUR DIOXIDE RECOVERY, THE SULPHURIC ACID,
THE AMMONIUM SULPHATE AND THE ZnMnS PROCESSES



A sample of mud taken from Glover Pond in 1990 assayed 18.0% Hg (Ball / Cominco, TECK 0110497). This mercury assay is likely correct. For example, Electrolytic Zinc Company of Australia recovered 309,000 tons of zinc from concentrates containing up to 10 ppm Hg (1968 – 1970). The settled scrubber solids assayed between 10% and 40% Hg on a dry basis (Argall, 1971, p 33). The company dried the sludge from its scrubber-sludge pond, then fed it to a retort to recover flasks of mercury metal byproduct (3.4 tons/year).

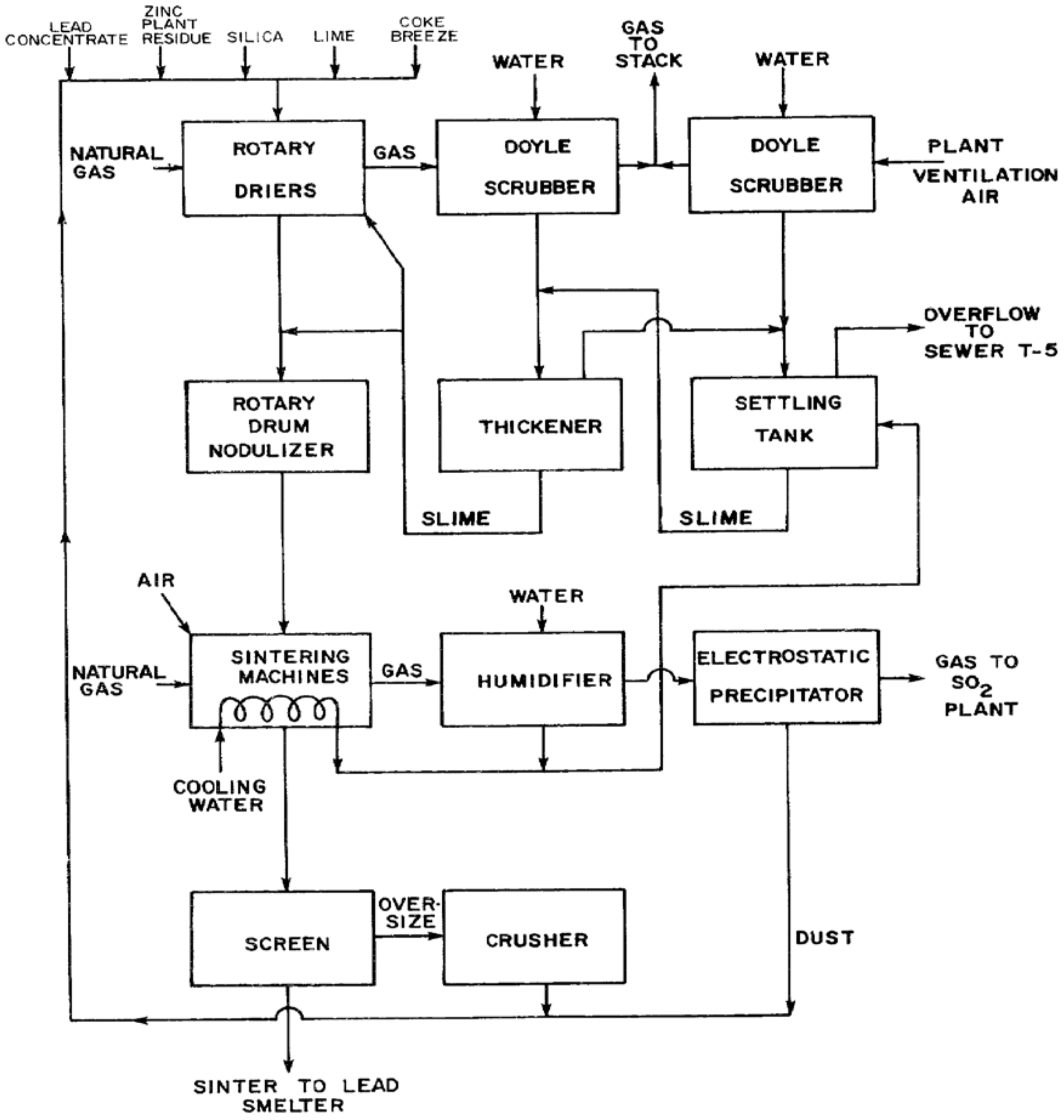
B. Mercury Recovery from Lead Sintering-Plant Offgas

Until the early 1930s, lead sinter-machine offgas was passed through a humidifying flue, then through a Cottrell, followed by discharge to a 400-ft stack. A portion of the lead concentrate's mercury content likely reported to the solids collected during this flue humidification. The mercury-containing material was sent to yard storage, then returned to the second sintering operation (Huttl, 1938a, p 35). Recycling all of Hg-containing material back to sintering likely forced mercury to exit via the stack.

From the early 1930s to 1953, offgas from the sintering machines was still being humidified before dust collection in a Cottrell (90% dust removal). But now the Cottrell exit gas was scrubbed in packed cooling towers in order to provide dust-free gas for production of ammonium bisulfite. Tower wash water went to the Columbia River. The scrubber residue likely contained a portion of the mercury content of the lead concentrates fed to sintering. See the upper right portion of Figure 21. The remaining mercury entered the smelter's SO_2 absorption plant. This mercury would likely have split between the absorber stack, the ammonium sulfate product, and the acid plant.

In 1953, the sinter plant was upgraded to include wet-mix rotary drying of sinter-plant feed. (Wet mixing continued until the start of Kivcet smelting in 1997, when feedstock sintering was no longer required.) The relatively cool vent gas (350 F; 175 C) from the driers was cleaned in Doyle wet scrubbers. Doyle scrubbers, which are very efficient, likely captured as slimes most of the mercury vented from the driers. These slimes returned to the rotary driers; see Figure 21. The mercury would have eventually exited in the sinter-machine offgas, then behaved as before, i.e., from the early 1930s to 1953. Scrubber slurry went to #7 Sewer until 1998 (TECK 0338974). However, the effect of indirect heat exchange in the lead smelter in 1994 largely decreased Hg in #7 Sewer. JFH calculated that the 1993 to 1994 drop in Hg in #7 sewer was 97.7% (JFH's Expert Opinion, p 20).

Figure 21. <ECY3-00000502>



COMINCO LTD., TRAIL
SIMPLIFIED FLOW DIAGRAM OF THE
LEAD SINTERING PROCESS

Sewer #7 was the most contaminated of all the individual sewers at Trail, and represented the highest concentration and loadings of mercury, arsenic, and cadmium that went to the Columbia River (BCE 0001494 / Cominco, 1991, p 20).

C. The Quicksilver Material Balance for Mercury

This section examines a Cominco presentation titled *Chasing the Elusive 'Quicksilver' at Trail Operations*. The subtitle of this presentation is *A Review of Mercury Control Improvements: 1979 – 2002* (TECK

0338946, dated December 10, 2002).

JFH in his 30Nov10 Expert Opinion (p 20) provided the following caution on use of this document after I had submitted my 17Sept10 Expert Opinion:

> *The 2002 Quicksilver document cannot be used for the purpose quoted. This document is very much an order-of-magnitude look at the mercury issues in Trail written for a motivational Tuesday seminar in Research. Although it does present data on page 16 and 41 these are order-of-magnitude estimates at best… (JFH's Expert Opinion, 30Nov10, p 20).*

This presentation was made at a time that Cominco's R&D group recognized that the Trail was being challenged in its efforts to control mercury. Portions of the Quicksilver presentation are accurate; other portions are not. The on-going challenge with respect to mercury at Trail operations between 1979 and 2002, according to the Quicksilver document, included the following:

- *A product and a waste*
- *Control, (well) better….*
- *Much less discharge to the environment*
- *Just when Hg seems "under control"…*
- *It shows up in either air or water*
- *For no explained reason*
- *What does is take to control it?*

Included in the presentation are steps taken at Trail metallurgical operations from 1995 to 2002 to minimize outflow of mercury to the Columbia River (Teck 0338977):

- Installing a mercury pad
- Lining the lagoons
- Property-wide paving

- TMT (sulfide reagent) to precipitate Hg from Glover Tower effluent
- Start-up of the Kivcet smelter
- Corrective action on spikes and spills

Included in the Quicksilver Presentation were approximate mercury inputs and outputs:

- Mercury input with concentrates: 73 tons / year[11]
- Mercury recovered as calomel: 27 tons / year
- Mercury in residues and slag: 26 tons / year
- Unknown mercury: 20 tons / year
- Mercury in product elemental sulfur: 750 lb / year
- Mercury to stack and sewers: 440 lb / year
- Mercury in product sulfuric acid: 240 lb / year
- Mercury in fertilizer and other: 220 lb / year

My observations on these mercury inputs and outputs are as follows:

Mercury in feedstock concentrates: Mercury input with concentrates in 2002 was approximately 34 tons based on the attached *Inputs and Distributions* spreadsheets, rather than the 73 tpy according to the Quicksilver. This update is supported by JFH's 30Nov10 Expert Opinion (p 20), much of which is supported by the 1800+ documents that were provided to me after my 17Sept10 Expert Opinion had been submitted.

Mercury output as calomel (Hg_2Cl_2): The Quicksilver Presentation reported that the Norzink scrubber captured 27 tpy Hg as calomel. Four findings related to this total are:

1) A Cominco patent applied for in 1995 (U.S. 5,601,795) stated that:

> *Levels of mercury in concentrate fed to the zinc roasters at the Cominco Ltd. plant in Trail, British Columbia, have been increasing over time due to an increasingly higher mercury content from ore concentrates of the Red Dog and Sullivan mines. This level of mercury results in more than 20 tonnes* (22 tons) *per year of crude calomel being formed.*

The calomel in the patent assayed 74.3% Hg, so that the more than 22 tpy of calomel in the patent contained more than 16 tpy of Hg. The Quicksilver Presentation identified an average of 27 tpy of Hg as calomel, which indeed is more than the 16 tpy Hg in the patent.

2) One might reasonably expect that 98% of the Quicksilver mercury in concentrates fed to Trail made it to the Glover Towers (G.T.), and that the towers captured 65% of this mercury (Steintveit, 1980, p

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[11] JFH calculated that the Hg input to Trail operations was about 34.5 tons in 2002, not the 73 tons that appears in the 2002 Quicksilver document (JFH's 30Nov10 Expert Report, p 20).

87). However, Cominco's SE Thornton provides the following guidance (TECK 1547250, 1990):

- 85 to 95% of the incoming Hg can be accounted for.
- Of the approximately 90% of the mercury that was accounted for, about 40% was captured in the Glover Towers, i.e., about 36% of the mercury in the zinc-plant feedstocks reported to the Glover Tower stripper effluent.
- The balance of the mercury (about 54% of zinc-plant feed) reported to the mist treaters (M.T.), where a portion of the mercury was collected.
- Mercury not captured by M.T. entered the Mercury Removal Plant, where 90% was captured. Most of the uncaptured Hg distributed between the sulfuric acid, liquid SO_2 byproduct, and ammonium sulfate byproduct. Thornton's summary (1990) is as follows:

Inputs:		
Roaster Feed	92. - 117.	lb Hg/day
Outputs:		
Calcine	1.9	lb Hg/day
G.T. Effluent	35.6	
M.T. Effluent	1.4	
Mercury Removal Plant (Calomel)	43.6	
Sulfuric Acid	1.3	
Liquid SO_2	0.44	
Ammonium Sulfate	1.4	
Treatment Tank	1.9	
Stack Gas	1.5	
Total Output	89.0	lb Hg/day

- A 1974 Cominco Memorandum (Martin, TECK 0327622) discusses M.T. drainage being higher than previously experienced. The write-up refers to a thickener underflow, indicating that the mercury content of M.T. effluent was being collected.
- In 1973 (prior to installation of the Mercury Recovery Plant), Cominco carried out a *new survey* to supplement a *preliminary mercury deportment study* that had been carried out about a year earlier (McIver, TECK 1125382). Mercury input to the zinc plant was about 89 lb/day, based on the Inputs and

Distributions Spreadsheets. Findings from the 1973 survey were as follows, which Cominco's Senior Development Engineer stated were *based on the preliminary survey and are indicative only*:

a. G.T. effluent Hg entered G.T. Pond, then was recycled to the smelter: 2 lb Hg/day.
b. M.T. effluent Hg entered *Sewer: 7 lb Hg/day + probably significant unaccounted*. The Memorandum states that *mercury collects in flues or in mist treater effluent and mud*.
c. The Acid Plants captured Hg to acid for Sale and Fertilizer: 2 to 6 Lb Hg/day.
d. Residual Hg exited the Acid Plants to the Retreatment Plant to #4 fan to "*Out*", i.e., 5 lb Hg/day exiting with ammonium sulfate solution to Warfield (Jones, TECK 112318).

Three problems were identified in this 1973 Memorandum:

a. <u>Pollution control</u>: proposed new regulations are stringent.
b. <u>Level in the H_2SO_4</u>: This is a problem for internal use and for sale (one lot has already been rejected).
c. <u>Because of lack of recovery</u>, potentially profitable concentrate purchases have been rejected.

<u>Conclusion</u>: Based on 1973 operation, it appears that until installation of a thickener to handle M.T. slurry discharge in 1974, at least 8% of the Hg fed to the zinc plant discharged to the Columbia River as M.T. effluent slurry.

- In 1972, A.F. Jones (Development Engineer, Metal Production) described two surveys carried out in September of 1971 to determine mercury deportment from the Zinc Roasters and Acid Plants. The Hg concentrations in the gas, dust, and effluent streams were measured.

Inputs:	<u>Lb Hg/day</u> <u>Sept. 23/71</u>	 <u>Sept. 30/71</u>
Roaster Feed	70.5	95.5

Outputs:

Calcine	1.6	1.6
#30 Roaster Baghouse Catch	0.02	0.01
#30 Roaster Alpha Fan	0.02	1.6
G.T. Effluent to pond	2.1	1.6
G.T. Outlet to M.T.	32.3	18.8
Unaccounted Loss:	**34.5**	**71.9**
	70.5	95.5

Inputs:	Lb Hg/day	
	Sept. 23/71	**Sept. 30/71**
M.T. Inlets	32.3	18.8
Outputs:		
M.T. Effluent	7.4	6.6
Sulfuric Acid	1.9	5.6
Ammonium Sulfate	0.7	0.7
#4 Fan Outlet[12]	-	5.4
Zinc Stack	0.2	0.2
Unaccounted Loss:	**22.2**	**1.15**
	32.3	18.8

The Memorandum notes that *since there appears to be wide variations in the Hg content of Sullivan zinc concentrate (60 ppm is high), it will be essential to do a thorough sampling of roaster feed during the next deportment.*

Conclusion: Based on September 1971 operation, it again appears that until installation of a thickener to handle M.T. slurry discharge in 1974, 7 to 10% of the Hg fed to the zinc plant discharged to the Columbia River as M.T. effluent slurry.

3) In 1990, Magoon / Cominco (p 403) stated that *this process* (Boliden Norzink) *results in the production of approximately 500 kg* (0.5 tonnes) *of impure calomel per year*. *JFH's Expert Opinion (p 20) states: The paper is in error. Thornton (35) reports 19.8 kg/day*

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[12] Sept 23 #4 Fan Outlet was not used because the calculated 1910 lb Hg/day was unrealistic.

> *being produced for a total of 7.8 tons/year, very close to Mr. Queneau's estimate.* Calculations summarized in the *Inputs and Distributions Spreadsheets* indicate about 8.0 tpy Hg being recovered as calomel in 1990.[13]

Mercury output as residues and slag: The Hg-rich residues in the Quicksilver Presentation were likely the total of those collected from the ETP plant. In regard to Cominco's fumed slag output, the Hg content of both Trail's fumed and BF slags was insignificant, i.e., nil.

Unknown mercury output: When the Quicksilver Presentation compared mercury in with mercury out, an average of 20 tpy was missing. Where mercury is missing at Trail, difficulty in sampling mercury may well have resulted in the discrepancy. Mercury is readily reduced to metal, which can form dense Hg agglomerates. Accurately sampling streams with suspended solids with mercury, and filter cake containing isolated high-density particles of mercury, would require substantial expertise. An unknown but possibly significant portion of the missing mercury may have volatilized.

Sampling ETP clarifier / thickener overflow exiting to the Columbia would likely have been straightforward. Furthermore, in the absence of foaming, dense metallics are unlikely to overflow.

Mercury output to elemental sulfur: Elemental sulfur is a byproduct of Trail's autoclaving zinc concentrate. Zinc sulfide oxidizes in aqueous solution to produce zinc sulfate electrolyte and elemental sulfur. About 750 lb of mercury per year was contained in Trail's elemental sulfur output, according to the Quicksilver Presentation. This quantity of Hg is small compared to Hg input from concentrates.

Mercury contained in sulfuric acid product: About 260 lb of mercury per year was contained in Trail's sulfuric acid output, according to the Quicksilver Presentation. Acid output, when protected by the Norzink process, assayed 0.6 ppm Hg (TECK 0340694). Assuming about

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[13] SE Thornton reported a rate of 19.8 kg/day (7.8 tons/year) of calomel output in 1990, where calomel is expressed as 100% Hg (TECK 0138442).

400,000 tpy acid output containing 0.6 ppm Hg, contained mercury calculates to 240 lb. The quantity of Hg to acid is indeed small when compared to Hg input from concentrates.

Mercury contained in fertilizer and other: The Quicksilver Presentation stated that the annual mercury content of Trail's fertilizer output was less than 220 lb/yr. This quantity of Hg going into fertilizer is small when compared to Hg input from concentrates.

Mercury output to stack and sewers: About 440 lb of mercury per year reported to stack and sewer, according to the Quicksilver Presentation. In 2002, mercury loss to stack, the Columbia, and Stoney Creek, via the *Inputs and Distribution Spreadsheets*, as reported by Cominco, totaled 340 lb. These two values are reasonably consistent, when considering that the Quicksilver Presentation referred to averages.

Mercury Input: In 1992, Cominco Research wrote that *Hg inputs to the roasters in zinc concentrates are projected to be about 40 t/y* (44 short tons / year). Because the autoclaves received somewhat less than 25% of the total zinc concentrate input, total projected mercury input from zinc concentrates was likely about 55 tpy. Our *Inputs and Distribution Spreadsheets* show 28.1 tpy in zinc concentrates (1992).

D. Opinions from Section XIII

Opinion #39 (Contested): For about eight decades, an unknown tonnage of mercury-rich mud collected from Trail's roaster-gas scrubbers and mist eliminators was stored, rather than directly discarded into the Columbia River.

JFH's *Expert Opinion* (p 17) included the following critique of Opinion #39 above:

> *Disagree. This opinion is incomplete. Substantial quantities of Hg mud were sold, see K.L. Beynon November 1968 (32).*

Opinion #39 is indeed incomplete. The *Inputs and Distributions Spreadsheets* have been updated to include the Hg input and distribution data in JFH's 30Nov10 Expert Opinion, attachments, and 1800+ references. Toward this end, the following references appear to be particularly significant:

1932 April – TECK 1120964 and 1120965 (E.L. Jones)

<u>Conclusion from Jones' Findings</u>: In 1932, acid-plant wastes discharged to the sewers. Because a major portion of the mercury in Trail's feedstocks that was captured did so during gas cleaning and handling in the Glover Towers and in the acid plants, this discharge provided an important purge for mercury from the plant.

<u>Specifically</u>: Plant sewer losses included 1350 gallons per day from the mist treaters; solids were suspended in the solution. Acid content ranged from 5 to 33 gpl.

About 1,200,000 gallons per day discharged to sewer from the Glover Towers. Approximately 3,200,000 gallons per day discharged to sewers from the total acid plant. No mention of mercury was discovered in the Trail literature examined.

Glover Tower Seals and Flues — These are cleaned out once every three days. The dust for the greater part is dry and covers an area of 66 sq. ft. at a thickness of 1.5 inches. The weight was estimated at 60 lbs per cubic foot. This dust does not settle in the sewer solution….only 480 lbs of solids are washed down each time the flues are cleaned.

Glover Tower Cooling Coils — These are cleaned out once every 15 days. The coils are coated with a soft layer of substance about 1/8- to 1/4-inch thick….The wash water carried 2085 lb solids (40 gpl solids).

The dirty appearance of the sewer discharge is due, not to excessive amounts of solids in the water, but to the colloidal nature of these solids.

1944 May – TECK 1120969 and 1120970 (R.R. McNaughton)

<u>Conclusion from McNaughton's Findings</u>: Until Glover Tower Ponds were installed, Glover Tower effluent discharged directly to sewer, thus providing a mercury-rich purge from Trail. To recover mercury from Glover Tower and Acid-Plant effluents, a pond or thickener would likely have been required.

<u>Specifically</u>: *The principal regular discharges to the river from each plant…* include *Three tons/day of Glover Tower Discharge Solids…*

discharge to river as Solids. Also discharged are *150,000 gallons per day with 1.5 tons of zinc…* There was no mention of mercury.

1946 March – TECK 1122290 (Anonymous)

Conclusion from Anonymous' Findings: In 1946, wash tower and mist treater effluents went to sewer, thus maintaining a suitable mercury purge.

Specifically: Acid plant mercury distribution, Lb/day: Glover Tower pump tank (6 Lb); Wash Tower (2 Lb); Mist Treaters (8 Lb Max); Converter Heat Exchanger (0.1 Lb).

1967 Dec, and July65 (?) - TECK 1122305 and 1122309 (Anonymous and K. Beynon)

Conclusions from Anonymous and Beynon's Findings:: Successful recovery of mercury for sale began at Trail in 1959. Mercury pricing per pound during this period was $3.25 (1957), $3.01 (1958), $2.99 (1959), $2.77 (1960), $2.60 (1961), $2.52 (1962), $2.49 (1963), $4.14 (1964), $7.51 (1965), $5.81 (1966), and $6.44 (1967). Mercury sales thus provided an important Hg purge from Trail operations from 1959 through 1968.

Specifically: Mercury recovery at Trail appears to have begun in 1959. Three relatively small lots of high-grade solids (33.1% Hg average; 20% moisture) were recovered from roaster-offgas cleaning equipment from Dec 1959 to Feb 1961. The page's title is *Mercury Recovered To Date*.

A hand-written page signed by Mr. Beynon (29Dec67) stated that *total mercury shipped from our operations… 1959 – 1967… is 155,500 lbs Hg*. The mercury was recovered from the acid plants, specifically from: 1) wash tower systems, 2) the mist treaters, and 3) mist-treater inlet and outlet flues.

Mt. Beynon then briefly describes three items regarding mercury recovery:

- *Attempts were made to condense mercury from the gases from #30 Roaster….About 17% of the mercury present in zinc concentrates was accounted for.*

- *Tests were done to determine the profitability of recovering the mud washed from the acid-plant mist treaters. The reference was C&F Section 433, Report No. 50.*
- *Additional earlier work on measurement of Hg in various locations is given in C&F Section 433 and the File index should be received for anything of interest.*

1968 July – TECK 1123320 (JPB)

<u>Conclusion from JPB's Findings</u>: In 1968, Glover Ponds solids were returned to the zinc plant for processing.

<u>Specifically</u>: Zinc (est. 1000 tons/year) in the Glover Tower Ponds was not counted as a loss.

1968 November – TECK 1122313 (K. Beynon)

<u>Conclusion from Beynon's Findings</u>: It is important that mercury sales be included in the Inputs and Distributions Spreadsheets. Mercury pricing per pound during this period was $7.05 (1968), $6.65 (1969), $5.37 (1970), and 2.53 (1971). Mercury price remained below $4/lb from 1971 until 1979.

<u>Specifically</u>: *A total sales income* {from Hg, with silver credits} *of $609,600 and a recovery cost of $113,000 realized a net income after recovery of $496,600 from the 1965 through 1968 mercury mud program. All of the Hg lots were recovered from the acid plants, which includes inlets, flues, treaters, wash towers, and outlets.*

1970 November – TECK 1547198 (W.F. Hastings)

<u>Conclusions from Hasting's Findings</u>: I have been unable to discover reference to mercury-rich mud being landfilled or inventoried at Trail for its mercury content, other than that collected to be sold for mercury values (1959 – 1968; see above).

Most of the mercury mud exiting Glover Tower would likely have been captured in Glover Pond(s) during the years that this pond existed. I have been unable to discover when the Glover Ponds first went into operation.

JFH in his 30Nov10 Expert Opinion on p 16 states that *there were neutralization and settling ponds in use from at least 1950 until 1993*. I was unable to discover a document describing how or when these ponds were used, or what happened to the captured solids.

Glover Ponds did not appear to be in operation in 1954, when Glover Tower discharge *flows to a small solids-settling tank, and* is *returned through lead circulating pumps* (ECY3-00000296).

Specifically: Exits reported for mercury in 1970 from Trail's combined Metals and Chemical Fertilizer operations totaled 8.75 tons Hg/yr: Accumulation in flues and material balance closure (3.94), the metallurgical sewers (2.33), stacks (1.30), gypsum discarded to fertilizer sewers (0.78), sulfuric acid sales (0.22), ammonium sulfate fertilizers (0.10), and phosphate fertilizers (0.08).

1972 January – TECK 1122316 (A.F. Jones)

Conclusion from Jones' Findings: The combination of mercury tonnage, concentration, and price (2.87/lb Hg)[14] after 1968 did not permit its profitable sale.

Specifically: *Recovery and removal of the metal* {Hg} *should be done at the inlet to the Glover Towers. Previous samples have shown that the metal concentration* {Hg} *ranges from 2% in the Glover Towers to 60% in the Mist Treater outlet mud. The Glover Tower outlet flue to the acid plants contains about a foot of mud, the inlet flues to the acid plants are another point of mud accumulation.*

1973 – TECK 0068593 (BC Environment and CH2MHILL)

Conclusion from BC and CH2MHILL Findings: In 1973, Cominco was preparing for meeting anticipated permit restrictions, which included upgrading its mercury capture capabilities.

Specifically: *Cominco first applied for permits for discharge industrial waste to Columbia River.*

1973 April – TECK 1125382 (P.J. McIver)

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[14] Annual Hg prices for Hg in $U.S. appear in the *Engineering and Mining Journal*, and have since been compiled by the U.S.G.S. To obtain these prices, Google "usgs, mercury, price".

Conclusions from McIver's Findings: Cominco was preparing to meet anticipated environmental permit restrictions, which included upgrading its mercury capture capabilities. Mercury captured in Glover Pond returned to the lead smelter.

Based on the combined findings of Martin (March 1974; see below) and McIver (April 1973), in combination with being unable to discover contrary information in earlier years, I conclude that Trail's acid-plant Mist Treater Effluent discharged into sewer prior to 1974.

This mist treater effluent thus provided an important purge for mercury from Trail operations.

Specifically: A new mercury deportment survey was carried out that includes a diagram showing *Mist Treaters* going to *Sewer Effluent*. The daily mercury output from the Mist Treaters was *7 lb/day + probably significant unaccounted*. In 1973, two lb Hg/day from the Glover Tower Pond went to the lead smelter.

1973 June – TECK 0326543 (CJK, PJMcI, GM, MTM, DHM, and RWR))

Conclusions from CJK, PJMcI, GM, MTM, DHM, and RWR's Findings: In 1973, Trail Operations partially satisfied its need to purge mercury from its zinc plant by disposing of its mist eliminator discharge to the Columbia River. This discharge decreased the adverse effects of mercury build-up within the plant.

Specifically: *The continuous drainage and washings from the mist treaters in No. 7 and No. 8 Acid Plants is at present sent directly to the sewer and investigation has been initiated to study the possibility of treating this stream to remove the solids and also precipitate some of the impurities.*

1973 October - TECK 1122319 (C.J. Krauss)

Conclusion from Krauss's Findings: Trail in 1973 clearly understand that their operation was not meeting a proposed environmental regulation for mercury effluents. Thus, in 1973, it was also clear to Trail management that it was imperative that *an environmentally acceptable mercury outlet for mercury be developed immediately.*

Specifically: *The present total input of mercury to the* {lead} *smelter is estimated to be 5 to 8 pounds per day… . Since our existing smelter effluent from 07 sewer exceeds the proposed "C" standard for mercury by a factor of seven no significant increase in mercury input should be allowed until both effluent control and a mercury outlet are established. A realistic interim standard would be to impose a limit of ten pounds per day maximum mercury input to the smelter.*

1974 March – TECK 0327622 (M.T. Martin)

Conclusion from Martin's Findings: Beginning in 1974, the M.T. drainage was passed through a thickener to capture a substantial portion of its Hg-rich solids content. The ETP plant (1981) ultimately captured most of this material.

Specifically: *Recent results have shown that the Hg in mist-treater (M.T.) drainage and washing is higher than previously experienced....A means of treating this effluent must be studied….The method of treating the thickener underflow… . At present a vacuum filter is proposed…*

1975 September – TECK 1122371 (M.L. Jaeck)

Conclusion from Jaeck's Findings: Interest in mercury deportment at Trail had increased by 1975, as indicated by a Development Engineer requesting that the mercury content of current feedstocks be updated.

Specifically: *Many of the Hg assays available for new material inputs to the smelter are 1-2 years out of date….New material inputs to the smelter should be assayed for Hg as least once a year if any attempt is to be made at monitoring and controlling new mercury input to the smelter.*

1979 October – TECK 0111962 (L.S. Krochmaknek of Hatch Associates for Cominco)

Conclusion from Hatch's Findings: Trail's ETP plant came on line in 1981. This plant treated contaminated water from lead and zinc operations by liming. An exception was Sewer #7, which discharged solution from lead sinter-plant offgas cooling and scrubbing.

Specifically: *Process water effluent from a variety of plant sources in Trail Metallurgical Operation are presently discharged to the Columbia River. The quality of these process water effluents will not meet the B.C. Pollution Control Branch objectives for heavy-metal contamination. A treatment facility is required to reduce the levels of Zn, Cd, Pb, Hg, As and suspended solids in these effluents to levels acceptable to the Pollution Control Branch.*

1984 October – TECK 0337312 (Anonymous; Cominco – Technical Description of Trail Operations)

Conclusion from Anonymous' Findings: To meet sulfuric acid quality standards, the Boliden Norzink Process was installed in 1981 to remove mercury from the sulfur dioxide gas before it entered the sulfuric acid plants.

Specifically: *Gases from dry electrostatic precipitators and the wet-gas scrubbers of the Lurgi roasters and the glass fiber baghouse of the suspension roaster are combined, cooled and scrubbed in packed towers* {Glover Towers}*….The gas is further cleaned in mist treaters and scrubbed for mercury removal.*

1990 November – TECK 1547250 (S.E. Thornton)

Conclusion from Thornton's Findings: By 1990, Trail recognized that all of the Glover Tower sludge could not be recycled within Trail operations without unacceptable disruption of zinc-plant operations. It had become essential for Trail to implement means to purge mercury from the plant.

Specifically: *Removal of mercury-rich solids from the Glover Tower effluent is necessary to reduce the increasing recirculating mercury load.*

1991 August – TECK 0369275 (D.W. Ashman)

Conclusion from Ashman's Findings: In 1991, mercury captured at Trail to meet environmental regulations was difficult to recycle within Trail operations.

Specifically: *The high mercury level in ETP sludge (0.15% Hg) has restricted its treatment through the roasters and created an environmental concern over the ETP sludge stockpile….However, past experience indicates that treatment rates of ETP sludge through the roasters is unlikely to exceed production rates by enough to reduce the size of the stockpile. It appears that the new lead smelter is the only realistic hope for this.*

About 18,500 tons of ETP sludge containing about 28 tons of Hg were produced from 1986 through 1990, of which only about 5,400 tons were recycled. Effort was made to process as much as possible of the mercury in the Mercury Recovery Plant.

1992 January – TECK 1122272 (E.T. deGroot)

Conclusion from DeGroot's Findings: In 1992, mercury captured at Trail during gas treatment was difficult to recycle within Trail operations.

Specifically: *The balance also shows a very high recycle of mercury via treater dust. Because mercury tends to accumulate in treater dust, treatment of a portion of this material through the roasters is a very effective bleed from the smelter circuit. Adverse effects of treating treater dust in the roasters are the possibility of a bed freeze-up due to its contained lead and corrosion of the tank room due to chlorine. Currently, four tons per week of treater dust are mixed with the concentrate charge to the roasters. It was felt that this could be increased to a maximum of eight tons per week without serious harm to Zinc Operations.*

1995 January – TECK 1554798 and 1554799 (J. Brown)

Conclusions from Brown's Findings: In January 1995, impurities bled from Trail Operations outfall solutions, some with suspended solids, were difficult to return to Trail Operations for recovery of contained metal values.

> <u>Specifically</u>: *Outlook for Mercury Deportment….The current situation has two* {principal} *outlets for mercury; calomel and ETP sludge. These outputs account for approximately 70% of the mercury inputs.*
>
> *The biggest impact on the movement of mercury at Trail will come from treating the G.T.* {Glover Tower} *effluent and the ETP* {Effluent Treatment Plant} residue stockpile. *This will result in an increase in calomel production* {i.e., mercury chloride recovered from acid-plant input gas via Trail's Boliden Norzink process}.

1995 February – TECK 0341989 (D.L. Ball)

> **<u>Conclusion from Ball's Findings</u>**: In February 1995, impurities bled from Trail Operations outfall solutions via lime precipitation were difficult to return to Trail Operations for recovery of contained metal values.
>
> <u>Specifically</u>: *Sludge disposal* {from the Effluent Treatment Plant}*, and metal recovery, was originally intended via the Roasters. Despite many attempts the Roasters have been unable to successfully handle this material, largely due to an apparent fouling of the gas handling system. The Smelter has not been an outlet for ETP sludge mainly due to sintering problems…. Consequently, the sludge has accumulated over the years to constitute a stockpile of at least 46,000 (dry) tonnes.*
>
> *By 1995, the ETP sludge inventory appears to have more than tripled since 1991. Refer back to Ashman's August, 1991, findings on ETP-sludge inventory and Hg content.*

Opinion #39 (Revisited): The 17Sept10 Inputs and Distributions Spreadsheets not only failed to account for mercury sold, but also improperly quantified and dealt with other mercury inputs and outputs. The Spreadsheets were therefore revisited to include Hg input and distribution information discovered in JFH's 30Nov10 Expert Opinion, attachments, and 1800+ references.

Mercury discharged from tower Towers directly to sewer until the Glover Pond(s) were instituted after 1954, but before 1959. Pond settled solids, including mercury content, were recycled back to the plant for metal recovery.

Mercury discharged from the Mist Treaters directly to sewer until 1959, when Hg recovery began. This recovery / sale of mercury maintained the essential need for a principal purge of Hg from Trail Operations. Mist Treater discharge to sewer resumed in 1969, when mercury sales ceased, thus maintaining the purge. Discharge of mercury to sewer ceased in 1974, when a thickener was installed to collect the mercury from Mist Treater discharge in order to meet B.C. Provincial environmental standards.

Opinion #40 (Contested): Prior to 1940, the mercury content of Trail lead concentrates reported to the stack. After 1940 and at least until 1998, at least half of lead concentrate mercury content reported to Sewer #7, which discharged to the Columbia. The remaining mercury reported to the absorber stack, the ammonium sulfate product, and the acid plant.

JFH's *Expert Opinion* (p 17) included the following critique of Opinion #40 above:

> *Disagree. This opinion is incorrect. The date of the "turning point" was the "early 1930s" as Mr. Queneau says in last paragraph on page 56 when absorption was installed at the Pb smelter, not 1940. The opinion that "at least half of Pb concentrate mercury content reported to Sewer #7" is not correct. Between 1973 and 1996 the actual deportment exceeded 50% only twice, in 1977 and 1990 both of which were very low Sullivan Pb concentrate production years. In the other 21 years this deportment averaged 22.4%, as I've shown in reference (33).*

Opinion 40 has been revisited. Specifics on Hg distribution provided by JFH in his 2010 Excel worksheet (Reference 33 in his 30Nov10 Expert Opinion), in combination with the references that he provided, will be used as the principal bases to update the Inputs and Distributions Spreadsheets, i.e., the Hg distribution in streams exiting from the sinter plant.

Opinion #40 (Revisited): Prior to the early 1930s, most of the mercury content of Trail lead concentrates reported to the stack. In the early 1930s, Cottrell exit gas was scrubbed to provide dust-free gas for production of ammonium bisulfite. A portion of the Hg reported to the scrubber residue. Scrubber wash water was routed to Sewer #7. Remaining mercury entered the smelter's SO_2 absorption plant. This mercury would likely have split between the absorber stack, the ammonium sulfate product, and the acid plant.

In 1953, the sinter plant was upgraded to include wet-mix rotary drying of sinter-plant feed. Doyle scrubbers likely captured as slimes most of the mercury vented from the driers. Captured slimes returned to the rotary driers. The mercury eventually exited in the sinter-machine offgas, then behaved as before. Scrubber slurry reported to Sewer #7 until 1998.

Opinion #41 (Not contested): The mercury content of Trail's fumed slag and BF slag waste was insignificant.

Opinion #42 (Contested): The unknown whereabouts of the 20 tpy Hg reported in Trail's Quicksilver Presentation may have been due to difficulty in sampling inputs to Glover Pond. An unknown but possibly significant portion of the missing mercury may have volatilized.

JFH's *Expert Opinion* (p 17) included the following critique of Opinion #42 above:

> *Disagree. The Quicksilver presentation is wrong. The actual input of mercury in 2002 was 34.5 tons (34), not the 66,500 kg which the Quicksilver author called an average. The Sullivan mine closed in 2001 and so inputs of Hg had dropped significantly in 2002. The Opinion above suggests the Hg may have volatilized but all the stack emissions were routinely measured and are kilograms per year, far from this "missing" 18 tonnes. The "missing mercury" allegation goes back many years into the 1980s. It was examined in some detail in 1990 by Thornton 1990 (35) who clearly shows the range in uncertainty in the Hg into the roasters. Thornton observed variations in the feed mix of 40 to 50 ppm giving an unaccounted input of 2 to 13 kg/day or 5 to 32%. Brown 1995 (36) examined all product, byproduct, and waste streams and concluded that only 70% of alleged inputs could be accounted for. Other balances I have seen by Cecchini and Seminiuk showed the same range in 1985, and Hastings 1970 (37) shows 45% with later confirmation that the buildup in acid plant flues was large and could not be measured year by year. In each instance, measurements of the stacks were included and gave no indication of such large losses. I have concluded that it is the way in which the Hg data for large tonnages of concentrates is gathered and the way those results are averaged that leads to a consistent bias towards estimating 15-30% more in inputs that can be substantiated in all outputs.*

Opinion #42 (Revisited): In regard to mercury, my conclusions include:

- The 2002 Quicksilver document is an order-of-magnitude look Trail mercury issues, written by Trail R&D for a motivational seminar.
- Build-up of Hg in flues could not be measured year-by-year.
- At Trail there has been a consistent bias towards estimating 15-30% more in inputs that can be substantiated in all outputs.
- Fugitive emission data was missing from the Trail documents that I reviewed. Both Trail metallurgical balances (JFH's Expert Opinion, 30Nov10, top of p 18), and the Inputs and Distributions Spreadsheets, show substantially more Hg entering Trail operations than exiting. Fugitive Hg emissions thus may account for much of the unaccounted mercury.

Opinion #43 (Not contested): The quantity of mercury in byproduct sulfur, sulfuric acid, and fertilizer was small compared to Hg input from concentrates.

XIV. THE MODERNIZATION OF TRAIL: 1979 to 1991

By the early 1970s, it was apparent that Trail operations were aging and needed upgrading. Looking back, Charlie Sutherland (a senior Cominco engineer) observed that in 1970 economic and environmental considerations called for updated technologies. Sutherland's comments included the following observations (1988, p 86):

> *The many previous years of operation with steadily increasing capacity had seen continuing change in processes and in equipment, but many of the plants were aging and becoming increasingly expensive to operate*. [In 1970], *it was clearly necessary to regenerate the plants with the most efficient technology in order to restore the competitive position of the Trail smelter and also to bring it into conformity with stringent new standards in plant hygiene and the environmental impact.*

The need to meet new environmental standards became particularly apparent when the Water Investigations Branch of the B.C. Ministry of Environment (B.C. MoE) published in two phases (1977 and 1979) the *Kootenay Air and Water Quality Study*. These reports detail the types and volumes of liquid wastes discharged into the Trail operations' sewers, and thence primarily into the Columbia River. Refer below to Section XV (The Sewers) for details.

In June 1978, the daily lead and zinc outputs from Trail were 425 and 625 tons, respectively. Fish wrote that much of the lead smelter was essentially 40 to 50 years old, dating back to the 1930s when lead-BF slag fuming was implemented. There had been no major lead plant renovation for 38 years. *Cominco would have to spend millions more over the next decade if present provincial and federal government proposals for effluent and emission standards became law* (Fish, 1978**,** pp 34-36).

Modernization projects were of particular importance for minimizing transfer of As, Cd, Hg, Pb, and Zn to the Columbia River and Stoney Creek.

A. The Effluent Treatment Plant (1981)

The plant (ETP) was originally designed to treat contaminated water from lead and zinc operations by neutralizing with lime. An exception was Sewer #7, which carried strongly acidic solution from lead sinter-plant offgas cooling and scrubbing to the Columbia River until 1998. In the ETP, neutralization with lime generated a precipitate that was recovered by thickening. Neutralized thickener overflow liquor carried what was not precipitated, which flowed by sewer to the Columbia River.

Figure 22 shows the ETP thickener under construction. The thickener separated most of the solids away from liquid by decantation. Pulp density of the thickener underflow solids was maximized by recycling a major portion of these solids back to neutralization. A portion of the thickened sludge was either returned to the smelter or stored on site. About 18,500 tons of ETP sludge were produced from 1986 through 1990, of which about 5,400 tons were recycled (Cominco, 1991, TECK 0369275).

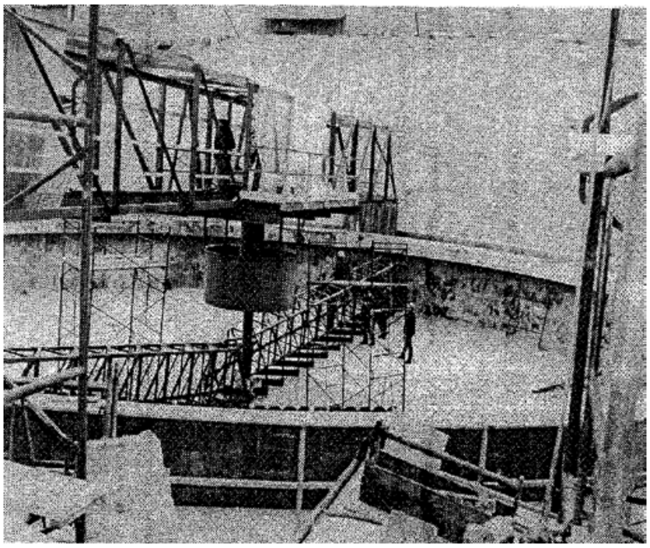

Figure 22. Construction of the effluent-treatment-plant thickener to collect heavy-metal precipitate from waste water (Fish, 1981, p 52)

Over the following decades, Trail 1) continued to improve the efficiency of metal precipitation in the ETP plant, 2) implemented process modifications to create less waste per ton of feedstock, 3) routed additional plant discharge streams to ETP feed, 4) expanded ETP capacity, 5) captured plant runoff, 6) added ferric iron to increase capture of arsenic, and 7) added TMT (trimercapto-s-triazine trisodium salt) to increase capture of mercury.

By 1991 there were five major sources for effluent feeds to the ETP: lead smelter, zinc operations, refinery (including refinery scrubber and silver refinery cooling water), copper products, and No. 13 Lagoon. The lead smelter, zinc operations, and copper products accounted for 97% of ETP sludge production: 34%, 40%, and 23%, respectively (Cominco, 1991, TECK 0369274).

Problems related to the ETP plant included the following:

- Mercury entering the ETP behaved inconsistently, in that this impurity occasionally passed through the ETP into the Columbia River (Cominco, 1997, TECK 0113293). Research was therefore undertaken to correct this problem, which likely resulted in the use of TMT sulfide reagent to more completely precipitate the mercury.

- The majority of the precipitated solids were put into storage due to difficulties in finding a suitable means to process them at Trail. This growing stockpile had its own set of environmental problems (Cominco, 1991, TECK 0369266). By 1995, the stockpile of ETP sludge (28% Zn) had grown to at least 41,000 dry tons (Cominco, 1995, TECK 0341989).

- The high mercury content of ETP sludge restricted its treatment through the roasters, and created an environmental concern over the ETP sludge stockpile (Cominco, 1991, TECK 0369275). Mercury content of ETP sludge inventory in 1991 was about 0.15% (Cominco, 1991, TECK 0369283).

- An unusual feed input could cause settling problems in the clarifier. A major clarifier upset could cause a spill situation to the Columbia River (Cominco, 1990, TECK 0359487).

- The flow of effluents to the ETP increased far beyond its design capacity. This high loading resulted in process upsets which adversely affected treated effluent quality (Cominco, 1991, TECK 0309266).

Condensed water purge from the Kivcet gas scrubber passed through an SO_2 stripping tower before being pumped to the effluent treatment plant.

B. Modernization of the Zinc Refinery (1981)

The principal environmental benefit of modernizing the zinc refinery was minimizing both the potential for spills and the likelihood that any spill would leave the plant.

C. Boliden Norzink Process (1981)

To meet sulfuric acid quality standards, it became necessary to remove mercury from the sulfur dioxide gas before it entered the sulfuric acid plants. The Boliden Norzink process reacted mercury-contaminated pre-scrubbed gas with recirculating solution of mercuric chloride. The mercuric – mercurous chloride couple captured most of the mercury vapor and mist that had passed through the Glover Tower and the mist eliminators.

The result was an impure mercurous chloride byproduct (calomel), most of which was inventoried. The mercury content of the sulfuric acid product was decreased to 0.5 to 0.7 ppm Hg, a level equivalent to about 1.5% of the total mercury input to the roasters (Magoon / Cominco, 1989, p 219). Before initiation of calomel recovery, mercury content of the acid averaged on the order of 7 ppm, i.e., about ten-fold higher than when the Boliden Norzink plant was brought on line.[15]

D. Electrolyte Purge Recycle (1981)

Trail installed a pipeline to carry stripped zinc electrolyte to the fertilizer plant at Warfield for use in manufacturing phosphoric acid. A purge of zinc solution was necessary to control the magnesium content of the electrolyte (Fish, 1981, p 52). However, the addition of stripped electrolyte to the fertilizer circuit proved to have an unexpected deleterious effect on fertilizer product grade. A new clarifier was constructed in 1984 to allow for increased consumption of stripped electrolyte in the fertilizer operation (ECY-000558).

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[15] This latter value (7 pm) was sensitive to the mercury content of the roaster feed.

E. Halide Leach Plant (1982)

Zinc oxide fumed from BF slag is high in halide content, e.g. chloride and fluoride, which causes problems during zinc electrolysis. This fume therefore was leached for its zinc content separately from the zinc oxide derived from roasting zinc concentrate.

To minimize process constraints associated with halides, Cominco built a plant in 1982 to remove halides from fume ZnO. Before leaching with spent electrolyte to extract zinc, the fume was leached with soda ash solution. Soda ash selectively dissolved most of the halides, along with a portion of the arsenic, cadmium, and thallium. The upgraded oxide dust was then leached in a single circuit with spent electrolyte, along with ZnO roasted calcine.

The halide waste liquor from the soda ash leach discharged to the Columbia River. This filtrate was high in thallium, cadmium, and arsenic; therefore, Cominco developed a means to treat this effluent. Implementation was delayed until it could be confirmed that the Kivcet smelter could handle the output metals (Cominco, 1997, TECK 0113262).[16]

The Halide Leach effluent stream continues to be discharged without treatment because it is controlled by pH and its turbidity is monitored. This approach minimizes the Cd and As in the effluent and the stream continues to meet permit requirements. A treatment process has been devised but not implemented due to its high cost, both capital and operating, and cannot be justified as long as we meet our permit (JFH, 30Nov10 Expert Opinion, p 20).

F. Copper Products Plant (1989)

An improved copper products process reduced copper and arsenic effluent loadings (TECK 0068596).

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[16] I do not know whether the Kivcet furnace was eventually able to recycle metals recovered when treating rather than discarding the halide-leach waste liquor.

With respect to arsenic, the Copper Products Plant is important. The inputs, operation, and capacity of the Specialty Products Plant and Copper Products Plant dictate what happens to the arsenic stockpile. The Kivcet smelter was not expected to affect the arsenic stockpile (Cominco, 1995, TECK 0095487).

In 1989, about 500 tonnes of arsenic entered the sinter plant. This arsenic ended up distributed between the silver refinery dust (≈310 tons), softening slag (≈210 tons), waste slag (≈22 tons), and product copper matte (≈11 tons). Subsequent processing of the refinery dust and softening slag produced arsenical lead product (Larouche / Cominco, 1989, pp 103-109).

Trail also produced high-purity arsenic products for the electronics industry, as well as copper arsenate for wood treatment. Arsenic oxide from treatment of Betts process anode slime provided the feedstock for electronic products. For details, see Hirsch / Cominco, 1980, p 360.

The two raw materials used to produce copper arsenate were copper sulfate (derived from copper matte) and high-As dust. The arsenic-rich dust came from the silver refinery (fumed off when processing Betts slimes), and from rotary-furnace rejection of arsenic and antimony from lead bullion (Davies, 1988, ECI-000513, Set #7). Test samples of copper arsenate were planned for shipment to a customer in 1991 (Ball, 1990, TECK 0110486) .

Effluent from the copper products plant resulted in spikes of copper and arsenic reporting to the ETP (Cominco, 1997, TECK 0113291). Installing a cyclone on the copper sulfate drier vent was expected to provide a significant reduction in copper input to the ETP.

At Trail, more arsenic may be received in feedstocks than can be sold in product. Arsenic fuming from antimonial lead alloy furnaces can be recovered in a baghouse, then fused to a slag which is stockpiled in a special protected area.

G. Thallium Removal Plant (between 1989 and 1998)

The Thallium Removal Plant mentioned here was started in 1989 but shut down within weeks as a failed process. It was re-developed and put on-line in the Drossing Plant in 1998. Actual thallium removal started in 1993 with a Thallium Dichromate Precipitation Process in the Cadmium Plant (JFH, Expert Opinion, 30Nov10, p 19).

In 1991, thallium (Tl) input to Trail metallurgical operations was about 50 tons per year. Shutting down the Sullivan mine decreased Trail's thallium input by 65%. (Cominco, 1995, TECK 0095485). About 1 tpd of zinc dust precipitated thallium, nickel, and cadmium from spent cadmium solution. Expected output was 200 to 300 tons/year of thallium-nickel residue assaying 10 to 20% Tl. This residue was then to be refined in the new cadmium plant (Cominco, 1991, TECK 0337422).

The thallium removal plant improved the efficiency of thallium removal from process waste waters. No details were found on how these improved efficiencies were attained, or on the magnitude of these efficiencies (Cominco, 2007, Teck 0058577).

A disadvantage of using lime in the ETP was the inability of this reagent to precipitate thallium (Cominco, 1995, TECK 0341989). Thallium, like sodium, forms a soluble hydroxide, but like mercury, forms an insoluble sulfide.

Historically, Trail discharged about 20 tons of thallium per year to the Columbia River; the average in 1997 was about 8 tpy (D'Odorico / Cominco, 1997, TECK 0104762). Cominco examined in some detail the feasibility of producing thallium nitrate and thallium dichromate byproduct specialty chemicals (Knoerr / Cominco, TECK 0700834). Mr. Knoerr noted that current storage facilities were nearing capacity.

H. Elimination of the Electrolyte Purge Discharge (1990)

Elimination of electrolyte stripping discharge resulted in reduced zinc effluent loading to the Columbia River (TECK 0068596). This development was a major improvement, e.g., in the early 1970s, the discharge rate of acidic 15 - 18 gpl Zn stripped electrolyte was approximately 35,000 gallons/day; an equal quantity was converted to fertilizer micronutrient.

The 15-18 g/L Zn in strip solution only became the norm in 1968-69 as a) treatment of Pine Point Zn concentrate with its high magnesium content and b) corroding cooling coils in the aging tankrooms required more stripping volume to be treated, beyond the ability of the strippers to remove Zn to its former lower concentrations (JFH Expert Opinion, 30Nov10, p 16).

A means for productively consuming zinc tankhouse electrolyte purge had been developed at Trail in 1947. One added aqueous ammonia to the stripped electrolyte, cooled, then added ammonium bisulfite. A complex of zinc ammonium sulfite precipitated, which was returned to the roasters (King, 1950, p 2246).

This sulfite process operated until 1964 to remove at least a portion of the zinc from the purged electrolyte – a process limited only by Zn economics rather than by fertilizer demand. By Zn economics is meant whether the price of zinc was sufficiently high to justify the cost of recovering zinc and other values in the electrolyte purge. In 1964, this process was abandoned. That year Trail implemented its ZnMnS precipitation process that operated until 1989 to recover Zn from at least a portion (Tech 1123437, 1977) of the purge – again limited only by Zn economics. After 1989, this latter process was also abandoned. Thereafter at least a portion of the purge was piped to the phosphate fertilizer plant for its zinc and acid content (abstracted from JFH's 30Nov10 Expert Opinion, p 16, then edited).

I. Collection and Treatment of Surface-Water Runoff (1993)

A drainage control system routed storm water and washdown to the ETP, which involved paving and guttering a large area of the site. Traffic patterns were altered to keep industrial vehicles on site, and to limit exposure of the plant site to light vehicles (Cominco, 2007, TECK 0058578).

J. Indirect Heat Exchanger for #7 Sewer in the Lead Smelter (1994)

Installation of an indirect heat exchanger in the lead smelter separated process water from cooling water, i.e., a closed-cycle gas cooling system. The result was reduced levels of mercury and other metals discharged into the Columbia River via Sewer #7 (Cominco, 2007, TECK 0058577).

…This was effectively the elimination of the major contaminants Hg and As in this sewer… even though it ran acidic solution to river until 1998 {as noted in Section XIV-Q below}. {JFH} *calculated the 1993 to 1994 drop in Hg in #7 sewer was 97.7%* {JFH referred to an 2010 Excel Workbook that I understand will be provided} (JFH, Expert Opinion, 30Nov10, p19).

K. Effluent Treatment Plant Lagoon (1994)

Collection systems for storm water were upgraded, providing sufficient surge capacity to maintain a reasonable and steady flow to the ETP plant (Cominco 2007, 0058578).

L. TMT Addition for Mercury Precipitation (1995)

TMT is an organic reagent that contains sulfide. Cominco added TMT to the first tank in the ETP plant to precipitate mercury as its insoluble sulfide (ECI-001834).

M. Eliminating Slag Discharge to the Columbia River (1995 - 1997)

A closed-circuit granulation and dewatering system to collect all of the slag was scheduled for construction (Kenyon, 1995, ECY-00968). *Slag discharge to the Columbia was 99.5% eliminated in July 1995; only a few hundred tons discharged in 1996-1997 as Cominco stabilized the closed granulation system. After that time barren slag continued to be produced but was stockpiled, not put into the river. The stockpile was retreated through #2 SFF starting in 2000 to make a commercial product now called Ferrous Granules* (JFH, Expert Opinion, 30Nov10, p 19).

In 1996, granulated fumed slag slurry was diverted to a collection pond; this diversion was completed in 1997 (Cominco, TECK 0715785). Discharge conveyers were installed so that the slag could be trucked to containment pads. The result was a 99.5% reduction of slag particulate loading of the Columbia River (Cominco, 1996, TECK 1087693; Cominco, 1997, TECK 0113261).

Cominco found a use and a market for its slag, which was supplied to several cement plants as a key ingredient to manufacture Portland cement (Kenyon, 1998, p 549).

N. Treatment of Copper Matte Granulation Water (1996)

Water used to granulate copper matte discharged directly to the Columbia River prior to 1996. This water contributed to effluent toxicity due to cadmium content. A pumping system was therefore installed to deliver this waste to the ETP (Cominco, 1997, TECK 0113292).

O. Roof Drains and Perimeter Drainage (1997)

Plant modifications were targeted for completion in 1997 to divert roof and perimeter drainage, which can be contaminated, to the ETP rather than to *soakaways* (Cominco, 1997, TECK 0113293). Research was therefore undertaken to correct this problem.

P. Start-up of the Kivcet Smelter (1997)

In 1997, Trail's Kivcet lead smelter was commissioned, and became fully operational in 1999 (Report by G3 Consulting, 2001, CCT1 000625). Cominco had initially attempted to use the QSL continuous lead smelting process. The QSL process was unsuccessful in handling feedstocks that were very high in residue, rather than sulfide, content. Blast-furnace smelting continued to operate during start-up of both the QSL and Kivcet processes.

Kivcet smelting replaced the sinter plant, the blast furnaces, and the slag fuming furnaces with new technology to produce lead bullion. Kivcet smelting integrated the various smelting steps to substantially decrease dust evolution. Fugitive emissions were also decreased, especially those associated with sintering BF feed. Sewer #7 was eliminated in 1998.

Cominco summarized these improvements in its August 1997 <u>Effluent Management Plan</u> (TECK 0113291); see Figure 23:

> *The new lead smelter…will achieve a major reduction in dust emissions, which can impact the river directly as fall out and via surface runoff. It includes a closed circuit slag granulation system that eliminates any discharge of slag to the river. A*

> *fourth sewer (07 sewer) becomes redundant, as there is no need for gas scrubbing* [of sinter-plant offgas]… *In addition, the open storage areas associated with the old* plants *will be eliminated so that spills historically caused by snow melt and precipitation will be prevented. The new smelter is expected to be in full production by the second half of 1997*.

Successful start-up of the Kivcet process decreased stack emissions of particulate matter, lead arsenic, mercury, fluoride, and SO_2 by 68 to 98% (Cominco, 2007, TECK 0058578).

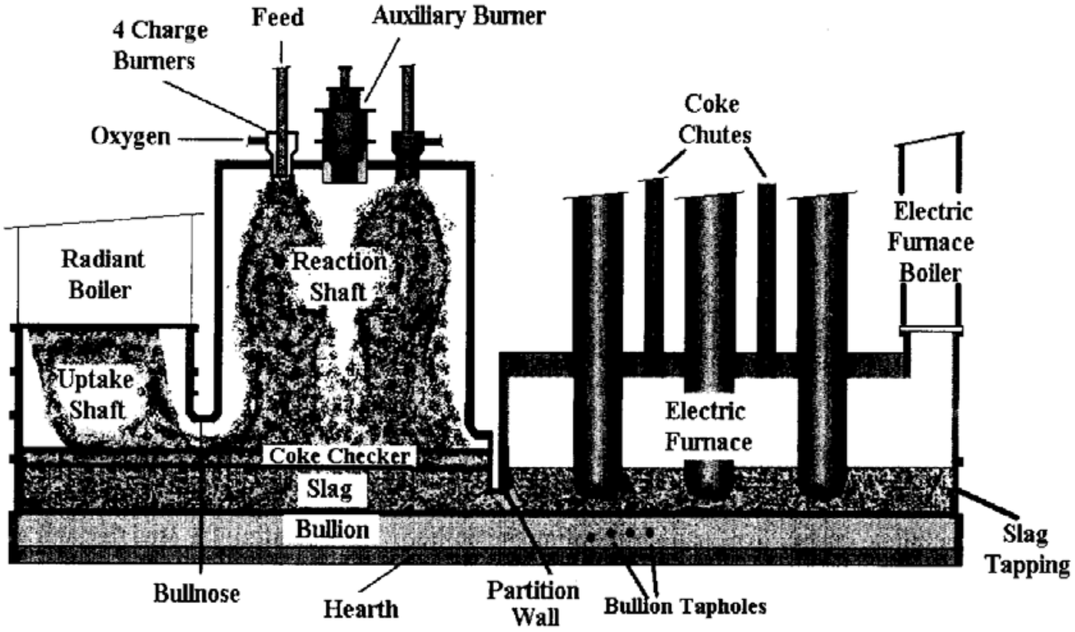

Figure 23. Trail's Kivcet furnace (Ashman, 2000, p 175)

Processing of stockpiled materials: Beginning in 1983, the lead smelter could no longer keep up with processing the zinc leach residue, which had to be stockpiled (Werniuk, 2000, ECY3 00000807); *from a business point of view, it is preferable to minimize inventories so as to improve the timing of metals recovery* (de Groot / Cominco, 2000, p 315). By 1999, continuing to 2005, residue treatment was again in balance with production from zinc operations (Ashman, 2000, p 183; Heale, 2008, p 54). Sufficient fuming capacity was also available to process stockpiled BF slag (Heale, 2008, p 54).

The Kivcet smelter had been expected to consume the zinc residue stockpile by 2010 (Cominco, 1995, TECK 0095486). The furnace also has the capability of consuming contaminated soil (Cominco, 1995, TECK 0095489). A key was economic viability.

Consuming Zn Plant Fe residues by 2010 was infeasible both economically and due to several process constraints including copper and zinc into KIVCET; copper because KIVCET removed sulfur more completely than expected and zinc because it turned out to be one of the factors causing accretions in the electric furnace. Both constraints are being addressed and processing does continue at a reduced rate; these Fe residues are now forecast to be consumed by 2016 (JFH 30Nov10 Expert Opinion. P 20).

Handling of Kivcet offgas: Furnace offgas passes through a boiler, Cottrell (590 F; 310 C), a spray tower (150 F; 65 C), then to a packed cooling tower (65 F; 19 C), prior to the acid plant (Ashman, 2000, p 177). Dust caught by the boiler and the Cottrells is recycled back to the Kivcet charge burners.

Essentially all of the Hg is vaporized into a SO_2 gas stream from which the Hg is efficiently captured by water cooling/scrubbing following which the gas is cleaned by the Norzink treatment. Between scrubbing and Norzink treatment, elemental mercury is condensed in the transport duct, collected, and sold separately. Finally, the mercury-bearing scrubber solution is sent to effluent treatment (the ETP) where the mercury is removed into the ETP sludge and recycled to the KIVCET and to the roasters to force it into the Norzink plant for recovery (JFH’s 30Nov10 Expert Opinion, p 18).

Q. Elimination of Sewer #7 Discharge (1998)

Sewer #7, which discharged to the Columbia River, carried strongly acidic solution from lead sinter-plant offgas cooling and scrubbing, which in 1977 included 45% of the Pb, 40% of the Cd, and 10% of the Hg discharged from the Cominco complex. This sewer was the only one (of 12) that was not renovated in the early 1980s to flow into the ETP plant.

Sewer #7 continued to handle scrubbing water from ammonia absorption of SO_2 from sinter-plant offgas. Even though Sewer #7 was

> the most highly contaminated of all the individual sewers, its contents continued to flow to the Columbia River for over a decade after the other sewers had been diverted to the ETP plant. For further details, refer to Section XV (The Sewers).

R. Opinions from Section XIV

Opinion #44 (Contested): Filtrate waste from the Halide Leach Plant was high in thallium, cadmium and arsenic content. A procedure to remove thallium, cadmium, and arsenic from halide leach effluent was developed at Trail, the implementation of which awaited demonstration that the Kivcet smelter would be able to handle the thallium, arsenic, and fluoride.

JFH's *Expert Opinion* (p 18) included the following critique of Opinion #44 above:

> *Disagree. This opinion is misleading. The filtrate from the Halide Leach Plant (actually known as the Zn Fume Leach plant in Trail Ops) does contain thallium, cadmium, and arsenic but these are not "high" whatever that means. They met and continue to meet the plant design specifications and when discharged via #3 Combined sewer that stream meets the permit levels for all these metals. The "..procedure to remove…" refers to design of a second effluent treatment plant, an investment which has not been made because this effluent continues to meet regulatory requirements.*

I suggest the following. Opinion #44 means exactly what it says, which includes that stated in Cominco's 1997 Trail Operations *Effluent Management Plant* (TECK 0113262):

> *Fume Leach Filtrate*: ***This filtrate is high in thallium, cadmium and arsenic*** *and is a purge for fluoride from the plant. Research has developed a process and conducted successful test work to treat this effluent…*
> *Benefit: Reduced lead, cadmium and thallium to the river through Combined III.*

Opinion #45 (Contested): The mercury content of material fed to the Kivcet furnace was efficiently captured by water cooling / scrubbing, followed by Norzink treatment. Mercury-containing Kivcet feed materials included lead concentrates and ETP sludge.

JFH's *Expert Opinion* (p 18) included the following critique of Opinion #45 above:

> *Disagree. This opinion is incomplete. The mercury content of material fed to the KIVCET furnace is*

> *effectively all vaporized into the SO2 gas stream which is (i.e. not was but continues to be) efficiently captured by water cooling/scrubbing following which the gas is cleaned by the Norzink treatment. Between scrubbing and Norzink treatment, elemental mercury is condensed in the transport duct, collected and sold separately. Finally, the mercury bearing scrubber solution is sent to effluent treatment (the ETP) where the mercury is removed into the ETP sludge and recycled to the KIVCET and to the Roasters to force it to the Norzink plant for recovery.*

Opinion #45 (Includes JFH findings): The mercury content of material fed to the Kivcet furnace is efficiently captured by water cooling / scrubbing, followed by Norzink treatment. Mercury-containing Kivcet feed materials included lead concentrates and ETP sludge.

More specifically, essentially all of the Hg is vaporized into a SO_2 gas stream from which the Hg is efficiently captured by water cooling/scrubbing following which the gas is cleaned by the Norzink treatment. Between scrubbing and Norzink treatment, elemental mercury is condensed in the transport duct, collected, and sold separately. Finally, the mercury-bearing scrubber solution is sent to effluent treatment (the ETP) where the mercury is removed into the ETP sludge and recycled to the KIVCET and to the roasters to force it into the Norzink plant for recovery (JFH's Expert Opinion, 30Nov10, p 18).

XV. THE SEWERS

Liquid and slurried solid wastes were discharged, primarily into the Columbia, using sewers; see Figures 24 and 25. In Figure 24, effluents can be seen discharging into the Columbia River in the middle of the left side of the photograph.

Figure 24. Discharge of effluents from Trail metallurgical sewers into the Columbia River in 1927 (B.C. Archives)

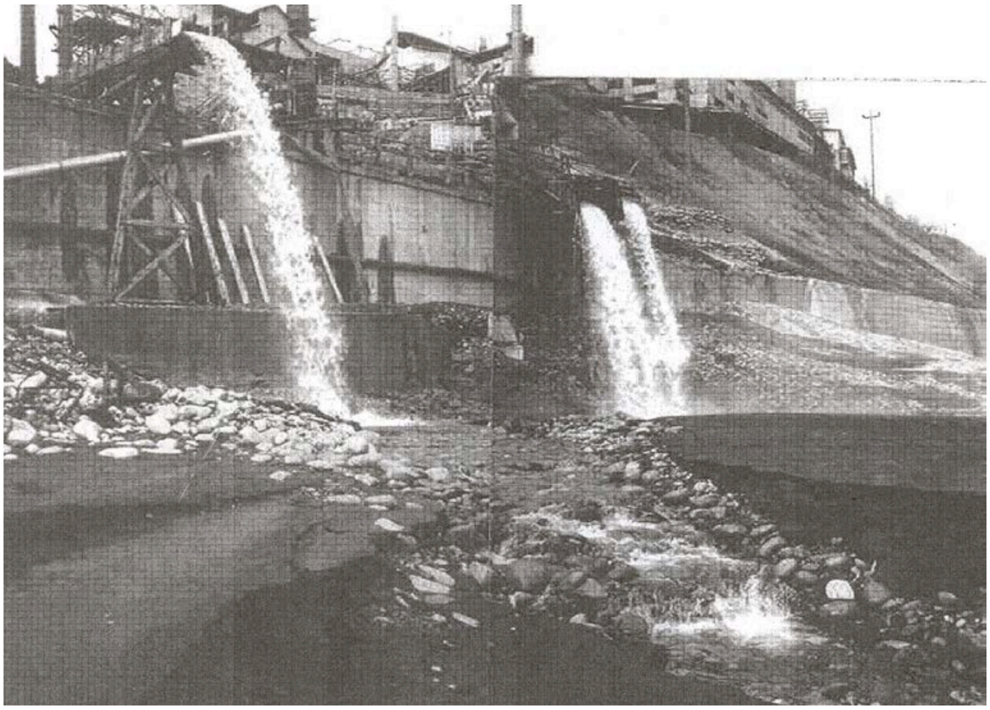

Figure 25. Cominco Metals slag discharge from Sewer #1 on the west bank of the Columbia River just upstream from the Highway 3 bridge (Nener, 1992, p 4,TECK 0715504)

Recall from Section XIV above that the B.C. MoE published in two phases (1977 and 1979) the *Kootenay Air and Water Quality Study*. These reports provide details on the contents of the sewers that carried Trail's wastes into the Columbia River and Stoney Creek. Phase 1 also provides useful process flow diagrams (Figures 8-8 through 8-13). Without Cominco's full cooperation, I doubt that such clear and professionally prepared diagrams would have been prepared.

A significant shortcoming of the B.C. MoE Phase 1 Study was that the small-diameter tubing used for sample collection (1972 to 1975) did not achieve representative sampling of suspended material.

> *The results reported for total constituent are probably not accurate, and… remarks will apply mostly to results from dissolved constituents* (1977, p 32).

Sewer sampling procedures used in the B.C. MoE Phase 2 Study were much improved.

The only metals entering Stoney Creek that are accounted for in this report are mercury and zinc. Mercury was in Trail's sulfuric acid used to produce fertilizer. Zinc electrolyte byproduct was delivered to the fertilizer plant as a source of both sulfuric acid and zinc micronutrient.

A. Findings on the 12 Sewers, as Detailed in the B.C. MoE Phase 2 Study

- **Sewers #1, #3, #4, #9, and #10** outflows, which discharged into the Columbia River, were relatively uncontaminated. These effluents included indirect cooling water, overflow from the lead-BF slag pond, wash-down water, solution containing tellurium from processing Betts slimes, and nitrate liquor from precious-metal refining. These five sewers combined accounted for 4% of total lead discharged from Trail operations in 1977.[17]

- **Sewer #2** flushed fumed slag to the Columbia River using cooling water from the lead-BF cooling jacket. Granulated and blast furnace

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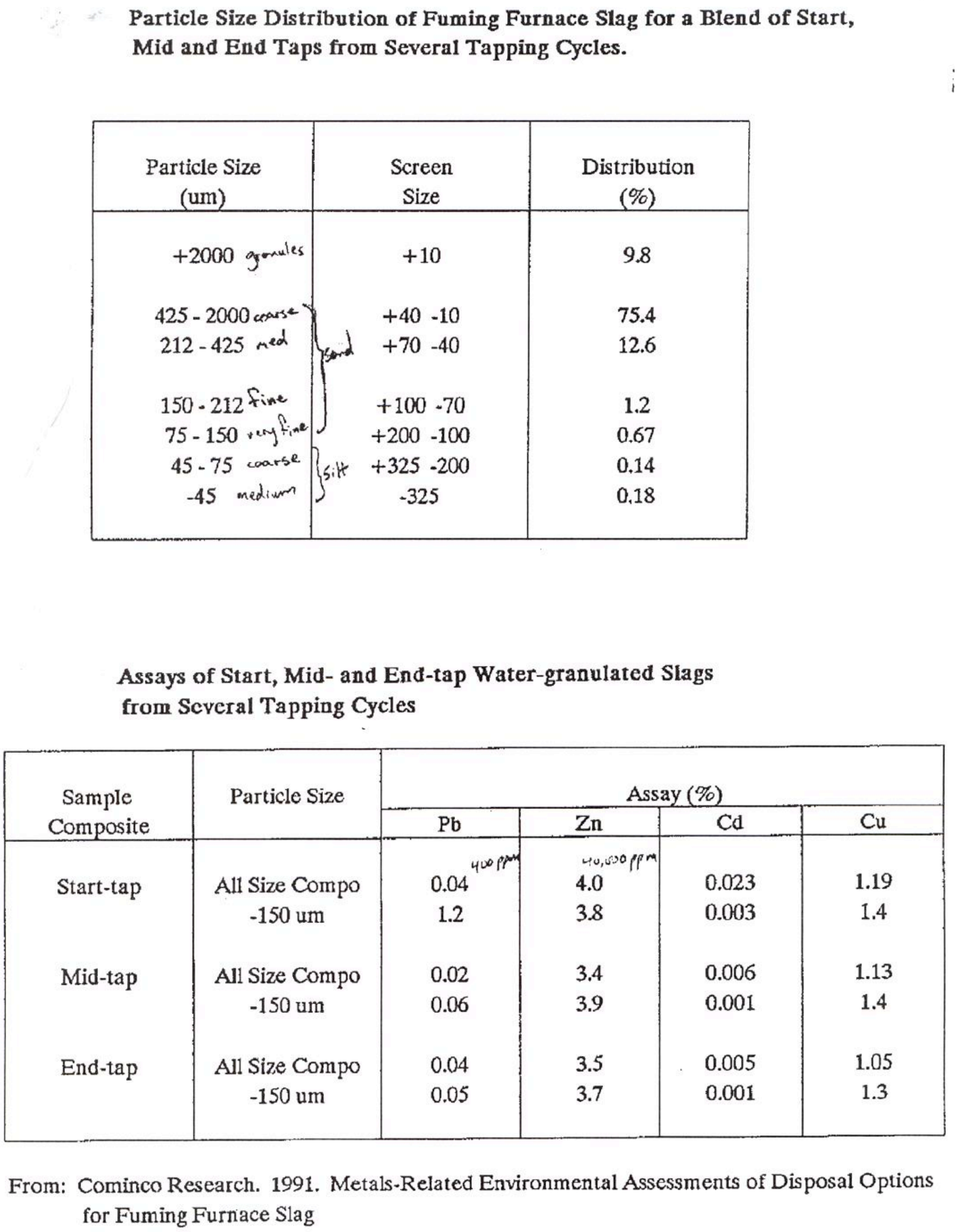
[17] The percentages of total metal discharges to the river for each metal carried in each sewer in 1977, as presented in the B.C. MoE Phase 2 study, were calculated by Environmental Control, Cominco Ltd., at Trail.

slag produced by smelting lead at Trail included the following properties:

1. Typical specific wet weight range of fumed granulated slag: 117 to 130 pounds per cubic foot (pcf), with in excess of 180 pcf occasionally recorded (Cominco, 2007, TECK 0058571). Fumed slag at Trail was granulated.
2. Fumed slag is coarse- to medium-grained sand-sized particle that is black in color and has the appearance of obsidian (Cominco, 2007, TECK 0058572).
3. Up to 1% of the granulated slag consisted of fine particles (minus 150 micron) that can break into an eggshell- and needle-like morphology. These fines remain suspended in the granulation water for extended periods (Cominco Research, 1991, TECK 0338636).
4. Grain size of fumed slag is well-sorted sand-sized particles containing 0.1 to 0.3% of fines having diameters less than 75 microns (Cominco, 2007, TECK 0058572). See Figure 26 in Section XV-B below for additional details.
5. Composition of Trail's granulated slags from lead smelting – blast furnace and fumed – varied in composition. Reasons for this variation included:
    - Upgrading of operating practice with experience over the years.
    - Variations in the ratio of the major gangue constituents.
    - Variation of slag composition as a function of particle size.
    - Variation of slag composition from start to finish during granulation.
6. The silica (SiO_2) concentration of Trail's fumed slag was reported in 2007 as about 31% (Cominco, TECK 0058572). Silica content recorded in historical analyses of the fumed slag (1931 – 1994) ranges from 26 to 30% SiO_2. See Spreadsheet 5 for Trail fumed slag analyses found in literature and documents. Typical SiO_2 in 1992 was 26 to 28% (Cominco, TECK 0338545). Silica analyses in BF slag in 1922 and 1923 were 15.8 and 18% respectively (Spreadsheet 5). Trail's lead and copper blast furnace slag, to my knowledge, was granulated beginning in the early 1900s.

7. The lime (CaO) concentration of Trail's fumed slag was reported in 2007 as about 15% (Cominco, TECK 0058572). Lime content recorded in historical analyses of the fumed slag (1937 – 1994) range from 9 to 17% CaO. See Spreadsheet 5 for Trail fumed slag analyses found in literature and documents. Typical CaO in fumed slag in 1992 was 14 to 16% (Cominco, TECK 0338545). Lime in BF slag in historical analyses between 1922 and 1925 was 6 to 10% (Spreadsheet 5).
8. The iron (Fe) concentration of Trail's fumed slag was reported in 2007 as about 30% (Cominco, TECK 0058572). Iron content recorded in historical analyses of the fumed slag (1937 – 1994) ranges from 31 to 37% Fe. See Spreadsheet 5 for Trail fumed slag analyses found in literature and documents. Typical Fe in fumed slag in 1992 was 33 to 34% (Cominco, TECK 0338545). Iron in BF slag between 1922 and 1925 in historical analyses was 31 to 33% (Spreadsheet 5).
9. Alumina (Al_2O_3) in a 1923 analysis in BF slag was 3%. Fumed slag in 1954 was 8.5% Al_2O_3. Typical alumina in fumed slag in 1992 was 3 to 5% (Cominco, TECK 0338545).
10. Analyses of lesser fumed slag constituents reported by Cominco in 2007 (TECK 0058572) are as follows: zinc 2.6%; lead 0.1%; arsenic 0.01%; cadmium 0.001%; antimony 0.003%; copper 0.5%; potassium 0.6%; magnesium 0.5%; manganese 0.5%; and sodium 1.1%.
11. Zinc variability in Trail's fumed slag was 2.3 to 3.4% (Spreadsheet #5). Typical zinc in 1992 in fumed slag was 2.5 to 3.5% (Cominco, TECK 0338545). Blast furnace slag (unfumed) was much higher in zinc content (14 to 22% between 1920 and 1930; see Spreadsheet #5).
12. Lead variability in Trail's fumed slag was 0.03% to 0.20% (Spreadsheet #5). Blast furnace slag (unfumed) was much higher in lead content (1.2 to 2.4% between 1920 and 1930; see Spreadsheet #5).
13. Arsenic variability in Trail's fumed slag between 1984 and 1995 was 0.008% to 0.017% (Spreadsheet #5). During the 1920s, blast furnace slag reportedly contained about 0.15% As (Spreadsheet 5).

14. Cadmium variability in Trail's fumed slag was <0.0006% to 0.002% (Spreadsheet #5). Assays taken in 1991 of fumed slag granules during tapping varied from 0.001 to 0.023% Cd (Cominco Research, TECK 0338651). Typical cadmium in 1992 in fumed slag was 0.002% (Spreadsheet #5). During the 1920s, blast furnace slag reportedly contained about 0.01% Cd (Spreadsheet 5).
15. An additional complication is that the analysis of slag produced during fuming – a batch process – varies not only from start to finish, but also depends on particle size; see Figure 26. For example, the lead content of the fine slag granules (smaller than 150 microns) ranged from 1.2% Pb during the first slag tap to 0.05% Pb in the last slag tap. The overall slag lead content (average of all particle sizes) was reasonably constant (0.02 to 0.04%). See Cominco Research document TECK 0338651 (1991) for additional details.
16. Mercury is so volatile at slag-granulation temperatures that mercury is not a significant constituent in granulated slag. This wording is mine, but it reflects the gist of Cominco's 2007 finding (TECK 0058572).
17. The granulated slag particles are vitrified into a glass-like matrix (Cominco, 2007, TECK 0058572).



Particle Size Distribution of Fuming Furnace Slag for a Blend of Start, Mid and End Taps from Several Tapping Cycles.

Particle Size (um)	Screen Size	Distribution (%)
+2000 granules	+10	9.8
425 - 2000 coarse sand	+40 -10	75.4
212 - 425 med	+70 -40	12.6
150 - 212 fine	+100 -70	1.2
75 - 150 very fine	+200 -100	0.67
45 - 75 coarse silt	+325 -200	0.14
-45 medium	-325	0.18

Assays of Start, Mid- and End-tap Water-granulated Slags from Several Tapping Cycles

Sample Composite	Particle Size	Assay (%)			
		Pb	Zn	Cd	Cu
Start-tap	All Size Compo	0.04 400 ppm	4.0 40,000 ppm	0.023	1.19
	-150 um	1.2	3.8	0.003	1.4
Mid-tap	All Size Compo	0.02	3.4	0.006	1.13
	-150 um	0.06	3.9	0.001	1.4
End-tap	All Size Compo	0.04	3.5	0.005	1.05
	-150 um	0.05	3.7	0.001	1.3

From: Cominco Research. 1991. Metals-Related Environmental Assessments of Disposal Options for Fuming Furnace Slag

Figure 26. Fumed slag particle size distribution and analyses at start, middle, and end of tapping, from a Cominco document on slag disposal options (1991, TECK 0715529)

- **Sewer #5** mainly carried clarified aqueous effluent from lime neutralization of effluent generated when scrubbing offgas from the rotary driers in the lead sintering plant. This sewer, which discharged to the Columbia River, also carried aqueous waste generated when humidifying sinter-machine exhaust gas, as well as floor washings. Refer back to the Settling Tank on the right side of Figure 21.

Also included were floor washings and indirect cooling water. Sewer #5 carried 33% of the cadmium, 10% of the zinc, 2% of the lead, and 2% of the mercury discharged from Cominco in 1977.

- **Sewer #6** carried effluent to the Columbia River from scrubbing zinc melting furnace offgas, which likely included vapor from a zinc ammonium chloride melt covering. Also included was indirect cooling water, and various washdown and runoff solutions from the zinc sulfide leaching plant. Sewer #6 effluent contained about 9% of the zinc, 4% of the lead, and 2% of the cadmium discharged from the Cominco complex in 1977.
- **Sewer #7** carried strongly acidic solution from lead sinter-plant offgas cooling and scrubbing to the Columbia River. This sewer carried 45% of the Pb, 40% of the Cd, and 10% of the Hg discharged from the Cominco complex in 1977.
- **Sewer #8** also discharged into the Columbia River. This sewer primarily carried acidic stripped zinc electrolyte purge. Sewer #8 also carried effluent from zinc roaster gas scrubbing, plus clarified wash water from the Glover Tower and Cottrells. Also included were indirect cooling water, and various wash solutions This sewer carried major shares of the total Zn (88%[18]), Hg (43%), Cd (25%), and Pb (23%) that exited from Trail operations into the Columbia River.

  The B.C. MoE Phase 1 Study stated that the stripped zinc electrolyte purge was 35,000 gal/day of liquor assaying 18 gpl Zn. The 35,000 gallons gal/day of 18 gpl Zn discharged in 1977 calculates to less than 10% of the total zinc (not including slag) sent to Trail's sewers that year. An equal quantity of stripped electrolyte went to the fertilizer plant to produce ZnMnS micronutrient (1977, pp 25-26). Total effluent volume from all sewers was 55 to 60 million gallons per day (1977, p 31).
- **Sewers #11 and #12** came from the Warfield fertilizer plant. These sewers contained most of the calcium sulfate (gypsum),

---

[18] The percentage of zinc reported as going to the twelve sewers appears to be greater than 100%.

phosphorus, ammonia, and fluoride discharged from the Cominco complex, plus 40% of the mercury and 4% of the lead.

Sewers #11 and #12 discharged into Stoney Creek, 600 meters upstream from the Columbia River, until mid-1978. They were then discharged via a submerged diffuser to the Columbia. However, the new line and diffuser encountered wear problems. While work was undertaken to overcome these problems, Sewers #11 and #12 continued to discharge into Stoney Creek (B.C. MoE Phase 2 *Kootenay Air and Water Quality Study*, 1979, p 51).

B. Rearrangement of Trail's Sewers in the 1980s

By 1985, there were five sewers (TECK 0617717); one, Sewer #7, was a holdover from the earlier days of 12 sewers. Descriptions of these sewers published in 1991 and 1995 include the following (BCE 0001475; TECK 0112310). A more detailed description of Trail sewer permitting history appears in Cominco, 2007, TECK 0058569.

- **Sewer I**: This sewer, which discharged to the Columbia River, collected effluent discharged from the Blast Furnace Pond, the old #2 Sewer, and the fumed slag launder. Most of the water in the Blast Furnace Pond was indirect cooling water. This sewer also carried yard runoff, and contaminated water from granulation of copper matte. Details on fumed slag particle size distribution and analyses, as provided by Cominco in 1991, appear in Figure 26 (TECK 0715529).

  Sewer I was a significant contributor of Cu (15%), as compared to other sources. Considerably more metals were lost to the Columbia River via this source during slag tapping cycles (TECK 0112310).

- **Sewers II and III**: These two sewers, which discharged to the Columbia River, collected the cleaner portions of the process water from the balance of the metallurgical operations. Highly contaminated streams were piped directly to the ETP. Road and plant wash water passed directly into Sewers I, II, and III.

  A portion of contaminated property drainage was stored in a lagoon (#13) for eventual treatment in the ETP plant. A second lagoon (#12) collected contaminated runoff from roadways and material handling areas for eventual ETP processing. These two lagoons were also available to provide surge capacity, should the ETP go down for maintenance or for an operating adjustment.

In addition to carrying outfall solution from the ETP, Sewer III serviced the fume leach plant, pressure leaching, the zinc oxide plant, zinc electrolysis and melting, the lead refinery, and stockpile areas.

Sewer II was a minor source of As and Hg, a negligible source of Tl (thallium), and a significant source of Cd (24%) and Zn (18%). It was a major source of copper (40%) and lead (59%); see TECK 0112310.

Sewer III was a minor source of As, but a major source of Hg (80%) and dissolved thallium (99%). Its Cd, Cu, and Zn content was similar to Sewer II; lead loading was lower (TECK 0112310).

Sewer IV: This sewer collected from the fertilizer plant and Stoney Creek (which flows into the Columbia), which received leachate from a variety of waste and residue landfills. See TECK 0112310, 1996. I understand that Sewer IV discharged into the Columbia River, and that problems encountered with a submerged diffuser in 1978 were rectified.

The 1996 assessment of metal sampling results, as prepared by the B.C. Environmental Protection (Kootenay Region), indicates that Stoney Creek was a major source of As (80%), Cd (52%), and Zn (61%). Most of the Cd and Zn, and half of the As, were in dissolved form, which suggests a groundwater source rather than surface runoff. By 1996, Cominco had discovered that groundwater was indeed seeping into both sides of Stoney Creek, resulting in contamination with Zn, Cd, and As. Work commenced to find a means to divert this outfall into the ETP plant (Cominco, 1997, TECK 0113262). This diversion was completed in 1999, reducing As, Zn, Cd, and ammonia loads to the river (TECK 0068599).

Additional details on mercury output from the fertilizer plant are provided in ECI-000896 and TECK 0079018. It appears that the phosphate rock (700 tons/day in 1989) was providing on the order of 1 tpy of Hg. The balance, on the order of 0.3 tpy Hg, was dissolved in the sulfuric acid (which contained about 0.6 ppm Hg).

1. Cominco ceased producing phosphate-based fertilizer in 1994, which eliminated Warm Springs Mine (Montana) phosphate rock as a mercury source.
2. During 1988-89, Warm Springs rock was unusually high in mercury content. Note the spike in mercury discharged during

this period into Trail's fertilizer operation's sewers, as shown in Figure 27.

3. Prior to installation of the Norzink process in 1981, the mercury content of the sulfuric acid was substantially higher than 0.6 ppm Hg, e.g., about 7 ppm Hg. See the attached *Inputs and Distributions Spreadsheets* for details.

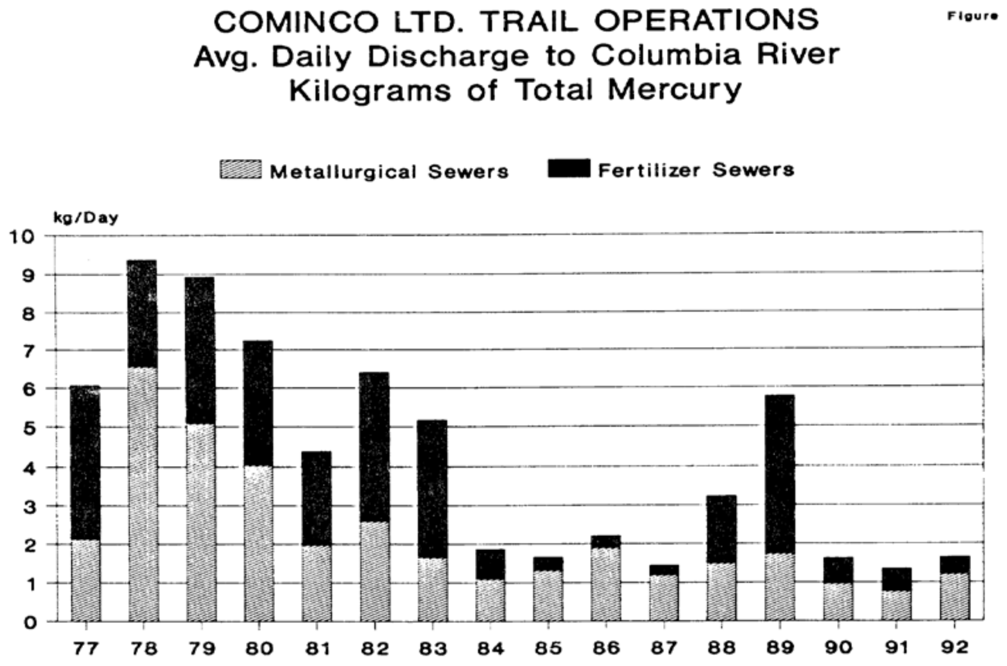


Figure 27. Mercury outfalls (1992 Trail Environmental Report; TECK 0079018)

4. Figure 27 also indicates that even though the Norzink mercury removal plant went on line in 1981, it did not attain consistent mercury capture until 1984.

5. An unknown portion of the mercury entering the fertilizer plant stays with the fertilizer.

- **Sewer #7**: This sewer, which discharged to the Columbia River, survived from the old sewer system. It continued to handle scrubbing water from ammonia absorption of SO_2 from sinter-plant offgas. Even though Sewer #7 was the most highly contaminated of all the individual sewers, its contents flowed to the Columbia River rather than to the ETP plant. Sewer #7 solution was saturated with

SO_2, making individual treatment difficult. Its piping was specially constructed to resist corrosion (BCE 0001494, 1991, p 20).

By 1997, the Kivcet furnace was sufficiently proven to permit shutting down the blast furnaces, along with their sinter-plant feed-preparation facility (TECK 0338974). The Kivcet furnace produced sulfur dioxide of sufficient strength to feed a conventional acid plant, so ammonia scrubbing to concentrate SO_2 was no longer necessary. A difficult metal-contaminated waste was therefore no longer generated, leading to Sewer #7's demise in 1998.

C. Total vs Dissolved Metals, Primarily Discharged to the Columbia River

A substantial portion of the metals discarded by Trail, primarily into the Columbia, were solids; see Figure 28 below. The graphs provide average daily measurements of total and dissolved metal outfalls (Pb, Zn, Cd, As, Cu and Hg) for various periods between 1980 and 1996. Most of the lead and copper discarded to sewer were carried as particulates. A substantial portion of the cadmium and arsenic were dissolved. In regard to zinc, the graph is difficult to read. The graph for mercury outfalls compares metallurgical and fertilizer outfalls for 1980-96 (1997 Trail Effluent Management Plan; TECK 0113283).

D. Opinions from Section XV

Opinion #46 (Not contested): Without Cominco's full cooperation, I doubt that such clear and professionally prepared diagrams would have been prepared by the B.C. MoE, as published in Phase 1 of the *Kootenay Air and Water Quality Study* (1977).

Opinion #47 (Not contested): Figures 8-8 through 8-13 in the B.C. MoE Phase I *Kootenay Air and Water Quality Study* (1977) appear to depict with reasonable accuracy the relationship between Trail's metallurgical operations and its sewers.

Opinion #48 (Contested): Cooling water that does not contact a plant process stream should carry very little of the metals in Trail's feedstocks when discarded into Trail's sewers. In contrast, direct-contact cooling water can be expected to carry process constituents.

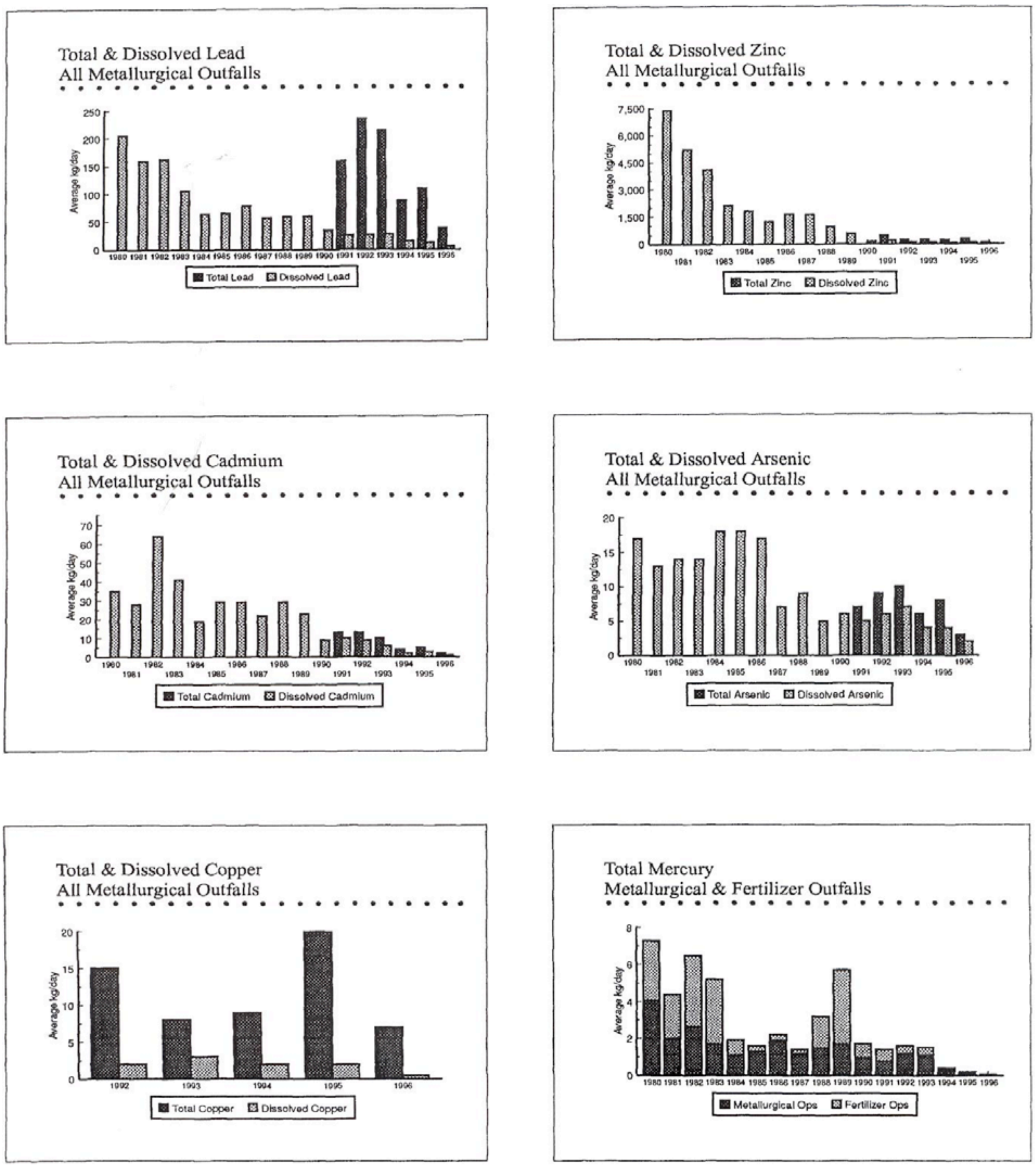
JFH's *Expert Opinion* (p 18) included the following critique of Opinion #48 above:

Disagree. This opinion is incomplete and therefore misleading. It should read "…can be expected to carry process constituents and therefore are all collected and directed to the effluent lagoon and then to the Effluent Treatment Plant".

Opinion #48 (Provides requested addition): Cooling water that does not contact a plant process stream should carry very little of the metals in Trail's feedstocks when discarded into Trail's sewers. In contrast, direct-contact cooling water can be expected to carry process constituents. Beginning in 1981, direct-contact cooling water was directed to the effluent lagoon and then to the Effluent Treatment Plant (ETP) to recovery process constituents.

Opinion #49 (Not contested): The B.C. MoE Phase 2 *Kootenay Air and Water Quality Study* (1979) tabulates total weights of Cd, Hg, Pb and Zn discharged into the Columbia from Trail metallurgical and fertilizer operations in 1977 (Table 23 on pp 169-72). These values, as provided by Cominco, are reasonably consistent with Cominco's 1980 data. Furthermore, these effluent assays are the best data provided from this period. I therefore have relied on these values.

Opinion #50 (Not contested): Prior to smooth operation of the Norzink mercury removal plant, a substantial portion of Trail's fertilizer-plant mercury effluent originated from mercury contained in the plant's sulfuric acid feedstock.



Total & Dissolved Lead
All Metallurgical Outfalls

Total & Dissolved Zinc
All Metallurgical Outfalls

Total & Dissolved Cadmium
All Metallurgical Outfalls

Total & Dissolved Arsenic
All Metallurgical Outfalls

Total & Dissolved Copper
All Metallurgical Outfalls

Total Mercury
Metallurgical & Fertilizer Outfalls

Figure 28. Average daily measurements of total and dissolved metals (Pb, Zn, Cd, As, Cu and Hg) for various periods between 1980 and 1996 (1997 Trail Effluent Management Plan; TECK 0113283)

XVI. INPUTS AND DISTRIBUTIONS SPREADSHEETS

The attached Inputs and Distributions Spreadsheets include estimates of the weight of Pb, Zn, As, Cd, and Hg originating from Trail's metallurgical operations in most years from 1920 to 2005 discharged directly into either the Columbia River or into Stoney Creek. Insufficient data were available to make similar estimates of copper outfall, with the exception of the copper content of the lead BF slag and of the fumed slag. Most of these data used to prepare these estimates were provided by Teck Metals, various environmental authorities, and technical publications. This data proved to be reasonably internally consistent, and credible.

A. Metal Discharges, Primarily to the Columbia River: 1920 to 2005

Results are summarized in Tables 2 and 3.

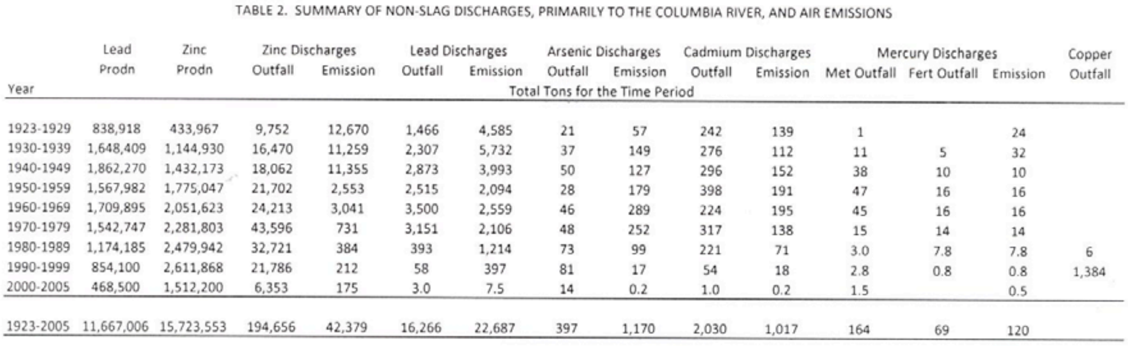


TABLE 2. SUMMARY OF NON-SLAG DISCHARGES, PRIMARILY TO THE COLUMBIA RIVER, AND AIR EMISSIONS

Year	Lead Prodn	Zinc Prodn	Zinc Discharges		Lead Discharges		Arsenic Discharges		Cadmium Discharges		Mercury Discharges			Copper Outfall
			Outfall	Emission	Outfall	Emission	Outfall	Emission	Outfall	Emission	Met Outfall	Fert Outfall	Emission	
	Total Tons for the Time Period													
1923-1929	838,918	433,967	9,752	12,670	1,466	4,585	21	57	242	139	1		24	
1930-1939	1,648,409	1,144,930	16,470	11,259	2,307	5,732	37	149	276	112	11	5	32	
1940-1949	1,862,270	1,432,173	18,062	11,355	2,873	3,993	50	127	296	152	38	10	10	
1950-1959	1,567,982	1,775,047	21,702	2,553	2,515	2,094	28	179	398	191	47	16	16	
1960-1969	1,709,895	2,051,623	24,213	3,041	3,500	2,559	46	289	224	195	45	16	16	
1970-1979	1,542,747	2,281,803	43,596	731	3,151	2,106	48	252	317	138	15	14	14	
1980-1989	1,174,185	2,479,942	32,721	384	393	1,214	73	99	221	71	3.0	7.8	7.8	6
1990-1999	854,100	2,611,868	21,786	212	58	397	81	17	54	18	2.8	0.8	0.8	1,384
2000-2005	468,500	1,512,200	6,353	175	3.0	7.5	14	0.2	1.0	0.2	1.5		0.5	
1923-2005	11,667,006	15,723,553	194,656	42,379	16,266	22,687	397	1,170	2,030	1,017	164	69	120	

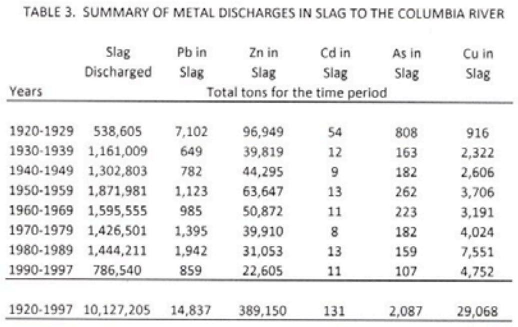


TABLE 3. SUMMARY OF METAL DISCHARGES IN SLAG TO THE COLUMBIA RIVER

Years	Slag Discharged	Pb in Slag	Zn in Slag	Cd in Slag	As in Slag	Cu in Slag
	Total tons for the time period					
1920-1929	538,605	7,102	96,949	54	808	916
1930-1939	1,161,009	649	39,819	12	163	2,322
1940-1949	1,302,803	782	44,295	9	182	2,606
1950-1959	1,871,981	1,123	63,647	13	262	3,706
1960-1969	1,595,555	985	50,872	11	223	3,191
1970-1979	1,426,501	1,395	39,910	8	182	4,024
1980-1989	1,444,211	1,942	31,053	13	159	7,551
1990-1997	786,540	859	22,605	11	107	4,752
1920-1997	10,127,205	14,837	389,150	131	2,087	29,068

B. Sheet 1: Lead Concentrate Analyses

Assays are provided for Sullivan and Red Dog lead concentrates. Average annual custom feedstock assays were not originally available; therefore Sullivan lead concentrate analyses were used to represent the custom feeds. The 1800+ documents provided by JFH have permitted use of many of these values in the updated Spreadsheets.

C. **Sheet 2: Zinc Concentrate Analyses**

Assays are provided for Sullivan, Pine Point, and Red Dog zinc concentrates. Where custom feedstock assays were not discovered, Sullivan zinc concentrate analyses were used. The 1800+ documents provided by JFH were most helpful for updating the Spreadsheets.

D. **Sheet 3: Copper, Lead, Zinc and Cadmium Production**

Estimates of Trail's copper, lead, zinc, and cadmium production (1920 to 2005) are provided for most dates, other than for copper.

E. **Sheet 4: Estimated Feedstock Tonnage (1920 to 2005)**

Estimated annual tonnages of Sullivan, Pine Point, and Red Dog feedstocks are provided.

F. **Sheet 5: Lead Blast Furnace and Fumed Slag Analyses**

Typical fumed (1930 to 2005) slag analyses are provided. Slag entering and leaving inventory is accounted for.

G. **Sheet 6: Estimated Metal Discharges in Slag to the Columbia River**

Annual slag production is provided from 1920 to 2005. Slag entering and leaving inventory is accounted for.

H. **Sheet 7: Production of Sulfuric Acid (100% Basis)**

The primary basis used in Sheet 7 to estimate acid production was available acid-plant capacity. Acid output (1923 – 2004) was based on plant capacity because published data on annual sulfur conversion at Trail were contradictory.

I. **Sheet 8: Summary of Non-Slag Discharges, Primarily to the Columbia River, and Air Emissions**

Emissions and discharge data are provided for Pb, Zn, As, Cd and Hg.

J. Sheet 9: Inventoried and Unaccounted Metals

The difference between the tonnage of feed inputs and the tonnage of (products + outputs + emissions) is material that is in inventory or unaccounted for.

Unaccounted-for material can arise from incorrect feed assays, incorrect feed weights, and undocumented material exiting from Trail's metallurgical facility, e.g., as product, river discharges, emissions, or theft. The 1800+ documents provided by JFH have provided important inventory details for use in the updated Spreadsheets.

K. Sheet 10: Emissions of Metals to Atmosphere

Detailed measured emissions data span from 1980 to 2002. Prior measured emissions values were available in some of the 1800+ documents provided by JFH. Where measured emissions were not available, they were estimated.

L. Sheet 11: Metals Outfalls, Primarily to the Columbia

Detailed measured outfall data span from 1977 to 2005. Prior measured outfall values were available in some of the 1800+ documents provided by JFH. Where measured emissions were not available, they were estimated.

Zinc and mercury discharges from fertilizer operations are compared below to that from metallurgical operations. Depending on the time period, both the Columbia and Stoney Creek were utilized for mercury and zinc disposal.

The metallurgists sent mercury to the fertilizer plant dissolved in sulfuric acid. A portion of the zinc sent to the fertilizer plant for micronutrient went to waste.

The zinc outfall data show:

1977 5,012 tpy metallurgical, 58 tpy fertilizer, 1.2% from fertilizer
Sheet 11 cells J63 and L63

1984 2,718 tpy metallurgical, 58 tpy fertilizer, 2.1% from fertilizer
Sheet 11 cells J70 and L70

1993 1,762 tpy metallurgical, 40 tpy fertilizer, 2.2% from fertilizer
Sheet 11 cells J79 and L79

The mercury outfall data show:

1977 1.11 tpy metallurgical, 1.05 tpy fertilizer, 49% from fertilizer
Sheet 11 cells U65 and V65

1984 0.20 tpy metallurgical, 0.24 tpy fertilizer, 55% from fertilizer
Sheet 11 cells U72 and V72

1993 0.18 tpy metallurgical, 0.15 tpy fertilizer, 45% from fertilizer
Sheet 11 cells U81 and V81

M. Sheet 12: Arsenic Balance

Sheet 12 provides the annual input/output balance for arsenic.

N. Sheet 13: Cadmium Balance

Sheet 13 provides the annual input/output balance for cadmium.

O. Sheet 14: Lead Balance

Sheet 14 provides the annual input/output balance for lead.

P. Sheet 15: Mercury Balance

Sheet 15 provides the annual input/output balance for mercury.

Q. Sheet 16: Zinc Balance

Sheet 16 provides the annual input/output balance for zinc.

R. Sheet 17: Inventory of Slag, Sulfide Residue, and ETP Solids

Sheet 17 provides in-process inventory.

S. Sheet 18: Fertilizer Balance

Sheet 18 provides the Hg inputs and outputs in the fertilizer plant.

T. Sheet 19: Calculation of Slag Volume

Slag height in the Trail's slag dump is calculated a three angles of repose.

U. Explanation of Spreadsheet Details

Explanation of Spreadsheet Details provides the bases used to construct the Spreadsheet.

V. Opinions from Section XVI

Opinion #51 (Contested): Most of the information and data provided by Teck Metals, various environmental authorities, and technical publications were found to be reasonably internally consistent and credible.

JFH's *Expert Opinion* (p 18) included the following critique of Opinion #51 above:

> *Disagree. This opinion is incomplete. Not all "information" obtained from working files in Teck Metals is reliable because it represents a work in progress or an opinion from an individual employee. In particular, the estimation of tail slag was derived from spreadsheets which are internally consistent but are not credible as they were not adjusted to account for available information on inventories. The Teck employee who generated these spreadsheets was using a rough approximation sometimes used as a rule-of-thumb in the plant and he used this approximation without knowledge of its limitations. These spreadsheets were not reviewed with knowledgeable personnel such as metallurgists. This approximation, now being called the Logan formula, produces a significant over-estimate of slag production.*

Opinion #51 (Provides requested addition): Most of the information and data provided by Teck Metals, various environmental authorities, and technical publications were found to be reasonably internally consistent and credible.

Not all "information" obtained from working files in Teck Metals is reliable because it represents a work in progress or an opinion from an individual employee. In particular, the estimation of tail slag was derived from Spreadsheets which are internally consistent but are not credible as they were not adjusted to account for available information on inventories.

Opinion #52 (Contested): Estimated direct discharges to the river from Trail's metallurgical operations from 1920 through 2005 are summarized in Tables 2 and 3. Details appear in the *Inputs and Distributions Spreadsheets*.

JFH's *Expert Opinion* (p 18) included the following critique of Opinion #52 above:

> *Disagree. This opinion is incorrect. The tables referred to over-estimate the wastes discharged for a number of reasons including:*
>
> 1. *The concentrate feed weights are over-estimated by 2.3 million tons of Zn concentrates and 1.1 million tons of Pb concentrates due to failure to close these balances as will be discussed in the next section of this report.*
> 2. *Effluents, particularly Zn effluent, are not proportional to production volumes or to the volumes of*
>   *concentrates processed. Prior to 1983, Zn in effluents was largely determined by the need to purge*
>   *impurities and water from the Zn plants as discussed under Opinion #35 above.*

3. *The barren slag tonnages are exaggerated by use of the Logan formula.*
4. *The average assays of Pb in barren slag are higher than at least 3 references between 1933 and 1962 as discussed below in my Critique of Mr. Queneau's spreadsheet, point 4.*
5. *The average assays of Hg in concentrate feeds are over-estimated as discussed in my Critique of Mr. Queneau's spreadsheet, point 7.*
6. *The average assays of Cd in concentrate feeds are over-estimated as discussed in my Critique of Mr. Queneau's spreadsheet, point 8.*

My response to JFH's findings on Opinion #52 are as follows:

1. JFH's data on stockpile inventories (Figure 1.4 in his 30Nov10 Expert Opinion, p 10) have been incorporated into the Inputs and Distributions Spreadsheets, from which Table 2 and 3 are derived.

2. I agree with JFH's *proportional relationships* statement, providing that the word *necessarily* is inserted: *Effluents, particularly Zn effluent, are not* {necessarily} *proportional to production volumes or to the volumes of concentrates processed.* Where minimal or no information is available, one ends up extrapolating from dates where information is available. In this case, important proportional relationships were:

   - Lead and zinc production: There tends to be less metal discharge to the Columbia in the earlier lower-production years due to lower availability of feedstock.
   - Sulfuric acid production: There tends to be less metal discharge to the Columbia in the earlier lower-acid production years due to less scrubbing of furnace offgas.

   I have therefore made a substantial effort to discover and incorporate zinc (and Pb, As, Cd, and Hg) inputs and distributions provided by JFH in his 30Nov10 Expert Opinion, attachments, and 1800+ references into the Inputs and Distributions Spreadsheets. Use of proportional relationships is thus minimized.

3. JFH's iron-in-feed method provides a more accurate estimate of BF and fumed slag tonnage than does application of the Logan Formula. Slag tonnages, as calculated by JFH's Method #3, have therefore been incorporated into the Inputs and Distributions Spreadsheets.

4. Substantial effort has been made to discover and incorporate fumed slag analyses provided by JFH in his 30Nov10 Expert Opinion,

attachments, and 1800+ references into the Inputs and Distributions Spreadsheets.

5. I have made a substantial effort to discover and incorporate mercury analyses provided by JFH in his 30Nov10 Expert Opinion, attachments, and 1800+ references into the Inputs and Distributions Spreadsheets.

6. Substantial effort has been made to discover and incorporate cadmium analyses provided by JFH in his 30Nov10 Expert Opinion attachments, and 1800+ references into the Inputs and Distributions Spreadsheets.

Opinion #52 (Updated): Estimated direct discharges to the river from Trail's metallurgical operations from 1920 through 2005 are summarized in Tables 2 and 3. Details appear in the *Inputs and Distributions Spreadsheets*. Substantial effort has been made to discover and incorporate findings provided by JFH in his 30Nov10 Expert Opinion, attachments, and 1800+ references into the Inputs and Distributions Spreadsheets.

Opinion #53 (Contested): Annual data show variations due to non-quantified metal in inventory. Therefore 10-year averages are a better basis for data comparison.

JFH's *Expert Opinion* (p 19) included the following critique of Opinion #53 above:

> *Disagree. This opinion is misleading. The 10-year averages may look better but are still based on only the annual Pb production. They do not take the large stockpile inventory reductions or increases into account. The Iron-in-Feed method discussed earlier, estimates the 1930 stockpiles of slag and Fe residue and includes the well defined 1963 and 1995 inventory information.*

JFH's providing data on stockpile inventories in Figure 1.4 (his 30Nov10 Expert Opinion, p 10) has rendered Opinion 53 out-of-date. The Inputs and Distributions Spreadsheets have been edited to reflect JFH's findings.

Opinion #53 (Revisited): When preparing annual data in the Inputs and Distributions Spreadsheets, it is important to take into account changes in Trail inventory stockpiles. If 10-year averages are also used as a basis of comparison, these averages then are more meaningful.

Opinion #54 (Not contested): When preparing this expert report, annual acid-plant capacity appeared to be the best basis for estimating annual acid-plant production.

XVII. STANDARDS FOR OPINIONS

My opinions in this report are expressed to a reasonable degree of scientific certainty.

APPENDIX A: A TRAIL PLANT PROFILE – 1954

The May 1954 supplemental issue of *Canadian Mining Journal* featured *The Story of Consolidated Mining and Smelting Company of Canada Limited* (Anonymous). The *Smelting and Refining* section is a detailed, well written description of Trail operations. This description provides a footprint of Trail practice that is helpful in understanding and quantifying plant practice prior to beginning the plant's major modernization in 1979.

Key findings abstracted from this 1954 publication are as follows:

A. Sintering Lead-BF Feedstocks

- <u>Feed proportions to sintering</u> were guided by 1) the relative tonnage of lead bullion and zinc oxide fume, 2) the BF slag assay, 3) Ag, Sb, and As reporting to the bullion, and 4) fuel needs for proper sintering. Trail's wet-mix technique, used to prepare sinter-plant feed, blended moist zinc-plant leach residues with the other feedstocks. These various sinter-plant feedstocks are tabulated in Table A1. Dust collected from sintering was returned to wet mixing (p 242).

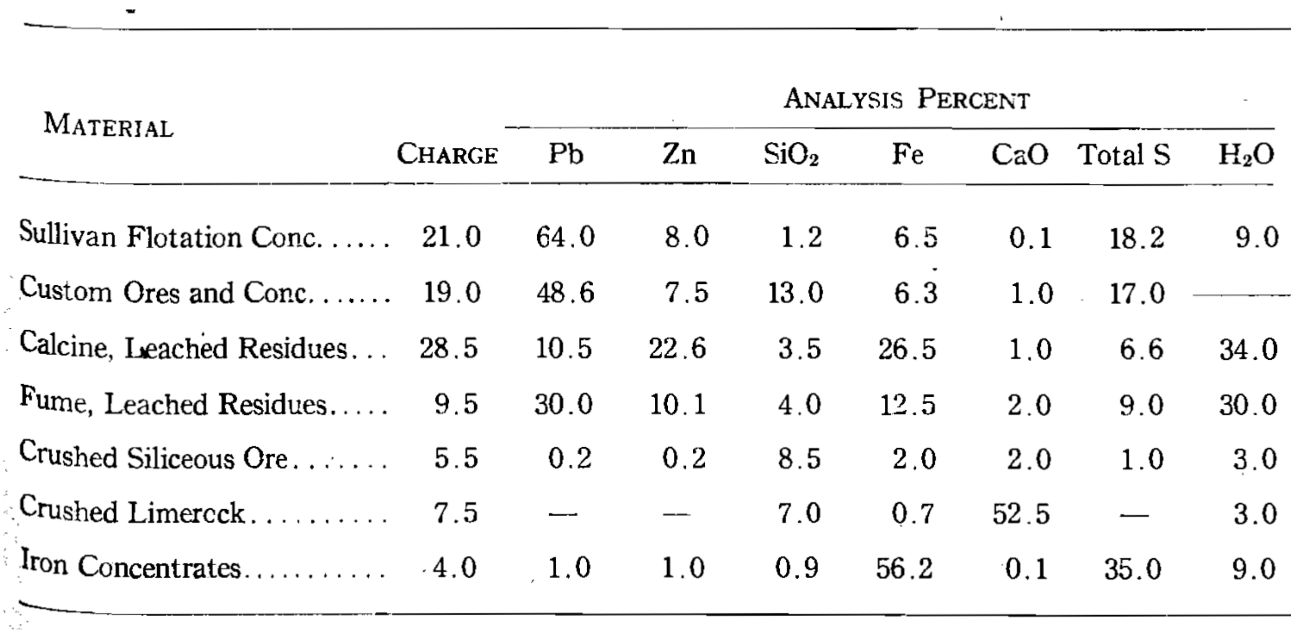
  The 14% moisture wet mix was dried to about 7.5% moisture in rotary driers. Output was nodulized in a rotary drum (no external heating) to attain suitable strength and permeability for efficient burning off of sulfur on the sintering machines. Vent gas from the driers (275 F) was vented to Doyle scrubbers, then released via a stack.

  Sulfur content in sinter feed was about 11.5% (p 237). The final sinter assayed 1.3% S (p 238). Sinter bed temperature was about 2000 to 2100 F.

- <u>Sinter plant feed</u> relative weights and assays are shown in Table A1 (p 237)[19].

- <u>Granulated BF slag and coke breeze</u>, about 9% and 1.5% respectively, were added to the charge fed to the second stage of sintering (p 240).

Table A1: Sinter-Plant Feedstocks (Anonymous, 1954, p 237)



MATERIAL	CHARGE	ANALYSIS PERCENT						
		Pb	Zn	SiO_2	Fe	CaO	Total S	H_2O
Sullivan Flotation Conc.	21.0	64.0	8.0	1.2	6.5	0.1	18.2	9.0
Custom Ores and Conc.	19.0	48.6	7.5	13.0	6.3	1.0	17.0	——
Calcine, Leached Residues. . .	28.5	10.5	22.6	3.5	26.5	1.0	6.6	34.0
Fume, Leached Residues.	9.5	30.0	10.1	4.0	12.5	2.0	9.0	30.0
Crushed Siliceous Ore.	5.5	0.2	0.2	8.5	2.0	2.0	1.0	3.0
Crushed Limerock.	7.5	—	—	7.0	0.7	52.5	—	3.0
Iron Concentrates.	4.0	1.0	1.0	0.9	56.2	0.1	35.0	9.0

- <u>Sintering machine dust, fume, and SO_2-laden gas</u> were first passed through a balloon flue, then to a humidifying chamber, then to Cottrells, then to SO_2 absorption using ammonia-rich solution. Cleaned gas vented to a 400-ft stack (p 241-242). Conditioning the dust to 4 to 6% moisture was key for its efficient collection in the Cottrells. Flue temperature was kept sufficiently high to avoid condensation of corrosive cake-forming moisture.

- <u>BF charge</u> consisted of about 85% sinter, plus pot-shell skulls, settler bottoms, and occasional lots of direct-smelting ore (p 242). The BF feed bins stocked 4000 tons of sinter, 1000 tons of furnace coke, and 500 tons of miscellaneous charge materials (p 243).

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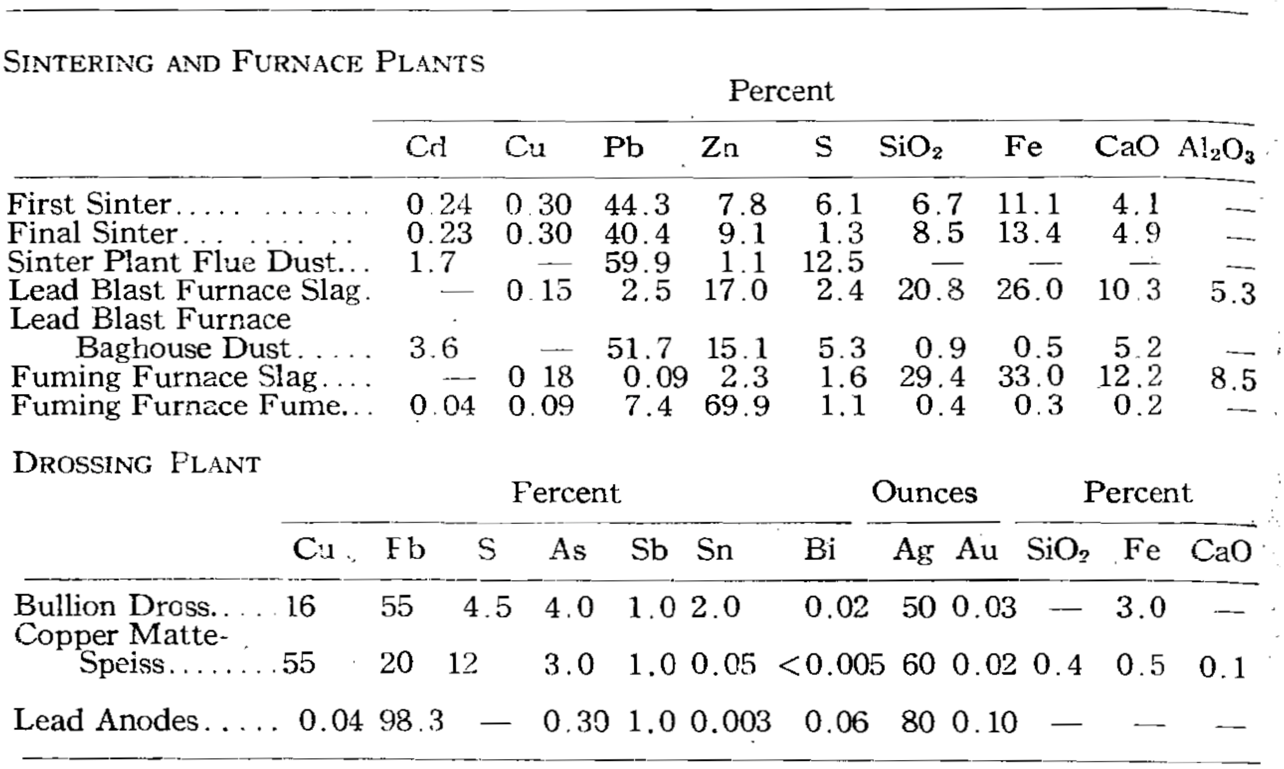
[19] The SiO_2 assay of Crushed Siliceous Ore is assumed to be 85%, not 8.5%.

Sulfur content in the BF charge was minimized. Sulfur in the BF slag output was detrimental to subsequent zinc fuming. Sulfur also increased the rate of BF accretion formation (p 243).

B. Lead Blast Furnace Slag

- <u>BF slag</u> was adjusted to be as high in zinc as possible, typically 17% Zn (Table A2). Iron, lime, and silica were proportioned to give reasonable fluidity at reasonable temperatures (p 243). Lead content, which averaged about 2.5%, was not a concern; it was recovered during subsequent slag fuming. For key assays, see Table A2 (p 248).

Table A2: Representative Analyses of Metallurgical Products
(Anonymous, 1954, p 248)



SINTERING AND FURNACE PLANTS

	Percent								
	Cd	Cu	Pb	Zn	S	SiO_2	Fe	CaO	Al_2O_3
First Sinter	0.24	0.30	44.3	7.8	6.1	6.7	11.1	4.1	—
Final Sinter	0.23	0.30	40.4	9.1	1.3	8.5	13.4	4.9	—
Sinter Plant Flue Dust	1.7	—	59.9	1.1	12.5	—	—	—	—
Lead Blast Furnace Slag	—	0.15	2.5	17.0	2.4	20.8	26.0	10.3	5.3
Lead Blast Furnace Baghouse Dust	3.6	—	51.7	15.1	5.3	0.9	0.5	5.2	—
Fuming Furnace Slag	—	0.18	0.09	2.3	1.6	29.4	33.0	12.2	8.5
Fuming Furnace Fume	0.04	0.09	7.4	69.9	1.1	0.4	0.3	0.2	—

DROSSING PLANT

	Percent						Ounces		Percent		
	Cu	Pb	S	As	Sb	Sn	Bi	Ag	Au	SiO_2	Fe	CaO
Bullion Dross	16	55	4.5	4.0	1.0	2.0	0.02	50	0.03	—	3.0	—
Copper Matte-Speiss	55	20	12	3.0	1.0	0.05	<0.005	60	0.02	0.4	0.5	0.1
Lead Anodes	0.04	98.3	—	0.30	1.0	0.003	0.06	80	0.10	—	—	—

Most of the BF slag was kept hot in preparation for fuming. A portion was granulated, then sluiced to a BF slag pond, where it was either reclaimed for the sinter plant, or to stockpile.

- <u>BF offgas</u> was first cooled countercurrently by water sprays and dilution air in a tower. A portion of the dust collected at the base of the tower, where it was removed by dragline. The cooled gas (250 F) then entered a baghouse for dust recovery, followed by discharge of the cleaned gas through a 284-ft stack. The recovered dust returned to the sintering plant (pp 243-245).

- Copper-rich dross was rejected from the BF bullion by cooling. This dross (16% Cu; 4% As) was skimmed off. If arsenic in the bullion remained above 0.3%, the excess was extracted into caustic soda. The bullion was then ready for Betts electrolytic refining (p 245).

  The copper-rich drosses were subsequently processed in a reverberatory dross retreatment furnace to produce a matte-speiss mixture for sale to a copper smelter, or for production of copper sulfate at Trail (p 245). CM&S consumed copper sulfate as a flotation reagent at the Sullivan concentrator, and also for solution purification in the zinc oxide leaching plant. Residual slag from copper dross retreatment was stored for recovery of lead, tin, and indium (p 246).

C. Lead Blast Furnace Slag Fuming

- Fuming of BF slag consumed about 200 lb of dried coal per minute (55 tons of BF slag fumed for 160 minutes). Fumed slag (2.3% Zn, 0.09% Pb, 33% Fe, 29% SiO_2, 12% CaO, and 8.5% Al_2O_3) was granulated, then went to waste. The leady zinc oxide dust (for processing in the zinc plant) was carried by the hot exhaust gas through a boiler for heat recovery, through a water-spray cooling flue, and then into a baghouse. The cleaned gas was vented to a stack (p 243; pp 246-248).

D. The Lead Refinery

- Lead refinery capacity in 1954 was 600 stpd (p 250). This refinery converted drossed BF bullion via Betts electrolysis to pig lead (99.99% Pb). The principal byproduct of electrolysis was slimes containing the Ag, Au, Bi, Cu, and Pb. The main outlet for antimony and arsenic was through the silver refinery (p 275). Outputs shown in the simplified flow diagram on p 250 are dross (to the smelter) and Sb-As-Sn slag (to antimonial lead production).

- About 3.5 lb of the tankhouse electrolyte per pound of refined lead exited from the tankhouse. Electrolyte contained 85 gpl Pb and 95 gpl H_2SiF_6. Losses were made up by addition of a 25% solution of H_2SiF_6 acid. Electrolyte volume was depleted when cathodes were removed from the tanks, by evaporation, and due to other unspecified losses (p 256).

E. The Silver Refinery

- The silver refinery processed Trail Betts refinery slimes. Principal outputs were silver and gold bars. Byproduct liquids and solids contained substantial values. These streams were therefore either sent back to the smelter for additional processing, or were sold. An exception was copper nitrate liquid effluent generated when parting silver from gold. See Figure A1 for details (p 257).

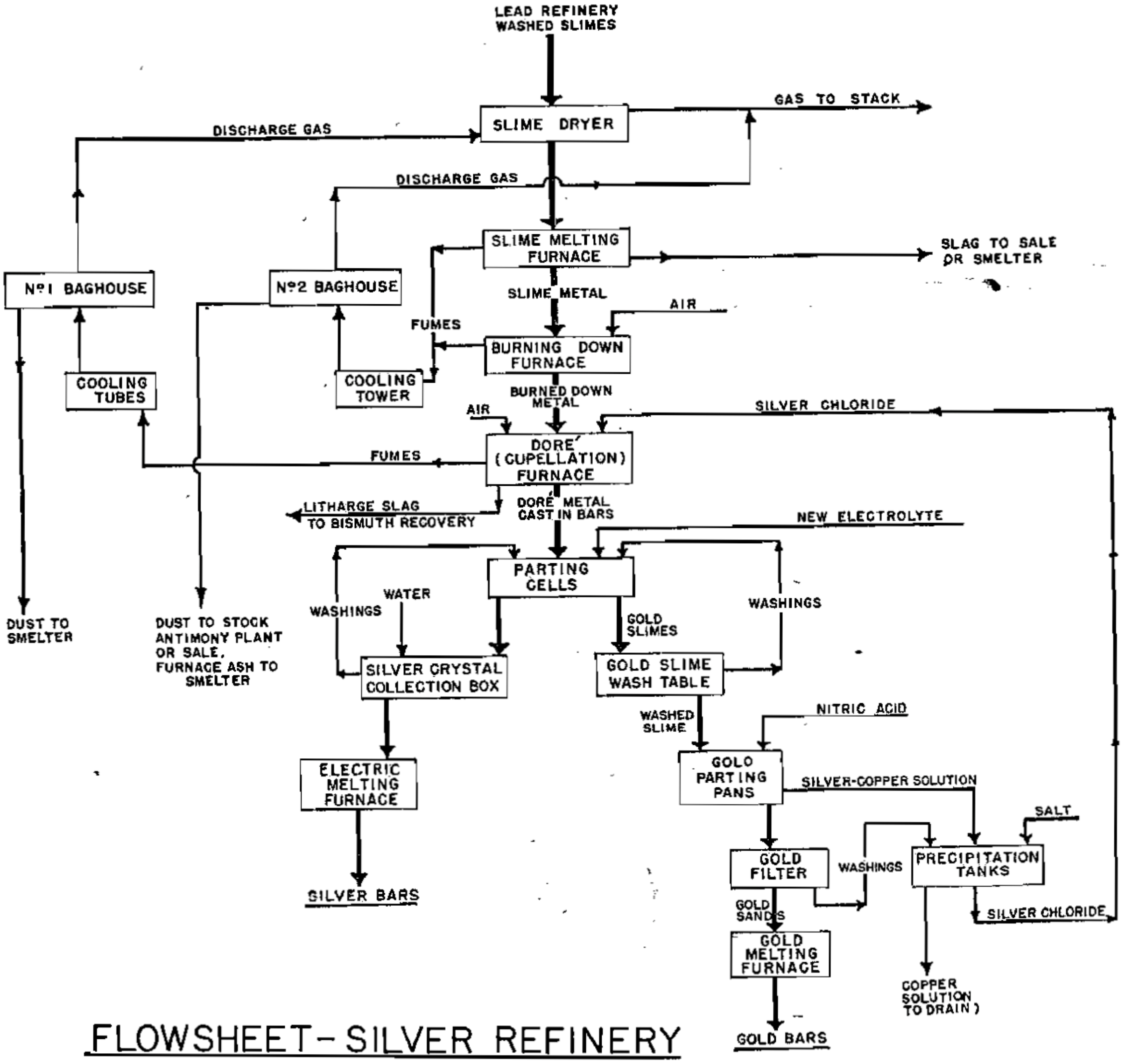


Figure A1. The silver refinery

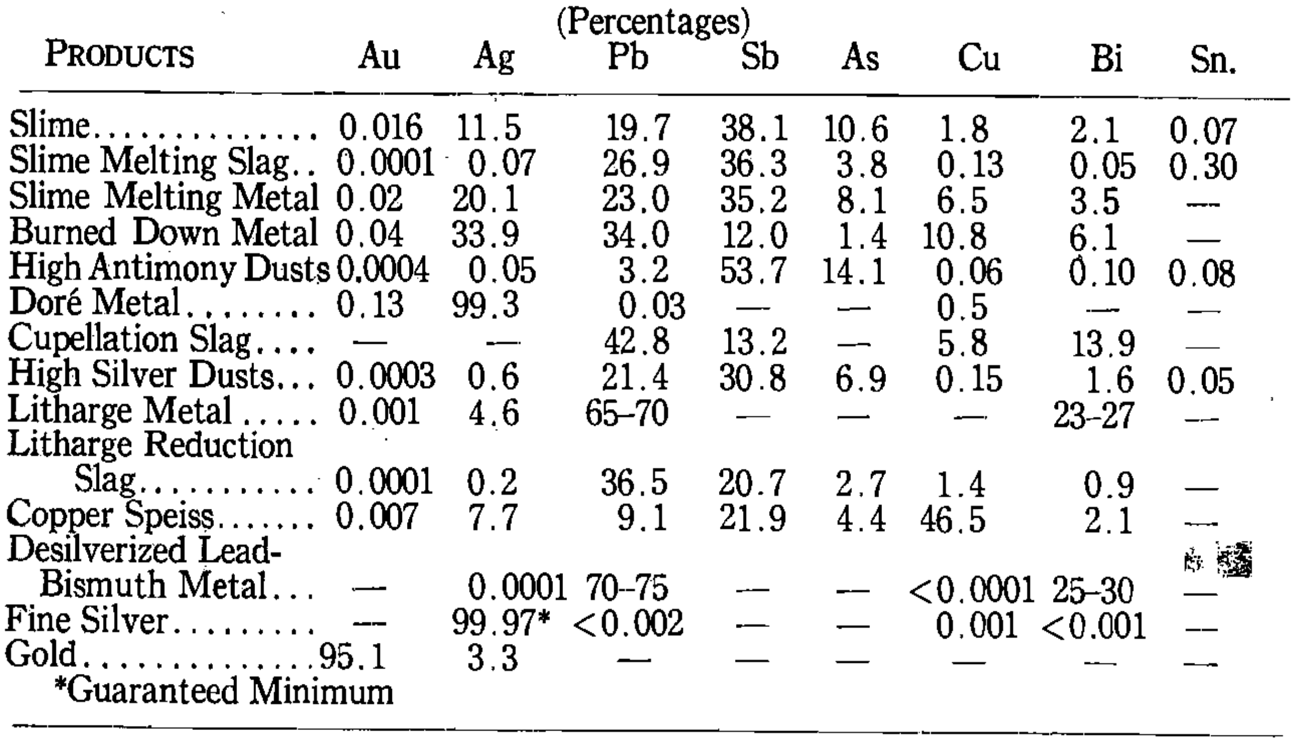
Most of the copper had already been recovered by cupellation prior to parting. The volume of copper nitrate liquid waste was likely not large, in that it was a product of the silver refinery. The Betts slimes feedstock to the refinery (13 dry tons per day) assayed about 1.8% Cu, 11.5% Ag, 0.016% Au, 38% Sb and 11% As. Metal yield after melting was 40 to 50% (pp 254, 257, 260).

- Antimony, arsenic, and bismuth: Antimony and arsenic were rejected by volatilization during slime melting and subsequent *burning down* (fuming) using air blowing. These fumes were cooled indirectly in tubes, then passed though a baghouse to recover the condensed dust. This Sb- and As-rich dust was either processed to recover antimony, or sold.

The burned down (fumed) metal was then further oxidized (by *cupellation*) to produce about 1,500 lb/day silver-gold dore metal. Bismuth (Bi), Pb, Cu, and residual precious-metal values were subsequently recovered from the dore-furnace slag in the bismuth refinery. See Table A3 for chemical analyses.

Table A3: Typical Analyses of Silver Refinery Products

(Anonymous, 1954, p 260)



(Percentages)

PRODUCTS	Au	Ag	Pb	Sb	As	Cu	Bi	Sn.
Slime..............	0.016	11.5	19.7	38.1	10.6	1.8	2.1	0.07
Slime Melting Slag..	0.0001	0.07	26.9	36.3	3.8	0.13	0.05	0.30
Slime Melting Metal	0.02	20.1	23.0	35.2	8.1	6.5	3.5	—
Burned Down Metal	0.04	33.9	34.0	12.0	1.4	10.8	6.1	—
High Antimony Dusts	0.0004	0.05	3.2	53.7	14.1	0.06	0.10	0.08
Doré Metal........	0.13	99.3	0.03	—	—	0.5	—	—
Cupellation Slag....	—	—	42.8	13.2	—	5.8	13.9	—
High Silver Dusts...	0.0003	0.6	21.4	30.8	6.9	0.15	1.6	0.05
Litharge Metal.....	0.001	4.6	65–70	—	—	—	23–27	—
Litharge Reduction Slag...........	0.0001	0.2	36.5	20.7	2.7	1.4	0.9	—
Copper Speiss.......	0.007	7.7	9.1	21.9	4.4	46.5	2.1	—
Desilverized Lead-Bismuth Metal...	—	0.0001	70–75	—	—	<0.0001	25–30	—
Fine Silver.........	—	99.97*	<0.002	—	—	0.001	<0.001	—
Gold..............	95.1	3.3	—	—	—	—	—	—

*Guaranteed Minimum

Production of bismuth at Trail began in 1929. Byproducts produced during recovery of bismuth, which tended to contain significant metal values, were recycled within the Trail smelting and refining complex.

F. Antimony Production

- Production of antimony at Trail began in 1938. The antimonial lead plant processed high-Sb dusts from the silver refinery, dross produced from Betts cathodes, and slag from the lead refinery dross retreatment furnace. Principal outputs were Pb-Sb alloy products, baghouse dust to stock, and dearsenizing slag to waste. See Figure A2 and Table A4. (p 260-261).

The Sb-rich feedstocks were processed in a reduction furnace at about 1800 F with coal, including caustic soda as a flux. Outputs were Pb-Sb-As bullion, dearsenizing slag, and high-As dust. The dust assayed 34.2% As, *which is collected in a baghouse for disposal* (pp 260 - 261).

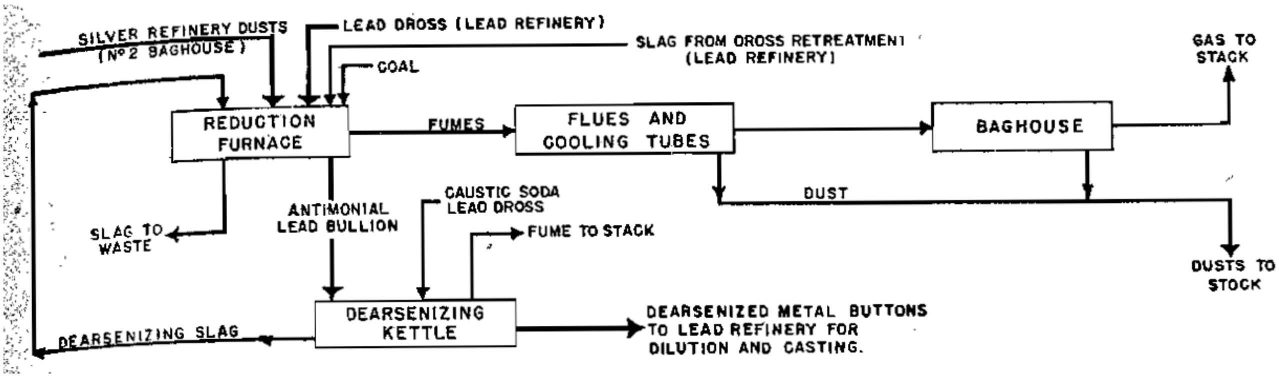


Figure A2. The antimonial lead plant.

Table A4: Average Analyses of Materials from the Antimonial Lead Plant

(Anonymous, 1954, p 261)

	Ag (oz./ton)	Cu %	Pb %	Sb %	As %	Bi %	Sn %
Silver Refinery Baghouse Dust....	19.0	0.03	3.4	57.0	12.4	0.13	<0.05
Reduction Metal................	—	0.05	5.82	35.4	5.5	0.11	—
Antimonial Lead................	8.0	0.04	74.6	25.0	0.02	0.08	—
Antimonial Lead Baghouse Dust..	—	—	2.3	31.0	34.2	—	—
Dearsenizing Slag (Typical)......	—	—	23.0	7.0	17.0	—	—

The bullion was dearsenized in a kettle with caustic soda and fine lead dross, producing sodium arsenate. This dearsenizing slag (17% As) was returned to the reduction furnace for Sb-Pb recovery.

G. The Zinc Department

- The zinc department began production in 1916, and by 1954 its capacity was 560 tons/day of cathode. About 320,000 tons of zinc concentrates were processed annually. An additional 75,000 tpy of zinc oxide fume was processed. This additional zinc originated from lead concentrate, some crude ores, and zinc leaching residue. Cadmium output was 2,000 lb/day (pp 262-263).

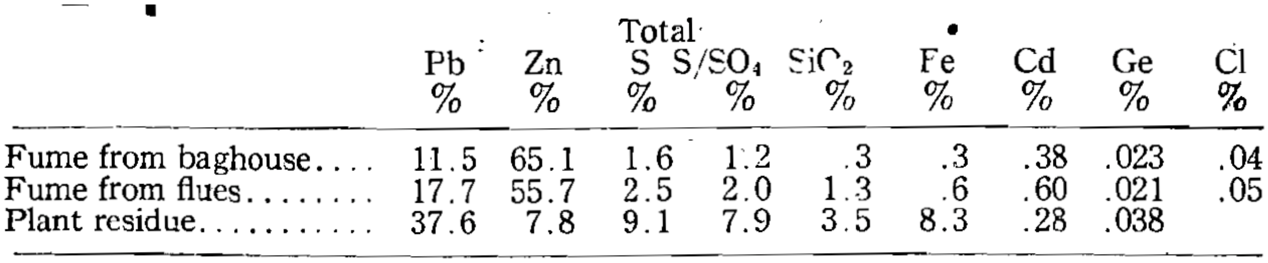
Heat from zinc concentrate roaster gas (6 to 7% SO_2) was recovered by boilers. Preliminary dust collection (20%) occurred in the boilers. Cycloning the boiler exit gas brought total dust recovery to over 90%. The recovered dust was returned to the suspension roasters. Next came electrostatic precipitators, the dust from which went directly to leaching (p 266).

- Handling roaster gas: Final roaster gas cleaning prior to SO_2 recovery entailed scrubbing with water saturated with SO_2. Collected solids were settled from the recirculating scrubber water. Aqueous purge from the recirculating water went to waste. The scrubbed gas then was rescrubbed and passed though Cottrells to reject all but 1% of the dust, as well as acid mist (p 266; pp 290-291). The coarser scrubber solids settled out in Glover Pond, through which scrubber water flowed prior to discharge to the Columbia (B.C. MoE Phase 1 Study, 1977, p 119).

- Calcine and fume leach residue: Roasted calcine and fumed zinc oxide were leached separately with spent electrolyte and make-up sulfuric acid to generate zinc sulfate for electrolytic production of zinc. The calcine leach residue, which usually returned to the lead smelter, on average assayed 25.7% Fe, 21.4% Zn, 11.9% Pb, 7.2% S, 3.6% SiO_2, 1.7% CaO, and 0.55% Cd (p 269). See Table A5 for the assay of the residue from leaching the fumed zinc (p 276).

- Tankhouse electrolyte purge: Leach liquor purge from both the calcine and fume leaching sections was electrolytically stripped down to 10 to 15 gpl Zn, then converted to a zinc-ammonium-sulfate complex for sale as micronutrient (p 278). This purge was essential to purge soluble impurities, including chloride, fluoride, and magnesium.

Table A5: Fume Plant Feed and Leach Residue
(Anonymous, 1954, p 276)



	Pb %	Zn %	Total S %	S/SO$_4$ %	SiO$_2$ %	Fe %	Cd %	Ge %	Cl %
Fume from baghouse....	11.5	65.1	1.6	1.2	.3	.3	.38	.023	.04
Fume from flues........	17.7	55.7	2.5	2.0	1.3	.6	.60	.021	.05
Plant residue...........	37.6	7.8	9.1	7.9	3.5	8.3	.28	.038	

H. Cadmium Recovery

- <u>The cadmium plant</u> applied leaching and electrowinning to recover cadmium from the various Cd-rich plant byproduct streams. Sullivan zinc concentrate averaged about 0.14% Cd. Other concentrates fed to Trail averaged about 0.36% Cd.
- <u>Cadmium sponge</u>: Other than cathode zinc and electrolyte purge, the principal other outfall from the zinc plant was the cadmium sponge derived from purification of the zinc sulfate leach liquor, prior to zinc electrowinning. This byproduct went to the cadmium plant (p 268; p 274).
- It was occasionally economic to leach <u>BF baghouse dust</u> for recovery of its cadmium values. The BF baghouse dust averaged about 3% Cd, a portion of which was present as sulfide. Cadmium extraction by leaching averaged 90%. Alternatively, the Cd-rich BF dust could be blown into the exit gas from slag fuming. Sulfides were oxidized; Cd then reported to the fume leaching circuit (p 275).

  About 50% of the Cd entering zinc calcine and fume leaching was dissolved, then precipitated as Cd sponge via addition of zinc powder. The balance (about 50%) returned to the lead smelter, where the Cd (very volatile) concentrated in the BF baghouse dust. This dust returned to the sintering plant, building up a circulating load of Cd. When this load became sufficiently high, this Cd-rich dust could be processed along with the dust produced during slag fuming (p 280).
- During <u>electrowinning of Cd</u>, impurities built up in the electrolyte (primarily F, Ca, Mg, Tl, Ni). A portion of the electrolyte (150 gpl Cd and 61 gpl Zn) was therefore purged to removed these impurities from the tankhouse. This purge was returned to the fume leach circuit.
- <u>Thallium (Tl)</u> was rejected from the cadmium plant using permanganate, which oxidized the thallium to the relatively insoluble thallic form. This precipitate ultimately returned to the lead smelter via addition to the zinc fume leach residue.

APPENDIX B: GLOSSARY OF TERMS

Ag: Silver

Al: Aluminum. Alumina (Al_2O_3) is a component of slag.

Anode: Lead at Trail was cast into flat shapes called *anodes* prior to subjecting them to electrorefining to produce purified cathodes. Impurities collected as slimes, which were processed in Trail's precious-metal refinery.

As: Arsenic

Ash: Ash is impurity mineral matter in coal or coke. During smelting, ash becomes a component of the slag.

Au: Gold

Baghouse: A baghouse captures dust by passing the gas through supported cloth socks. The dust is periodically released from the socks either by shaking, or with a puff of air. Baghouses typically collect dust more efficiently than do Cottrells.

Bi: Bismuth

Blast furnace (BF): A vertical smelting furnace that Trail used to recover lead, copper, and byproduct metals from ores and concentrates.

Blast Roasting: Agglomeration of particulate solids by roasting, prior to BF smelting of these solids.

Briquetting: Pressing of particulates into pillow-shaped agglomerates prior to BF smelting.

Cathode: The metal product from an electrolytic process. At Trail, lead cathodes were produced by Betts electrorefining, and zinc cathodes by zinc electrowinning.

Cd: Cadmium, which is a reasonably volatile element.

Coke: Coal that has been heated to remove volatile constituents. Coke is an important part of the charge fed to a BF.

Concentrate: Trail's two primary feedstocks were zinc and lead concentrates. Ore was upgraded to reject waste minerals (gangue), thus concentrating the zinc sulfide (ZnS) and lead sulfide (PbS) mineral values.

Cottrell: Gas carrying entrained dust is ionized in a Cottrell. Dust particles in this media gather sufficient electric charge to move under the force of the electric field, and thus are collected. These devices are also called electrostatic precipitators (ESP).

Cu: Copper, a non-volatile metal that is easily recovered by smelting.

Cyclone: A cone-shaped device in which gas containing dust is spun in a manner that separates out the coarser solids.

Dross: A solid or semi-solid residue that forms on top of molten metal, e.g., when refining impure lead in iron kettles. The dross is skimmed off.

Electrorefining: Refining a metal by using electricity to dissolve it (from an anode), followed by deposition of the metal from solution (on a cathode). Trail recovers lead by Betts electrorefining. Betts, a Trail technologist, invented the process.

Electrowinning: Recovering a metal by using electricity to deposit the metal directly from solution as a cathode. Trail recovers zinc by electrorefining this metal from purified zinc sulfate solution. This solution was made by leaching zinc oxide calcine. The calcine was produced by roasting zinc sulfide concentrate.

ETP: Effluent Treatment Plant, which precipitated metals via lime neutralization from Trail's waste liquor prior to its discharge to the river.

Fe: Iron. Iron oxide (Fe_2O_3) is an important component of slag.

Flue: A tube, pipe, or shaft designed to transport hot gas.

Flux: Additives to a smelting operation that combine with gangue minerals to produce slag having suitable physical and chemical properties.

Fugitive Emissions: Atmospheric emissions due to leaks (e.g., from processing plants, storage facilities and their interconnections).

Fume: Fume is gas that contains volatilized metal. One can also *fume* a slag in order to boil off a portion of metals contained in the slag. Scrubbing is an efficient means to recover metals from the evolved fume.

Gangue: Worthless minerals associated with economically valuable minerals. Gangue minerals are a major component of slag.

Glover Tower: At Trail, Glover Towers acid-scrubbed zinc-roaster offgas following its treatment in hot Cottrell precipitators. In 1932, there were four such towers 28-feet in height, lined with lead and brick. Each contained brick checker-work to distribute the acid as it flowed downward, thereby scrubbing the rising Cottrell offgas. These towers contacted the rising offgas with descending acid, thereby capturing dust and fume, as well as cooling the gas. Acidic slurry collected from the bottom of the tower was cooled, and the sediment removed by settling. The acid was then returned back to the top of the tower to carry out additional scrubbing. Spent acid purged from the zinc leaching plant provided make-up acid.

Granulation: Molten slag is granulated by spraying it with high-pressure water.

Halides: Chlorides and fluorides, which are impurities that interfere with economic electrowinning of zinc. These halides were rejected at Trail by leaching fumed zinc oxide with soda ash solution.

Hg: Mercury

JFH: John F. Higginson, Manager – Technical Support for Trail Operations

Leaching: Solids particulates are mixed with an aqueous solution to dissolve at least a portion of the feedstock. Thickening and/or filtration follows.

Lime: Calcium oxide, which is often used to neutralize acidic waste solutions.

Limestone: Calcium carbonate rock, which is often used as a flux to improve slag physics and chemistry.

Matte: A dense mixture of metallic sulfides that is often a product of smelting and refining.

Norzink Process: This process Trail used as a final mercury removal step from flue gas just prior to converting sulfur dioxide in the gas to sulfuric acid.

O: Oxygen

Ore: A naturally occurring collection of minerals that can be economically processed to recover metal values.

Pb: Lead

Purge: Impurities can build up in a solution during processing, e.g., in the electrolytes used during electrolysis of lead and zinc. A portion of the contaminated electrolyte is therefore removed (*purged*). Purged liquor is replaced by fresh pure electrolyte. Whether purged liquor is discarded or processed for reuse depends on technical, economic, and environmental constraints.

Refining: Processing of impure metal-rich intermediates to remove impurities.

Reverberatory Furnace (RVF): A horizontal smelting furnace, used by Trail in the early years to smelt copper ores.

Roasting: Combusting solid substances to drive off a volatile component, such as sulfur as sulfur dioxide. At Trail, ZnS concentrates were roasted to produce ZnO and sulfur dioxide gas (SO_2).

S: Sulfur. When sulfur combines with lead, zinc, or copper, the resulting compound is a sulfide, e.g., PbS.

Sb: Antimony

Scrubbing: Scrubbing involves contacting a flue gas with an aqueous solution, often as a fine spray, to capture dust entrained in the gas. Scrubbing also cools the gas, primarily by evaporation. During scrubbing, much of the metallic fume carried in the gas is condensed and recovered, e.g., arsenic, cadmium, and mercury.

SFF: Slag fuming furnace

Si: Silicon. Silica is SiO_2, which is a common gangue component.

Sintering: Heating fine solids to produce semi-fused porous chunks, in preparation for blast-furnace smelting. Trail operated Dwight-Lloyd (D&L) continuous sintering machines.

Skulls: Frozen residual metal that freezes on the ladle after the bulk of the metal has been poured off.

Slag: A byproduct of high-temperature recovery of metals. In the context of this report, slag is a glass-like material consisting primarily of silica, lime and iron oxide, as well as small amounts of base metals, including zinc, lead, copper, arsenic, and cadmium.

Slimes: Precious-metal-rich particulates that remain behind when electrorefining metallics. Slimes are sent to a precious metal refinery to recover values, e.g., gold and silver.

Smelting: Melting, and then processing metal-containing feedstocks to separate out valuable components. Inert oxides float upwards as slag; the metallics and matte sink, to be collected separately by tapping the furnace.

Soda Ash: A basic solution of sodium carbonate that Trail used to leach halides away from fumed zinc oxide.

Speiss: A mixture of metallic arsenides produced during smelting. A common component of speiss is iron arsenide, which is an alloy of arsenic and iron.

SST: Stripped spent electrolyte generated when recovering zinc from spent electrolyte that was purged from zinc electrolysis circuits.

Stripping Cells: In stripping cells, electrolyte purged from the zinc tankhouse was processed at high current density to recover much of its zinc content. The stripped electrolyte output contained 8.6 to 20 gpl Zn.

Sulfide: Examples of sulfide are PbS and ZnS. Trail's lead concentrate contained PbS, i.e., a compound composed of lead and sulfide-sulfur. The zinc concentrate also was rich in sulfide, primarily ZnS.

Sulfuric Acid: This acid (H_2SO_4) is produced by combining SO_2 gas with moisture and oxygen in the presence of a catalyst. The flue gas must first be thoroughly scrubbed to remove dust and fume, which would poison the catalyst.

Tankhouse: A building in which electrolytic processing of metals takes place in tanks.

Tapping: One taps a furnace through an opening to permit metal, slag, matte, or some other molten component to discharge from the furnace.

Thickener: Solids suspended in aqueous solution, e.g., precipitate formed by neutralizing waste solution in Trail's Effluent Treatment Plant (ETP), can be allowed to settle, then recovered. The device in which the solids are settled is called a *thickener*.

Zinc Dust: Fine zinc metal powder that is mixed with zinc sulfate solution to precipitate impurities.

Zn: Zinc, which arrived at Trail primarily as ZnS, i.e., zinc sulfide.

APPENDIX C: REFERENCES CITED, REVIEWED, AND CONSIDERED WHILE PREPARING MY EXPERT OPINION AND REBUTTAL, INCLUDING TECHNICAL PAPERS, BOOKS, AND DOCUMENTS (Separate File)

APPENDIX D: INPUTS AND DISTRIBUTIONS SPREADSHEETS, AND EXPLANATION OF SPREADSHEET DETAILS (Separate File)

APPENDIX E: PAUL B. QUENEAU – C.V.

Paul B. Queneau
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Areas of Expertise

Extractive metallurgy, metals recycling, resource location, and byproduct marketing.

Experience Summary

Dr. Queneau's technical and project management responsibilities focus on extractive metallurgy of nonferrous metals, treatment of metal-containing wastes, resource location and byproduct marketing. His 43 years of experience include the development of custom processes for primary and secondary feedstocks, plant startups and plant operation to increase output, yield, and product quality.

In-plant projects include recycling of tin solder and drosses, Ni-Co recovery from laterite ore (pressure acid leaching, Australia), processing spent copper etchants (Hong Kong), processing and utilization of nonferrous and waste-processing slags, production of ferro-niobium from enriched slag (Brazil), conversion of tungsten concentrates (U.S. and Russia), processing tantalum intermediates, production of molybdenum chemicals, Ni–Mo-W recovery from spent catalyst (Europe), recycling copper flue dust, production of secondary bronze ingot, recycling leady residues (seven plants in U.S., Canada, and Mexico), processing hazardous waste in rotary kilns (seven plants), production of antimony oxide (Bolivia), producing zinc and manganese micronutrient (five plants), recycling of secondary aluminum in short rotary furnaces (four plants), silver production (U.S. and Turkey), production of defluorinated phosphate, recycling calcium fluoride, processing ferromanganese furnace dust, and Ni-Cu-Co recovery from matte.

As an R&D supervisor for AMAX in Golden, CO, Paul Queneau led research on production of ammonium paratungstate (APT), leading to commercialization; he also led the team that innovated AMAX's acid pressure leach for treating nickeliferous laterite. Dr. Queneau was a member of the AMAX process engineering team that started up atmospheric and pressure leaching circuits, residue flotation and hydrogen reduction plant at Port Nickel. As a research engineer at Kennecott, he developed the process, then supervised the startup of a five-ton-per-day plant to upgrade high-rhenium molybdenite inventory.

Credentials

Ph.D. Metallurgical Eng., U. of Minnesota, 1967.
B.S. Metallurgical Eng., Cornell University, 1964.

Member of the American Institute of Mining, Metallurgical and Petroleum Engineers (AIME), Mining and Metallurgical Society of America, and Canadian Institute of Mining and Metallurgy (CIM).

AIME-TMS 2001 Extraction & Processing Distinguished Lecturer Award. Past President of the Denver Section, AIME-ASM Chapter.

Elected to membership in Tau Beta Pi
Adjunct Professor at the Colorado School of Mines (CSM).

Registered Professional Engineer, Colorado;
Authored 33 technical papers; holds 30 U.S. patents.

Employment History

1997 – Present	Consulting Metallurgical Engineer P.B. Queneau & Associates, Inc., The Bear Group
1990 – Present	Adjunct Professor Colorado School of Mines
1983 - 1997	Principal Metallurgical Engineer Hazen Research, Inc.
1982 - 1983	President/Owner P. B. Queneau Company, Inc.
1972 - 1982	R&D Supervisor AMAX, Inc.
1967 - 1972	Research Engineer Kennecott Copper Corporation

Key Projects

Developed and proved process to produce tungsten chemicals from scheelite and wolframite concentrates. A profitable commercial operation resulted.

Established operating criteria and started up plant to produce antimony oxide at a tin operation in Bolivia; a profitable operating facility resulted.

Worked with venture capital firms to evaluate the current capabilities and future potential of U.S. zinc smelters.

Evaluated primary zinc plant (roast/leach/electrowin) as an acquisition candidate for processing sphalerite concentrate output from proposed mine/concentrator.

Worked with slagging kiln incineration operations to maximize throughput, and with ingot-plant and industrial waste furnaces to enhance slag quality and marketability.

Doubled the lead output from a Canadian secondary lead producer over a two-year period by implementing a computer model to optimize feedstock selection and blending, and coke-flux inputs.

Worked closely with waste management operation in Hong Kong to recover copper from spent etchants and to market byproduct salts produced.

Assisted lead-acid battery recycler with selection of blast furnace formulations to maximize slag environmental acceptability without significantly affecting production efficiency.

Detailed technologies for nickel and cobalt recovery from spent lithium ion, nickel metal hydride, and NiCd batteries. Worked out N. American sources of these spent batteries, as well as capabilities of the established recycling operations.

Provided in-plant technical support to produce bronze secondary ingot from red-metal scrap, increasing the quality and quantity of alloy output.

Upgraded operating practices of rotary furnaces converting complex tin drosses to solder, improving yield by over 20%.

Carried out an in-depth technical and marketing evaluation for producing byproduct $MnSO_4$ and MnO, resulting in a profitable production facility.

Provided onsite startup assistance (three months) for large silver production facility in Turkey.

Worked with an international oil firm to evaluate alternative outlets worldwide for recycling spent resid and HDS catalyst.

Improved Al° furnace yield while recovering NaCl-KCl-NaF and Al° fines from salt cake at U.S. secondary aluminum smelters. Worked out alternative markets for the metallic aluminum fines.

Provided technical support for facility manufacturing molybdenum chemicals: troubleshooting, unit operation startups and new product development.

Selected and evaluated three routes to recover Mo/Co/Ni chemicals and aluminum-rich byproducts from spent catalyst; detailed market outlets.

Developed wet oxidation - solvent extraction process to recover vanadium and nickel from Venezuelan petroleum coke.

Identified volumes and producers of etchant, alternatives for processing the outputs, and market outlets for products therefrom.

Provided startup expertise to a refinery producing nickel, cobalt, and copper from matte; work included startup of the leaching and reduction operations.

Worked out handling of phosphorus electric furnace slags. Developed byproduct alternatives for the furnace flue dust.

Developed a process for beryllium hydroxide recovery from phenacite concentrate by leaching, solution purification, and precipitation.

Evaluated alternative technologies to recover gallium and germanium from carboniferous shale. Later examined likely areas worldwide for increased Ge output in response to escalating Ge price.

Worked with aircraft manufacturer to evaluate VC_4 production in U.S., Europe and Japan.

Worked with EPA contractor to assemble "a guide on recycling low-metal-content wastes for use by decision makers at superfund, RCRA, and other waste sites."

Presented on-site short courses on recycling metals from industrial waste. Locations include CSM, a DOE facility, EPA’s Office of Solid Waste in Washington, AIME and CIM annual meetings, and at a waste processing facility.

Assisted in the startup of a rhenium-chemical production facility from roaster flue gas.

Helped chemical producer to identify opportunities for production of nickel and cobalt chemicals, as well as secondary sources for feedstocks.

Worked with team evaluating hydromet process for Ni, Cu, Au, and pgms, recovery from flotation concentrates.

Worked with firm producing chromated copper arsenate to establish secondary sources for its copper, chromium, and arsenic raw materials.

As Technical Assessor reporting to the Tribunal for an international arbitration related to nickel production, was responsible for documenting agreements between 28 expert witnesses and providing technical assistance to the Tribunal during the trial.

Books

Meeting Chairman and Editor, Third International Symposium on Recycling Metals and Engineered Materials, Point Clear, Alabama, The Metallurgical Society of AIME, Warrendale, PA (1995).

Editor, International Symposium on Residues and Effluents Processing, The Metallurgical Society of AIME, Warrendale, PA (1991).

Editor, Symposium on Arsenic Metallurgy: Fundamentals and Applications, The Metallurgical Society of AIME, Warrendale, PA (1987).

Technical Publications and Presentations

Recycling Metal-Rich Industrial Products, 375th Anniversary, Nickelhütte Aue, Aue, Germany (2010).

Rich Country – Rich Wastes: Meeting Needs and Grasping Opportunities, MiMeR/Boliden Foresight Seminar, Lulea, Sweden (2008).

Recent Developments: Specialty U.S. Metals Recycling Plants, Recycling Metals from Industrial Waste Short Course, Colorado School of Mines, Golden, CO (2008).

Recycling Zinc in the United States, The EI Digest Gathering, San Diego, CA (September 2005).

Hazardous Waste to Valued Byproducts, The EI Digest Gathering, San Diego, CA (September 2004).

Recycling Non-Ferrous Metals from Industrial Waste, Hydrometallurgy 2003, AIME/TMS, 1543 – 1553.

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Production of Copper Chemicals from Secondary and Byproduct Sources in the United States, Journal of Metals, 34-37, 49 (October, 1997).

Production of Byproduct Mercury, Journal of Metals, 24-28 (October, 1995).

State of the Art in Mercury Recycling, Intl. Symp. on Treatment and Minimization of Heavy-Metal Waste, AIME/TMS Annual Meeting, Las Vegas (Feb. 1995).

Secondary Zinc Production and Waste Minimization, Pollution Engineering, 42-44 (November, 1994).

U.S. Mercury Recyclers Expand Process Capabilities, Hazmat World, 31-34 (February, 1994).

Recycling Lead and Zinc in the United States, 4th Intl. Symp. on Hydrometallurgy, Salt Lake City (1993).

Waste Minimization: Recycling of Spent Lead-acid Batteries, Hazmat World, 34-37 (August, 1993).

Slag Control in Rotary-kiln Incinerators, Pollution Engineering, 26-32 (January 15, 1992).

Producing Zn/Fe-Based Micronutrient from Copper Flue Dust, Intl. Sym. on Processing Residues and Effluents, San Diego, TMS/AIME, 239-254 (1992).

Application of Slag Technology to Recycling of Solid Wastes, Intl. Incineration Conf., Knoxville (1991).

Optimizing Matte and Slag Composition in Rotary- Furnace Lead Smelting, Intl. Symp. on Primary and Secondary Lead Processing, 145-178, Halifax (1989).

Processing Petroleum Coke to Recover Vanadium and Nickel, Hydrometallurgy, vol. 22, 3-24 (1989).

Germanium Recovery at Lang Bay, CIM Bulletin, 79(886), 92-97 (February, 1986).

Iron Control during Hydrometallurgical Processing of Nickel Laterite Ores, Iron Control in Hydrometallurgy, The Metallurgical Society of CIM, 76-105 (1986).

Silica in Hydrometallurgy: An Overview, Canadian Metallurgical Quarterly, 25(3), 201-209 (1986).

Control of Autoclave Scaling during Acid Pressure Leaching of Nickeliferous Laterite, Metallurgical Transactions B of AIME, 433-440 (1984).

Control of Silica Deposition during Pressure Let-down of Acidic Leach Slurries, Third International Symposium on Hydrometallurgy, 121-137 (1983).

Soda Ash Digestion of Scheelite, Extr. Metallurgy of Refractory Metals, AIME/TMS, 237-267 (1981).

Ion Exchange Purification of Ammonium Molybdate Solutions, Hydrometallurgy, vol. 6, 63-73 (1980).

Fluid-bed Electrolysis of Nickel, Metallurgical Transactions B, 659-666 (December, 1979).

Leaching of Cu/Ni/Fe Matte, Canadian Metallurgical Quarterly, Met. Soc. of CIM, 18, 145-153 (1979).

Nickel/Cobalt Separation by Ozonation, CIM Bulletin, 74-81 (October, 1978).

Leaching of Nickeliferous Limonites, Metallurgical Transactions B of AIME, 547-554 (December, 1977).

Processing WO_3/SnO_2 Concentrate for Brannerite Removal, AIME/SME Met. Trans., 218-221 (1975).

Turbine Mixer Fundamentals and Scaleup at Port Nickel, Met. Trans. B of AIME, 149-157 (1975).

Atmospheric Leaching of Nickel-Copper Matte at Port Nickel, CIM Bulletin, 74-81 (February, 1974).

Nitric Acid Processing of Copper Concentrates, AIME-SME Met. Transactions, 117-123 (June, 1973).

Acid Bake / Leach / Flotation of Molybdenite, Met. Transactions of AIME, 23-27 (November, 1971).

Sulfation of Copper/Iron Sulfides with Concentrated Sulfuric Acid, Journal of Metals, (December, 1970).

Kinetics of Scheelite Dissolution in Alkaline Solutions, Met. Trans. AIME, 2451-59 (Nov, 1969).

Patents

Autoclave Control during Pressure Oxidation of Molybdenite: U.S. Patent 6,818,191 (2004).

Producing Pure MoO_3 from Low-grade Molybdenite Concentrates: U.S. Patent 6,730,279 (2004).

Pickling of Refractory Metals: U.S. Statutory Invention Registration H2087H (2003).

Inhibiting Lead Leaching in Water: U.S. Patents 5,544,859, 5,632,285 & 6,013,382 (1996, 1997, 2000).

Electrolytic Dissolution and Control of NiS Scale, U.S. Patent 4,627,900 (1986).

Recovery of Alumina Values from Alunite Ore, U.S. Patent 4,618,480 (1986).

Stripping of Tungsten from Organic Solvents, U.S. Patent 4,450,144 (1984).

Recovery of Vanadium and Nickel from Petroleum Coke, U.S. Patent 4,443,415 (1984).

Silica Control during Acid Pressure Leaching of Nickel Laterite Ore, U.S. Patent 4,399,109 (1983).

Precipitation of Low-sulfur Calcium Tungstate, U.S. Patent 4,397,821 (1983).

Digestion of Scheelite Concentrates, U.S. Patent 4,351,808 (1982).

WO_3 Feedback Control When Producing Ammonium Paratungstate, U.S. Patent 4,325,919 (1982).

Combined Treatment of Wolframite and Scheelite, U.S. Patent 4,320,096 (1982).

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Separation of SiO_2, P_2O_5 and F from Tungsten Liquors, U.S. Patent 4,311,679 (1982).

Separation of Molybdenum from Tungsten, U.S. Patent 4,303,623 (1981).

Processing Concentrates with High MoO_3/WO_3 Ratio, U.S. Patent 4,303,622 (1981).

Electrolytic Cell for Oxidation of $Ni(OH)_2$, U.S. Patent 4,183,792 (1980).

Ion-exchange Process for Recovery of Copper and Nickel, U.S. Patent 4,100,043 (1978).

Selective Leaching of Ni/Cu/Fe/S Matte, U.S. Patent 4,094,754 (1978).

Sulfuric Acid Leaching of Nickeliferous Laterite, U.S. Patent 4,044,096 (1977).

Separation of Cobalt from Nickel by Ozonation, U.S. Patent 4,034,059 (1977).

High-temperature Neutralization of Nickel Laterite Ores, U.S. Patent 3,991,159 (1976).

Atmospheric Leaching of Nickel-Copper-Cobalt Matte Containing Iron, U.S. Patent 3,962,051 (1976).

Selenium Rejection during Acid Leaching of Nickel-Copper Matte, U.S. Patent 3,959,097 (1976).

Separating Copper, Lead, and Insol from Molybdenite Concentrates, U.S. Patent 3,834,893 (1974).

Nitric Acid Process Chalcopyrite Concentrates, U.S. Patent 3,793,429 (1972).

APPENDIX F: Response to John F. Higginson's (JFH's) *Additional Comments Identifying Errors in Mr. Queneau's Historical Review:* see p 19 of his 30Nov10 Expert Opinion

Page 14, Section VI (Executive Summary) - *Mr. Queneau's reference to "Lead Slag" is a misnomer. This term has never been used by the company or even by the local community in identifying this material. There are lead slags in Trail Operations – such as from the Silver Refinery -- but this is an Fe slag if anything…it just comes from a Lead smelter instead of a Copper smelter. The correct way to reference such slags is as a "lead blast furnace slag", a "copper blast furnace slag" and a "lead fuming furnace slag". Historically the latter has been called barren slag or tail slag or, in the earliest days, a retreatment furnace slag.*

Response: I wholeheartedly agree that we need to keep the terminology used for Trail's process materials and streams unambiguous and specific to Trail operations. My use of the term *lead slag* on p 14 (and on p 1) has therefore been updated to read *lead blast-furnace (BF) slag*. Also updated is my use of copper slag, which now distinguishes between copper BF slag and copper reverb slag.

There is flexibility in naming the slag fuming-furnace slag. The terms *lead fuming-furnace slag* and *tail slag* are clear enough. JFH pointed out that in the earliest days, this slag was called *retreatment furnace slag*, which is also clear. I in turn attempted to discover the terminology preferred by JFH (*barren slag*) and me (*fumed slag*) in Trail literature: *fumed slag* first appeared in the 1950s, and *barren slag* in the 1960s. The meaning of both of these latter terms is again clear.

JFH's p 14 rebuttal also includes the following: *This term* {lead slag} *has never been used by the company or even by the local community in* *identifying this material*. In regard to Trail's use of *never*, e.g., see R.R. McNaughton's (Assistant Smelter Superintendent) one-page memorandum (1936) that he wrote to W.W. Diamond (Assistant General Superintendent). The memo is titled *Smelter Slag Dump*: *Pipe Samples of Slag Behind Nurses' Home*; the letterhead reads: THE CONSOLIDATED MINING AND SMELTING COMPANY, LIMITED. The second-to-last sentence in this memorandum reads: *Lead varied from 0.1% in the copper slag to 3.2% in the lead slag averaging 2.2%* (TECK 1123873).

If Mr. McNaughton were alive today, I'm sure he would quickly agree with JFH's insistence on avoiding the use of *lead slag* and *copper slag* at Trail, particularly not in the same sentence! The only other use of *lead slag* at Trail that was discovered appeared in a *CHARGE TO FURNACES* sheet in 1980 (TECK 1554292).

Page 18 – Section VIII-A, (Copper ore…) *is incomplete. Since 1989 copper matte has been processed to produce copper sulphate and to better manage arsenic by recovering it as copper arsenate.*

Response: I have added to Section VIII-A (Copper ore) JFH's sentence: *Since 1989 copper matte has been processed to produce copper sulphate and to better manage arsenic by recovering it as copper arsenate.* Note that Trail's production of copper sulfate and copper arsenate from matte and high-arsenic flue dust since 1989 is (and was) included in Section XIV-F: *Copper Products Plant – 1989*.

Page 18, Section VIII-A (Location of the Trail Smelter, last paragraph**)** *is out of place. It belongs at the top of page 17.*

Response: Agree. This paragraph has been moved to precede Figure 1.

Page 19, Section VIII (Production of sulfuric acid from roaster offgas, Paragraph 2**)**, *incorrectly says "…captured metal values became available for disposal to the Columbia River". This statement ignores the use of settling ponds, called the Glover Tower ponds, to remove much of the suspended particulate and hence most of the metal values in the scrubber effluent. When errors in metallurgical accounting for effluents were being diagnosed by such engineers as Beley, the Glover Tower pond overflow was used, not the total from the process.*

Response: The context within *Production of sulfuric acid from roaster offgas* (Section VIII-A) is:

> *Acid production required thorough scrubbing of sinter-plant and roaster offgas. This scrubbing captured metal values that now became available for disposal to the Columbia River.*

JFH's findings above, and an explanation of my findings, are now included within the *Production of sulfuric acid from roaster offgas* subsection of Section VIII-A. I furthermore propose adding to the text of Opinion #9 to directly address JFH's concerns, as shown below:

> **Opinion #9** ***(Not contested, but expanded to address JFH concerns)*****:** Acid production required thorough scrubbing of sinter-plant and roaster offgas. This scrubbing captured metal values that were now available for recovery, inventory, landfill, and/or disposal to the Columbia River, rather than possible release to the atmosphere.

Page 30, Section VIII-A (The modernization of Trail) – *The Thallium Removal Plant mentioned here was started in 1989 but shutdown within weeks as a failed process. It was re-developed and put on-line in the Drossing Plant in 1998. Actual Thallium removal started in 1993 with a Thallium Dichromate Precipitation Process installed in the Cadmium Plant.*

Response: I have adjusted the date of thallium removal in Section VIII-A to match JFH's findings.

Page 30, Section VIII-A (The modernization of Trail) – *Slag discharge to Columbia was 99.5% eliminated in July 1995, only a few hundred tons discharged in 1996-1997 as Cominco stabilized the closed granulation system. After that time barren slag continued to be produced but was stockpiled, not put into the river. The stockpile was retreated through #2 SFF starting in 2000 to make a commercial product now called Ferrous Granules.*

Response: I have included JFH's findings above in Section XIV-M.

Page 30, Section VIII-A (The modernization of Trail) – *the "Indirect heat exchange in the lead smelter in 1994" is incomplete. It should read "Indirect heat exchange on #7 sewer in the lead smelter in 1994" because this was effectively the elimination of the major contaminants Hg and As in this sewer (as pointed out by Mr. Queneau page 75 item J) even though it ran acidic solution to river until 1998 as noted at the bottom of the list. I've calculated the 1993 to 1994 drop in Hg in #7 sewer was 97.7% in reference (33).*

Response: I have adjusted the *Indirect heat exchange…* sentence in Section VIII-A to match JFH's findings, and have inserted JFH's text above into Section XIV-J.

Page 57, Figure 19 (Section XII-D) *is misleading. The document is from much later than 1930, probably the late 60's just as the Cominco was gearing up research to develop a new process. R&D did begin at this time in many companies. Cominco ran into two big dead ends including a Hydrometallurgical Lead process which no company has yet made successful and a shaft smelting process which worked but could not finish the slag-bullion separation. The KIVCET process solved this in the 1980's by adding an electric furnace. "New Technology" took 20 years to develop and it was being done around the world! In addition, at the time this was written there would not have been technology to deal with the "effluent to the river" from the sinter plant…this technology was developed in the 1970's and resulted in the HDS Effluent Treatment Process installed by 1981.*

Response: Figure 19 has been replaced with JFH's figure from Appendix 1 of JFH's 30Nov10 Expert Opinion (p 28). I have modified this figure to include discharge of lead BF slag to the river

Page 63 (Section XIII-B) – *see comment for Page 30 above, #7 Sewer Hg was substantially eliminated in 1994 not 1998.*

Response: I have noted that 1994 marked a major reduction of Hg into #7 Sewer (Section XII-B).

Page 65 (Section XIII-C) – *The 2002 Quicksilver document (38) cannot be used for the purpose quoted. This document is very much an order-of-magnitude look at the mercury issues in Trail written for a motivational Tuesday seminar in Research. Although it does present data on page 16 and 41 these are order-of-magnitude estimates at best and are definitely not a year 2002 balance as Mr. Queneau takes it to be. I calculated the mercury input for 2002 (34) using the COCR documents (39;* {Custom Ores and Concentrates Received}*) and assays archived in LIMS6* {Laboratory Information Monitoring System} *and show that the measured inputs were very close to 34.5 tons in that year not 73 tons.*

Response: I have inserted JFH's findings above into Section XIII-C (the Quicksilver discussion). I have also have made a substantial effort in the Inputs and Distributions Spreadsheets to discover and use the Hg-related information that JFH provided to address mercury concerns detailed in JFH's 30Nov10 Expert Opinion.

Page 66 (Section XIII-C) – *Item 3 quotes from Magoon's 1990 paper which reports 500 kg of calomel produced in 1990; the paper is in error. Thornton (35) reports 19.8 kg/day being produced for a total of 7.8 tons/year, very close to Mr. Queneau's estimate.*

Response: I have inserted S.E. Thornton's findings into Section XIII-C (the Quicksilver discussion).

Page 66 (Section XII-C) – *Mr. Queneau refers to the Glover Tower ponds as possibly being part of the 2002 balance. These ponds were eliminated in 1993-94 to make room for a Zn concentrate receiving and preparation area.*

Response: I have eliminated reference to the Glover Tower ponds in the 2002 balance discussed in Section XII-C.

Page 72 (Section XIV-E) – *End of section E is misleading. The Halide Leach effluent stream continues to be discharged without treatment because it is controlled by pH and its turbidity is monitored. This approach minimizes the Cd and As in the effluent and the stream continues to meet permit requirements. A treatment process has indeed been devised but not implemented due to its high cost both capital and operating and cannot be justified as long as we meet our permit.*

Response: I have included the above at the end of Section XIV-E.

Page 77 (Section XIV-P) – *Consuming Zn Plant Fe residues by 2010 was infeasible both economically and due to several process constraints including copper and zinc into KIVCET; copper because KIVCET removed sulphur more completely than expected and zinc because it turned out to be one of the factors causing accretions in the electric furnace. Both constraints are being addressed and processing does continue at a reduced rate; these Fe residues are now forecast to be consumed by 2016.*

Response: I have included the above in Section XIV-P.

APPENDIX G: Response to John F. Higginson's (JFH's) Critique of the "Inputs and Distributions Spreadsheets"; see p 19 of JFH's 30Nov10 Expert Opinion"

1. *Pb production from 1906-2009 is over-estimated on Sheet 3 because Mr. Queneau took the values reported for the corporation. For 1969-71 however, these included production at another Cominco property called Magmont (see footnote "1" in 1970 annual report (17) page 1). The Iron-in-Feed Method 3 discussed earlier used the tons produced at Trail according to Trail Operations' reports. This resulted in 113,182 fewer tons than Mr. Queneau used. Minor differences, both positive and negative occur in other years. Overall these will result in an over-estimate of 75,000 tons of slag produced.*

Response: The Pb production data, as detailed in JFH's Iron-in-Feed Method 3 discussion, have been confirmed from the provided metallurgical reports. These data have been inserted into the Spreadsheets.

2. *Zn production differences on Sheet 3 appear to be mostly caused by difference between the product reported as sold versus the Trail records of Zn produced, i.e. there were a number of large year-end inventories of metal. The Iron-in-Feed Method 3 above relies on the Company's Annual Reports (17), corrected to Trail production records where these were available, particularly in year-end metallurgical statements.*

   Response: The Zn production data, as detailed in JFH's Iron-in-Feed Method 3 discussion, have been confirmed from the provided zinc plant metallurgical reports. These data have been inserted into the Spreadsheets. Where inventory information was available and discovered, it now is included in the Spreadsheets.

3. *Slag production in Sheet 14 Column G is over-estimated by about 20% due to dependence on the "DD Logan formula" and not taking off-setting factors into account. The Iron-in-Feed method is based on an iron balance and takes into account high grade and non-slag making feeds such as battery plates, battery sludge, and Zn oxide feeds as well as recorded weights and grades of custom concentrates as previously discussed in this report.*

   Response: Slag weights from JFH's Iron-in-Feed Method #3 have been inserted into the Spreadsheets.

4. *The tons of Pb in barren slag discharged is over-estimated on Sheet 14 and in Table 3 on Page 91 of the report. In cell O17 of Sheet 14 Mr. Queneau uses 0.11% for all years 1930 to 1997. From Murray 1933 (12) page 99 that Pb was reduced to 0.05% and from MacNaughton 1936 page 736 that Pb was reduced to 0.03% and in the 1962 survey over 3 months the Pb ranged from 0.06% to 0.08%. Using all these figures and metallurgical accounting numbers from 1974 onward,* ***I have calculated 8,014 tons of Pb in barren slag discharged compared to Mr. Queneau's calculation of 13,463 tons.*** *These figures do not include any possible discharge of lead in Pb BF slag which Mr. Queneau adds for 1921-1930.*

   Response: I attempted to discover fumed-slag lead contents from the documents and papers available to me (which included the Murray and McNaughton papers that JFH cited). Cominco's Richard Fish reported in May 1981 that the *typical lead analysis* of fumed *furnace slag* was **>0.10% Pb** (*Challenges Met at Trail: $700 Million Modernization*

Project, Canadian Mining Journal, 1981, p 55). Furthermore, Trail prepared in 1984 a detailed confidential description of its operations: ***Trail Operations*** *– A basic technical description of the main production facilities* (TECK 0337307). Table II provides the *typical assay* for lead in *Fumed Furnace Slag:* **0.10% Pb**.

Having access to 1800+ additional documents has resulted in discovery of numerous additional fumed-slag analyses, which now appear in the Inputs and Distributions Spreadsheets.

Several fumed-slag lead assays appearing in Trail memorandums I discounted due to my belief that they are not representative:

- Where special plant-scale fuming runs were undertaken specifically for obtaining slag analyses, e.g., TECK_1554104.
- Where I was unable to discover fumed slag assays for a given year, values typical for the period have been inserted and noted. See Explanation of Spreadsheet Details.
- One would expect that as the decades passed, slag lead content would decrease due to 1) improved fuming practice and 2) longer fuming times.

5. *The large As and Cd tons discharged in barren slag estimated by Mr. Queneau are what I would call order-of magnitude estimates. Mr. Queneau uses reasonable estimates of 0.01% As and 0.001% Cd respectively but I found no year-by-year data and very little data of any kind on which to base such an estimate. The only citable data found were two deportment surveys. These surveys are purposefully carried out when plants are running smoothly, so they are indicative of what can be achieved but not representative of average operations. The three 1-month results in a 1962 survey (40) showed As in slag was less than the detection limit of 0.005% in all cases. The Cd was 0.0007%, 0.0008%, 0.0009%, 0.0016% and 0.002%. In a 1976 survey (41) the 3-day cumulative sample showed no As or Cd as both were below reliable detection limits (unstated).*

Response: Care has been taken to discover fumed slag As and Cd contents from the documents and papers that are available to me. Several fumed-slag As and Cd assays I have discounted due to my belief that they are not representative:

- Where special plant-scale fuming runs were undertaken specifically for obtaining slag analyses, e.g., TECK_1554104.

- Where annual data are not available, typical values typical for the period have been inserted. See Explanation of Spreadsheet Details.
- One would expect that as the decades passed, slag As and Cd content would decrease due to 1) improved fuming practice and 2) longer fuming times.

6. *Mr. Queneau's estimation algorithm for effluents and emission losses is incorrect because the Zn and Pb inputs and outputs are not made to balance:*

6.1. ***Sheet 16 shows a Zn imbalance of +1,127,000 tons*** *in column K from 1921-19957. It would have been much more correct to close this balance to zero if actual inventory was not known. In fact the inventory is known – it was closer to 86,000 tons using approximate Zn assays for the stockpiles shown in Table 2 above from Abbey (19).*

Response: The revised spreadsheet shows a zinc imbalance of minus 367,000 tons for the period 1923 to 1996, i.e., within 2.7% of closure as compared to the amount of zinc in plant feed. This closure is well within JFH's finding on metallurgical accounting uncertainties (JFH's 30Nov11 Expert Opinion, p26):

> Met Accounting has to deal with uncertainties (e.g. weights are very rarely better than +5% and often +10-15%), measurements over longer time periods than reporting periods, and outright estimates rather than measurements (such as a surveyed volume of a slag pile times an average density). All of these result in unaccounted gains or losses and possibly systematic errors with no single way to resolve the differences so that the Financial Accounting systems are periodically forced to write-off the losses or adjust up for the gains.

6.2. ***Sheet 14 shows a Pb imbalance of +667,000 tons*** *in column K by 1921-1995. It would have been much more correct to close this balance to zero if actual inventory was not known. In fact, the inventory is known – it was closer to 40,000 tons using approximate Pb assays for the stockpiles shown in Table 2 from Abbey (19).*

Response: The revised spreadsheet shows a lead imbalance of plus 266,000 tons for the period 1923 to 1996, i.e., within 2.4% of closure as compared to the amount of plant feed. This closure is well within that experienced at Trail, i.e., *weights are very rarely better than +5% and often +10-15%*.

6.3. *The preceding two items cause the total feed tonnage being over-estimated by 2 million tons of Zn concentrates (50% Zn grade) and 1 million tons of Pb concentrates (60% Pb grade). This leads to an overestimate of effluents and emissions in the same proportion.*

Response: The Inputs and Distributions Spreadsheets have been adjusted to accommodate the additional data that JFH provided.

7. *Mercury inputs (Sheet 15) are greatly over-estimated for all years because Mr. Queneau's algorithm has three errors:*

7.1 *The tons and quality of Custom Pb and Zn concentrate are under-estimated. Using 2002 as an example, Red Dog Pb concentrate was actually 8,000 tons not 129,000 tons (Sheet 4 line 210) while Red Dog Zn concentrate was 278,000 tons not 447,000 tons (Sheet 4 line 210) from COCR's (39). The large tonnages of South American and Mexican concentrates were apparently not known to Mr. Queneau.*

Response: The Custom Ores and Concentrate Receipts (COCR) information was not available prior to submitting of my 17 Sept 10 Expert Opinion. This information, to the extent that I was able to discover its components, has been inserted into the Inputs and Distributions Spreadsheets.

7.2 *Mercury in Custom Zn concentrates averaged 22 ppm, much less than the 60 ppm assumed by Mr. Queneau, resulting in an input of 34.5 tons for 2002 (34) instead of 53 tpy Mr. Queneau computed.*

Response: The mercury assays of annual custom zinc concentrates received, to the extent that they could be discovered, have been inserted into the Spreadsheets. Where assays were not discovered, Sullivan zinc concentrate assays were used as the default.

I see that JFH also relied on the Sullivan default: *Custom ore's and concentrate's Fe grades were conservatively estimated at Sullivan grade* (p 9 in JFH's 30Nov10 Expert Opinion).

7.3. *Custom Zn concentrates were assumed by Mr. Queneau to be 60 ppm for all years back to 1921 but this misses the many years of very low Hg concentrates including Pine Point and Pend Oreille. So for example, we have data from Hastings (37) showing 8.75 tons Hg input in 1970 while Mr. Queneau calculates 18.96 tons per year (Sheet 15 row 63), a 215% over-estimate.*

Response: To the extent that Pine Point and Pend Oreille data have been both provided and discovered, these have been inserted into the Spreadsheets. Sullivan zinc concentrate was used as the default concentrate.

8. *Cadmium inputs (Sheet 13) are over-estimated (similar to the reason for mercury in point 6.1 above) for 1990-date because Red Dog concentrate tons are over-estimated*

and the 0.33% Cd in Red Dog is more than twice as much as Sullivan and Customs (0.14% average).

Response: Values from the COCR material and other metallurgical data summaries, to the extent that I was able to discover its components, have been inserted into the Inputs and Distributions Spreadsheets.

9. *Slag discharged on Sheet 6 Rows 7 to 16 shows all lead-BF slag produced as being discharged to Columbia rather than any to stockpile in spite of the comments in the first 2 paragraphs on page 27 of the "Expert Opinion" report (2). I agree with the latter comments; I think they should be reflected in the spreadsheet.*

Response: See Opinion #4 and #20 (Revisited). The Spreadsheets have been updated to include revised and pre-1930 discharges accordingly.

APPENDIX H: Response to John F. Higginson's (JFH's) Critique of the "Explanation of Spreadsheet Details"; see p 22 of JFH's 30Nov10 Expert Opinion"

Page 3 – *Assumes Red Dog Pb concentrate treated at relatively high levels since 2002. In fact, only very small amounts of Red Dog Pb have been treated in test lots due to its high Zn content. Regular shipments to Trail are only a few hundred tons per year to be used as a reductant in the In/Ge plant. The Pb did not come from Red Dog but from a variety of other, primarily South American sources and the production volume of Pb has declined.*

Response: COCR was provided to me after I had submitted my 17Sept10 Expert Opinion.[20] This material, to the extent that I was able to discover its components, has been inserted into the Inputs and Distributions Spreadsheets.

Page 3 – *The Pb concentrate assumptions are overestimated for 1975 to date, missing the facts of clean Pine Point lead concentrate for part of the 1970's and clean Pend Oreille concentrate 2004-2009 as well as the high volumes of recycled Pb from battery scrap since 1980's, in the range of 20,000 to 40,000 tpy (4).*

Response: The COCR data included the Pine Point and Pend Oreille lead concentrates plus battery scrap information. To the extent that I was able to discover these components, the information has been inserted into the Inputs and Distributions Spreadsheets.

Page 13 – *The statement "…beginning in 1943 it is assumed that the sintering off-gas*

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[20] The COCR provided to me was broken up into small sections in deactivated Tiff format. The remnants were laboriously reconstructed, retabulated, then the extracted data inserted into the Spreadsheets.

joined the roaster off-gas for acid production" is not correct. It misses the fact that sinter off-gas was treated separately in an ammonia absorption process and the product ammonium bisulphate was pumped to be treated with the Zn absorption solution resulting in liquid SO2 and ammonium sulphate fertilizer products, not sulphuric acid. The deportment of impurities such as Hg are therefore affected in significant ways.

Response: The deportment of mercury in the sintering plant's ammonia absorption process has been incorporated into the Inputs and Distributions Spreadsheets. Toward this end, TECK_1122418 (Hg Balance Smelter, 1983) was particularly helpful.

Page 14 - *Pressure leach residue containing mercury has always recycled to roasters, not sinter plant or KIVCET* (p 22 of JFH's 30Nov10 Expert Report).

Response: Once again, I have a problem with JFH's use of the word "*always*".

- Immediately above JFH states that *pressure leach residue containing mercury has always recycled to the roasters…*
- Three pages later, in JFH's ***Fe residues*** section (p 25), he states: *First the* {zinc} *concentrate is pressure leached… the residue is passed to the Pb smelter*.
- But Cominco's John Ashman states that autoclave leach residue, following rejection of elemental sulfur, *is currently pumped directly into the calcine leaching circuit (sulfide leaching plant).* See Ashman, 1990, p 265.

JFH's associate's use of *currently* may explain why all three destinations for autoclave residue may be correct.

Page 14 - 16 - *All of the mercury deportment assumptions are speculation, data does not exist to support them.*

Response: The 1800+ documents provided do include both specific and estimated deportments for mercury at Trail operations. Where data are either missing or not provided, values have been estimated. JFH's input toward these ends has been most helpful.

APPENDIX I: Response to JFH's Opinion #2: Constant Properties of Barren slag Put into Columbia River; see pp 11 - 12 of JFH's 30Nov10 Expert Opinion

Page 11 - *The granulated barren slag put into the Columbia River starting in 1930 and in each of the years until 1995 was essentially the same material in its elemental constituents, its mineral compounds, and its physical form.*

Response: Disagree. See my discussion below on the variability of the composition of both lead BF slag (prior to 1930), and fumed slag.

Page 11: ***Opinion #2.1*** *- The properties of barren slag are affected very little by process changes upstream of the slag fuming furnace so changes in sintering and blast furnace practices through this time did not have any effect on the barren slag produced.*

Response: By "practices", I understand that JFH is referring only to how the sintering and BF operations were practiced, but not the composition of the raw materials. If this understanding is correct, I agree.

Page 11: ***Opinion #2.2*** *– Variation in the slag fuming operating practices were few through this time, not enough to change the properties of the barren slag.*

Response: By "practices", I understand that JFH is referring only to how the fuming operations were practiced, but not the composition of the raw materials. If this understanding is correct, I agree.

Page 11: ***Opinion #2.3*** *– The variation in concentrate and Fe residue feeds to the Pb smelter were small because they were so dominated by the Sullivan Pb and Sullivan Zn concentrates.*

Response: Disagree. See my discussion below on the variability of the composition of both lead BF slag (prior to 1930), and fumed slag.

Furthermore, the degree that Sullivan concentrates dominated Trail's feedstock composition varied widely over the decades. This variation is illustrated by the percentages of Sullivan lead concentrate entering Trail's lead smelter during the following years:

- 1930: 96%: 219,000 tons out of 228,000 tons total
- 1957: 70%: 115,000 tons out of 165,000 tons total
- 1967: 43%: 123,000 tons out of 288,000 tons total
- 1969: 46%: 132,000 tons out of 288,000 tons total
- 1980: 55%: 121,000 tons out of 221,000 tons total
- 1993: 60%: 74,000 tons out of 123,000 tons total

Page 11: ***Opinion #2.4*** *– The changes in fluxing practice over this time did have an effect on the barren slag. However, fluxing is constrained to move in a narrow range to produce suitable melt viscosities so the silica, lime and iron ratios of the 1930 barren* *slag were very similar to those of 1995.*

Response: I agree that changes in fluxing practice did have an effect on the composition of both the lead BF slag (prior to fuming in 1930), and the fumed slag. I also agree that fluxing practice is constrained with respect to silica, lime, and iron addition in order to attain suitable melt viscosities (and to achieving suitable basicity to maximize zinc recovery).

<u>Page 11</u> - *The properties of barren slag are the result of four factors*

1. *The chemical analysis of the feed materials*
2. *The length of fuming time*
3. *The degree of oxidation-reduction in the fuming furnace*
4. *The granulation process*

Response: Agree.

<u>Page 12</u> - *None of the foregoing factors are affected by sintering or blast furnace practice. As the number of sintering machines changed and practices changed, they affected the blast furnaces but not slag fuming. As practices changed in the blast furnaces, the ferrous-to-ferric ratios in BF slag changed but these were changed again in the SFF and therefore the barren slag properties were not related to the blast furnace practice.*

Response: By "practice", I understand that JFH is referring only to how the sintering and BF operations were practiced, but not the composition of the raw materials. If this understanding is correct, I agree.

<u>Page 12</u> - *The chemical analysis of SFF feed materials is mainly determined by the fluxing which determines the ratio of SiO2-to-CaO and SiO2-to-Fe.*

Response: Disagree. The chemical analyses of SFF feed materials is determined not only by flux composition, but also by:

- The composition of ores and concentrates
- The composition of ash in the coke and coal
- The alumina, magnesia… content of the flux
- The tonnage and types of recycled residues, fume, and slag
- The tonnage and type of secondaries, e.g., spent battery components

All of the above contributors to feed composition varied significantly over the years.

<u>Page 12</u> - *These ratios have historically fallen into the same range as shown in Table 5.*

Response: Disagree. Table 5 averages out the analyses of *Barren Slag Chemical Constituents* over a whole year, which masks daily variations. Even with annual averaging, the variations shown in Table 5 are substantial. Blast furnace slag produced prior to 1930, before the advent of slag fuming, had an even higher variability of chemical constituents.

For additional details on the variation in lead BF slag (pre-1930) and fumed slag analyses, see my Section XV-A, as well as the paragraphs immediately below.

Variability lead BF slag analyses: *In regard to blast furnace practice, so many slag types have been run, of such varied analyses, that it is doubtful whether any other one smelter has ever had quite the same "ups and downs" with slag-forming elements as can be seen in the Trail slag-graphs. These show a variation in silica of from 16 to 39%, in Fe of from 17 to 35%; in CaO of from 6 to 19%, and in Zn from 2.5 to 22%.* See Trail's 1924 paper written by Consolidated Mining and Smelting Company of Canada Staff (p 401).[21]

Iron variability in fumed slag: Average values (1930 – 1995) varied from 31.1% to 37.5% (JFH's Table 5, p. 12). Fumed slag iron analyses at Trail have also been higher than this range, e.g., 43% (1989), 48% (1991), and 43.5% (1993); see TECK 084150.

Silica variability in fumed slag: Based on analyses that I discovered, the silica content of Trail fumed slag was maintained within a tight range, i.e., 26 to 31% SiO_2.

Lime variability in fumed slag: Lime content in Trail fumed slag was variable, depending on the desired silica-to-lime ratio. Average values for this ratio, which is a key variable when fuming slag, varied from 1.7 to 2.46% CaO (JFH's Table 5, p. 12). Lime content of Trail fumed slag varied from 9 (Anonymous, 1937, p 11) to 17% (Fish, 1981, p 55), based on documents that I was able to discover.

Alumina variability in fumed slag: Average annual assays for Al_2O_3 in JFH's Table 5 vary from 4.6 to 6.6%. Yet Consolidated Mining and Smelting's comprehensive 1954 publication cites 8.5% alumina as being a *Representative Analysis* of *Fuming Furnace Slag*; see p 55.

Copper variability in fumed slag: Copper content of fumed slag is clearly variable, as shown in JFH's Table 5, i.e., 0.18 to 0.7%. Furthermore, see the copper analyses of four fumed slag composites from 1991; variation is from

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[21] Note the contrast between the variability of Trail slag analyses reported by Trail with those provided by Riese on page 10 of his Expert Opinion.

0.76% Cu to 1.45% Cu (Cominco Research; TECK 0338655).

Metal Assay Variability by Particle Size: Fumed slag, once it has entered the river, will likely segregate by particle size. The finest fractions (<45 microns) tend to have substantially higher Pb, Cd, and Cu concentrations than the coarser fractions. See Cominco Research (1991, TECK 0338671):

Lead:	Fines: 0.69 to 1.28% Pb	Coarse: 0.03 to 0.11% Pb
Cadmium:	Fines: 0.013 to 0.018% Cd	Coarse: 0.001 to 0.007% Cd
Copper:	Fines: 1.43 to 2.05 % Cu	Coarse: 0.85 to 1.15% Cu

Page 12 - ***Fuming time*** *was reported as 135 minutes in 1931 (22) increased to 155 minutes in 1937 (16) in order to achieve under 3.0% Zn in barren slag. Fuming (or "blowing") time was up to 160-170 minutes in 1970 with a target of 2.5% residual zinc (18) which continued essentially unchanged through to 1995. Fuming time affects the residual Zn and other metals in slag but not the other chemical or mineralogical properties.*

Response: Agree.

Page 12 - ***The degree of oxidation-reduction*** *in the SFF is measured by the ferrous-to-ferric ratio or FeO:Fe2O3. This is very rarely measured but affects the slag melting temperature strongly so operating temperature is a very good indirect measure. Slag temperature was reported to be maintained at 2250 F (1220C) in 1931 (13) and the same 1200C continued to be the target until 1995. The sample #3 in Table 5 was taken when #2SFF was at 1240C. If all the FeO was oxidized to* Fe_2O_3 *the melting temperature would increase to about 1350C (8) so it was very much in the operator's interest to maintain strong reducing conditions with sufficient quantities of coal and the 1200C target because oxidation increases at higher temperatures.*

Response: Agree.

Page 12 - ***The granulation process*** *in 1931 for #1 SFF consisted of discharging through 2 tap holes into a rapidly flowing stream of water; 50 tons was discharged in 20 minutes (13). By 1970 the practice had changed only slightly using high pressure water jets to granulate the slag as the two tap holes were opened in succession (18). The water flow was 4 to 5 tons per ton of slag. The main physical properties affected by granulation are the size distribution and the bulk density of the slag. Density and size distributions are listed in Table 6.*

There is much variation in the most coarse fraction of barren slag but greatest part of the slag is -10+100 mesh with a quite consistent 0.1-0.2% in the -325 mesh fraction over the years shown. The dry bulk density is nominally 1.7. Reference (27) shows an increase of 0.5 units in wet bulk density and 0.3 units in dry bulk density as a result of packing indicating much irregularity of particle shapes.

Response: Agree.

APPENDIX J: Photographs

See attached file: Photos for PBQ Expert Opinion & Rebuttal

APPENDIX K: Tabulation of Slag Tonnages

See the attached file: TECK_0715785(1).XLS

APPENDIX L: Tabulation of Recorded Spills

See the eight pages on spill details that follow immediately below.

Table X. Reported spills from the Trail facility to the Columbia River, as compiled from various sources of information.

year	*constituent*	*spill date*	***[22]March 2003 Upper Columbia River Expanded Site Inspection Report, EPA Region 10***	***[23]February 20, 2004 Colville Confederated Tribes Briefing Document, based on documents provided by the Canadian government***		***[24]September 21, 2007 Upper Columbia River Remedial Investigation and Feasibility Study Work Plan***	
			quantity released	*quantity released*	*location*	*quantity released*	*permit limit*[*]
1980	**Hg**	March 19				7000 kg d^{-1}	0.258 kg d^{-1}
	NH_3HSO_3	July 13				500 gallons	
	H_2SO_4 (93%)	November 1				30 tonnes[†]	
	P_2O_5	November 4				24 tonnes	
1981	**Zn**	April 23				9500 kg d^{-1}	9070 kg d^{-1}

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[22] U.S. Environmental Protection Agency. *Upper Columbia River Expanded Site Inspection Report, Northeast Washington, TDD: 01-02-0028.* March 2003. ***Information based on Environment Canada Spilltracker Database, as provided in McDonald 1997, and personal communication with Environment Canada staff.***

[23] *Teck Cominco Metals Ltd. Trail Facility: Massive Pollution, Gross Non-compliance and Government Lack of Enforcement, a Briefing Document*. Submitted to the U.S. State Department and the U.S. Environmental Protection Agency by the Confederated Tribes of the Colville Reservation (CCT); February 20, 2004. ***Information based on the Freedom of Information and Privacy Act (FOIPA) documents produced by the Canadian Government to CCT.***

[24] *Upper Columbia River: Work Plan for the Remedial Investigation and Feasibility Study*. Prepared for Teck Cominco American Incorporated by Integral Consulting, Inc. and Parametrix in association with HydroQual, ENTRIX, HDR-|-FISHPRO and Archeological Investigations Northwest; September 21, 2007. ***Information based on facility information provided by Teck Cominco American Incorporated and records maintained by the B.C. Ministry of the Environment.***

Table X. Reported spills from the Trail facility to the Columbia River, as compiled from various sources of information.

year	*constituent*	*spill date*	[22]*March 2003 Upper Columbia River Expanded Site Inspection Report, EPA Region 10*	[23]*February 20, 2004 Colville Confederated Tribes Briefing Document, based on documents provided by the Canadian government*		[24]*September 21, 2007 Upper Columbia River Remedial Investigation and Feasibility Study Work Plan*	
			quantity released	*quantity released*	*location*	*quantity released*	*permit limit**
	H_2SO_4 (93%)	May 4				25-30 tonnes	
	NH_3HSO_3	May 13				4000 gallons	
	H_2SO_4 (93%)	August 4				53 tonnes	
	H_2SO_4 (93%)	October 6				40 tonnes	
1982							
1983							
1984							
1985							
1986							
1987	**H_2SO_4 (50%)**	September 2	15 tonnes				
1988	**Zn solution (150 g L^{-1})**	November 25	5 tonnes**				
1989	**As**	July 17	Unknown**				
	Gypsum and H_3PO_4	July 16	Unknown**				
	Neutral thickener	May 1	60,000 L				
	Yellow substance	August 18	305 meters long				
1990	**Hg**	March 6	14 kg				
	Zn	September 4	Unknown (electrolyte)				
	Sulfuric acid (H_2SO_4)	January 20	unknown (93%)**				
		April 26		300-400 gal (93%)	Sewer 08		
		June 11	909 L				
		August 23		> 30 tonnes	Outfall III		
		August 24	16,000 L				
1991	**Cd**	May 7		0.070 mg L^{-1}	Outfall III		
		May 7		0.090 mg L^{-1}	Outfall II		
		November 5				0.07 mg L^{-1}	0.05 mg L^{-1}
	Hg	March 6		0.056 mg L^{-1}	Outfall 07		
		July 18				0.014 mg L^{-1}	0.01 mg L^{-1}
	Pb	February 5		0.53 mg L^{-1}	Outfall II		
		March 6		1.80 mg L^{-1}	Outfall 07		
		March 6		0.56 mg L^{-1}	Outfall II		
		August 14				1.7 mg L^{-1}	1 mg L^{-1}
	Zn	January 30	576 kg				
		February 11	4,546 L (sulfide residue)				
		April 21	220 L (solution 160 g L^{-1})				
		September 17				8.5 mg L^{-1}	5 mg L^{-1}
		October 1				8.2 mg L^{-1}	5 mg L^{-1}
		November 5				5.8 mg L^{-1}	5 mg L^{-1}
		December 3				7.3 mg L^{-1}	5 mg L^{-1}
		December 7	881 L (electrolyte)				
	Copper Sulfate ($CuSo_4$)	February 5	3,000 L				
	Sulfuric acid (H_2SO_4)	March 16	4.54 tonnes				
		April 13	1,000 L (15%)				
		April 13	Unknown (160 g L^{-1})				
		September 16	132 to 176 L				
	Phosphoric acid (H_3PO_4)	February 7	0.9 to 1.8 tonnes				
		April 2	15 tonnes				
		April 6	1.35 tonnes				

Table X. Reported spills from the Trail facility to the Columbia River, as compiled from various sources of information.

year	*constituent*	*spill date*	***[22]March 2003 Upper Columbia River Expanded Site Inspection Report, EPA Region 10***	***[23]February 20, 2004 Colville Confederated Tribes Briefing Document, based on documents provided by the Canadian government***		***[24]September 21, 2007 Upper Columbia River Remedial Investigation and Feasibility Study Work Plan***	
			quantity released	*quantity released*	*location*	*quantity released*	*permit limit**
		June 15	2 tonnes (weak)				
		June 21	unknown				
		June 24	2.72 to 3.63 tonnes (27%)				
	Phosphates (PO_4^{3-})	June 21	6.7 tonnes				
	Total suspended solids (TSS)	December 20		1165.3 kg d^{-1}	Outfall III		
		January 16		157.0 mg L^{-1}	Outfall II		
		September 17				39 mg L^{-1}	
		October 1				12475 mg L^{-1}	
		November 5				10989 mg L^{-1}	
		December 3				18670 mg L^{-1}	
	Flow	June 18		426600 m^3 d^{-1}	Outfall II		
	Partially treated slag	August 24		50 tonnes (approximate)	Columbia River		
	Zinc slurry/ pressure leach slurry	May 13	22.7 L				
		December 20	2,273 L				
	$NaHSO_4$	September 16	20 L min^{-1}, quantity unknown				
	NH_3-N	May 13	90.9 L (ammonia)				
		August 14				45 mg L^{-1}	
		September 17				40 mg L^{-1}	
		November 5				40 mg L^{-1}	
	Coal dust/ water	August 1	220 L				
	Furnace oil	September 9	50 tonnes				
1992	**Hg**	June 24				6.8-10 kg d^{-1}	1.05 kg d^{-1}
		September 30	15 kg			60 kg d^{-1}	0.55 kg d^{-1}
		October 1				60 kg d^{-1}	0.55 kg d^{-1}
		December 2		0.014 mg L^{-1}	Outfall III	0.014 mg L^{-1}	0.005 mg L^{-1}
		December 16		0.021 mg L^{-1}	Outfall III	0.21 mg L^{-1}	0.005 mg L^{-1}
	Zn	April 20	25,000 L (electrolyte)				
		May 23	350 L (electrolyte)**			214.1 kg d^{-1}	63.7 kg d^{-1}
	H_2SO_4 (93%)	January 8				100-150 L	
		March 3				NA	
		March 7				1 gallon	
		March 19				20 gallons	
		April 14				30 gallons	
		April 18				100 gallons	
		August 4				5-10 gallons	
		November 3	434 kg			450 kg	
		December 16	25 to 30 tonnes			2.5 tonnes	
	H_2SO_4 (93.5%)	June 8				20 L	
	H_2SO_4 (98 %)	September 5				10-15 gallons	
	Sulfuric acid (H_2SO_4)	February 6				400 L	
		February 22				250 gallons	
		July 14				20 L	
		August 3	Unknown**				
		October 2				20-50 gallons	
		December 4				10-15 gallons	
	H_3PO_4 (21 %)	May 25				5 tonnes	
		May 26	5 tonnes				
	H_3PO_4 (27%)	May 8				NA	
	Phosphoric acid (H_3PO_4)	March 1				NA	
		March 14				NA	
		April 20				NA	
		June 26				1.5 tonnes	
		July 10				NA	
		July 11	unknown				
		August 10				1500 L	
		September 4				NA	
	Phosphates (PO_4^{3-})	March 11	unknown				
		April 2	unknown				

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			quantity released	*quantity released*	*location*	*quantity released*	*permit limit**
	NH_3SO_4	April 9				150 gallons	
	SO_3	May 15				40 gallons	
	Ammonium bisulphite (NH_4HSO_3)	June 4				15 gallons	
		September 14				30-40 gallons	
		December 20				15-20 gallons	
		December 22				400 L	
	Ammonium sulfate (NH_4SO_4)	December 8	12.3 tonnes			12 tonnes	
		December 11	12 tonnes				
	SO_4	October 2				50-100 gallons	
	Sulfide leach residue	April 22	Unknown**				
	Return acid, calcine	July 1				20 gallons	
	ESSO Teresso 68 oil/ Compressor oil	July 23	25 L				
		July 28				25-30 L	
	Transformer oil Voltesso 35	December 17				200 L	
1993	**As**	September 4	60 to 65 kg (dissolved)				
		September 5		Unknown	Outfall III		
		December 9	22 kg (dissolved)				
	Hg	January 5	up to 7 kg				
		January 6		0.13 mg L^{-1}	Outfall III	0.13 mg L^{-1}	0.005 mg L^{-1}
		January 8		0.013 mg L^{-1}	Outfall III	0.013 mg L^{-1}	0.005 mg L^{-1}
		January 12		0.014 mg L^{-1}	Outfall III	0.014 mg L^{-1}	0.005 mg L^{-1}
		April 25		0.028 mg L^{-1}	Outfall III	0.028 mg L^{-1}	0.005 mg L^{-1}
		May 1		0.012 mg L^{-1}	Outfall III	0.012 mg L^{-1}	0.005 mg L^{-1}
		June 4		0.018 mg L^{-1}	Outfall III	0.018 mg L^{-1}	0.005 mg L^{-1}
		June 10	18 kg	0.030 mg L^{-1}	Outfall III	0.3 mg L^{-1}	0.005 mg L^{-1}
		June 14		0.014 mg L^{-1}	Outfall III	0.014 mg L^{-1}	0.005 mg L^{-1}
		June 15		0.032 mg L^{-1}	Outfall III	0.032 mg L^{-1}	0.005 mg L^{-1}
		June 16		0.014 mg L^{-1}	Outfall III	0.014 mg L^{-1}	0.005 mg L^{-1}
		June 20		0.014 mg L^{-1}	Outfall III	0.014 mg L^{-1}	0.005 mg L^{-1}
		June 21		0.01 mg L^{-1}	Outfall III	0.01 mg L^{-1}	0.005 mg L^{-1}
		June 23		0.027 mg L^{-1}	Outfall III	0.027 mg L^{-1}	0.005 mg L^{-1}
		June 28		0.011 mg L^{-1}	Outfall III	0.011 mg L^{-1}	0.005 mg L^{-1}
		July 6		0.011 mg L^{-1}	Outfall III	0.011 mg L^{-1}	0.005 mg L^{-1}
		August 11		0.011 mg L^{-1}	Outfall III	0.011 mg L^{-1}	0.005 mg L^{-1}
		August 21		0.023 mg L^{-1}	Outfall III	0.023 mg L^{-1}	0.005 mg L^{-1}
	Cd oxide (CdO)	November 3	unknown				
	Zn sulfate (150 g L^{-1})	January 7	600 kg				
	Ammonia (NH_3)	March 14	unknown				
	Sulfuric Acid (H_2SO_4)	January 7	13,000 tonnes (50 g L^{-1})				
		July 30	10 tonnes				
1994	**As**	February 9	20 kg			21 kg d^{-1}	NA
		February 9		0.22 mg L^{-1}	Outfall III	0.02 mg L^{-1} ; 2.1 kg d^{-1}	0.05 mg L^{-1} ; 5.5 kg d^{-1}
		March 7		0.18 mg L^{-1}	Outfall III		
		June 7		0.06 mg L^{-1}	Outfall III		
		October 17		unknown	Outfall III		
		November		0.06 mg L^{-1} (once)	Outfall III		
		1994		0.10 tonnes	Outfall II		
	Cd	March 4		0.09 mg L^{-1}	Outfall II		
		1994		0.19 tonnes	Outfall II		
		1994		0.02 tonnes	Outfall I		
	Hg	February 10	1.3 kg				
		March 4		0.022 mg L^{-1}	Outfall II		

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			quantity released	*quantity released*	*location*	*quantity released*	*permit limit[*]*
		July 4	< 1 kg			< 1 kg d^{-1}	0.56 kg d^{-1}
		August 14				0.014 mg L^{-1}	0.01 mg L^{-1}
		October 2		0.006 mg L^{-1}	Outfall III		
		October 18		0.006 mg L^{-1}	Outfall III		
		October 20		0.006 mg L^{-1}	Outfall III		
		November		16 exceedances	Outfall III		
		December 18		0.011 (units NA)	Outfall III		
		December 19		0.009 (units NA)	Outfall III		
		December 21		0.011 (units NA)	Outfall III		
	Pb	March 4		1.50 mg L^{-1}	Outfall II		
	Chlorine	March 5	< 1 kg				
	Zn oxide (ZnO)	October 24	unknown				
	Ammonia (NH_3)	October 5	3,500 kg				
	Ammonium sulfate (NH_4SO_4)	June 1	2 m^3				
		June 13	unknown				
	TSS	March 4		89.0 mg L^{-1}	Outfall II		
		1994		5791 tonnes	Outfall I		
	Flow rate	November		all samples exceedances	Outfall I		
1995	**As**	June 25				12.5 kg d^{-1}	11 kg d^{-1}
	Cd	February 27				NA	3.9 kg d^{-1}
		March 10	70 kg (dissolved)	102 kg d^{-1}	Outfall III	102 kg d^{-1} ; 0.001 mg L^{-1}	60 kg d^{-1} 0.05 mg L^{-1}
		June 25				4.2 kg d^{-1}	4 kg d^{-1}
	Cu	June 25				11.5 kg d^{-1}	5.5 kg d^{-1}
	Hg	February 5		0.3375 kg d^{-1}	Outfall II	0.34 kg d^{-1}; 2.8 E-06 mg L^{-1}	0.15 kg d^{-1}; 0.005 mg L^{-1}
		February 26		0.1804 kg d^{-1}	Outfall II	0.18 kg d^{-1}; 1.7 E-06 mg L^{-1}	0.15 kg d^{-1}; 0.005 mg L^{-1}
		March 9		0.2350 kg d^{-1}	Outfall II	0.24 kg d^{-1}; 2.2 E-06 mg L^{-1}	0.15 kg d^{-1}; 0.005 mg L^{-1}
		March 26		0.6768 kg d^{-1}	Outfall III	0.68 kg d^{-1}; 6.0 E-06 mg L^{-1}	0.55 kg d^{-1}; 0.005 mg L^{-1}
		March 27		0.7659 kg d^{-1}	Outfall III	0.77 kg d^{-1}; 7.0 E-06 mg L^{-1}	0.55 kg d^{-1}; 0.005 mg L^{-1}
		April 3		0.6957 kg d^{-1}	Outfall III	0.70 kg d^{-1}; 8.0 E-06 mg L^{-1}	0.55 kg d^{-1}; 0.005 mg L^{-1}
		April 4		0.9636 kg d^{-1}	Outfall III	0.96 kg d^{-1}; 1.1 E-05 mg L^{-1}	0.55 kg d^{-1}; 0.005 mg L^{-1}
		April 5		0.6624 kg d^{-1}	Outfall III	0.66 kg d^{-1}; 7.8 E-06 mg L^{-1}	0.55 kg d^{-1}; 0.005 mg L^{-1}
		May 5		0.3496 kg d^{-1}	Outfall II		
		May 6		0.4440 kg d^{-1}	Outfall II	0.35 kg d^{-1}	0.15 kg d^{-1}
		May 7				0.44 kg d^{-1}; 3.7 E-06 mg L^{-1}	0.15 kg d^{-1}; 0.005 mg L^{-1}
		May 15		0.8280 kg d^{-1}	Outfall III	0.83 kg d^{-1}; 6.4 E-06 mg L^{-1}	0.55 kg d^{-1}; 0.005 mg L^{-1}
		May 16		0.7688 kg d^{-1}	Outfall III	0.77 kg d^{-1}; 5.5 E-06 mg L^{-1}	0.55 kg d^{-1}; 0.005 mg L^{-1}
		May 22		1.0413 kg d^{-1}	Outfall III	1.04 kg d^{-1}; 7.0 E-06 mg L^{-1}	0.55 kg d^{-1}; 0.005 mg L^{-1}
		May 31		0.2330 kg d^{-1}	Outfall II	0.23 kg d^{-1}; 1.3 E-06 mg L^{-1}	0.15 kg d^{-1}; 0.005 mg L^{-1}
	Pb	June 25				63.8 kg d^{-1}	27.5 kg d^{-1}
	Zn	June 13	960 kg	960 kg d^{-1}	Outfall III	960 kg d^{-1}; 0.005 mg L^{-1}	150 kg d^{-1}; 5 mg L^{-1}
		June 13				1321 kg d^{-1}	550 kg d^{-1}
		June 25				407.6 kg d^{-1}	150 kg d^{-1}
	H_2SO_4	June 25	~1,000 L	3000-5000 L	Outfall III	3000-5000 L	
	Slag	December 7				75 tonnes	
	Coal dust (suspected)	May 22	unknown				
1996	**As**	January 22		0.32 kg d^{-1}	Pond/ cooling water[††]	0.32 kg d^{-1}	0.1 kg d^{-1}
		January 28		0.18 kg d^{-1}	pond	0.18 kg d^{-1}	0.1 kg d^{-1}
		February 4		0.14 kg d^{-1}	pond	0.14 kg d^{-1}	0.1 kg d^{-1}
	Cd	January 10		0.87 kg d^{-1}	Cooling water	0.87 kg d^{-1}	0.5 kg d^{-1}
		January 22		0.14 kg d^{-1},0.82 kg d^{-1}	Pond/ cooling water	0.14 kg d^{-1}, 0.82 kg d^{-1}	0.1 kg d^{-1}, 0.5 kg d^{-1}

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			quantity released	*quantity released*	*location*	*quantity released*	*permit limit**
		February 27	0.01 kg	3.75 kg d^{-1}	Outfall II	3.75 kg d^{-1}	2.75 kg d^{-1}
	Hg	January 26		0.0115 kg d^{-1}	Pond	0.01 kg d^{-1}	0.009 kg d^{-1}
		February 26		0.0199 kg d^{-1}	Pond	0.020 kg d^{-1}	0.009 kg d^{-1}
	Pb	February 27	0.3 kg				
	Zn	January 17	40,000 L (& sulfuric acid)	2074 kg	Outfall III	2074 kg d^{-1}	150 kg d^{-1}
		January 22		39.66 kg d^{-1}	Pond/ cooling water	39.7 kg d^{-1}	20 kg d^{-1}
		February 9		31.52 kg d^{-1}	Pond	31.5 kg d^{-1}	20 kg d^{-1}
		February 21		16.2 kg d^{-1}	Cooling water	16.2 kg d^{-1}	5 kg d^{-1}
		February 21				25 kg d^{-1}	20 kg d^{-1}
		February 27	0.5 kg	35 kg d^{-1}	Pond	35 kg d^{-1}	20 kg d^{-1}
	TSS	January		6431 kg d^{-1}	Pond		
		February		6375 kg d^{-1}	Pond		
		February 15		3459 kg d^{-1}	Outfall III		
		February 21		6987 kg d^{-1}	Cooling water		
	Pb fume slurry	February 26	3 m^3				
	Slag/slurry	May 10	25 tonnes	35 tons (estimated)	Columbia River (unknown)	35 tonnes	
		November 8	35 tonnes (barren)	35 tonnes		35 tonnes	
	Na_2CO_3	February 27	3 m^3				
	NH_3-N	February 9				30 mg L^{-1}	
	White solution & foam	April 7	unknown				
	White discoloration	May 23	unknown				
	White oxide dust	December 31	unknown				
1997	**Cd**	March 13	3,000 kg (incl. Hg, dissolved)	40 kg	Outfall 07	40 kg d^{-1}	3 kg d^{-1}
		March 25	22 kg			22 kg d^{-1}	3 kg d^{-1}
		March 26		25 kg d^{-1}	Outfall III		
	Hg	March 13	3,000 kg (incl. Cd, dissolved)	8.9 kg	Outfall 07	8.9 kg d^{-1}	0.55 kg d^{-1}
		December 12		Unknown	Outfall II		
		December 17	700 L (incl. Zn)				
	Pb	March 13		1450 kg	Outfall 07	1450 kg d^{-1}	17.13 kg d^{-1}
	Zn	July 23	500 kg (as Zn slurry)	500 kg (approximate)	Outfall III		
		December 17	700 L (incl. Hg)				
	TSS	March 13		3200 kg	Outfall 07		
	H_2SO_4	May 20	Unknown (as acidic solution)	600 kg	Outfall III	600 kg d^{-1}	
		July 23		4500 L	Outfall III		
1998	**As**	March 6	5 m^3 (in slurry)	23 kg d^{-1}	Outfall III	23 kg d^{-1}	15 kg d^{-1}
		March 7				23 kg d^{-1}	15 kg d^{-1}
		June 1		20 kg d^{-1}	Outfall II		
		June 2	20.36 kg (total As)			20.36 kg d^{-1}	15 kg d^{-1}
		November 24	20 kg				
	Cd	May 3	15 kg (in solution)	15 kg d^{-1}	Outfall II	15 kg d^{-1}; 0.0002 mg L^{-1}	2.75 kg d^{-1}; 0.022 mg L^{-1}
		December 25	3 kg	6.5 kg d^{-1}; 0.08 mg L^{-1}	Outfall III		
		December 26		4.5 kg d^{-1}	Outfall II	6.5 kg d^{-1}; 0.08 mg L^{-1}	3 kg d^{-1}; 0.03 mg L^{-1}
	Cu	July 30		15 kg d^{-1}	Outfall II	15 kg d^{-1}	8 kg d^{-1}
	Tl	July 21		129 kg	Outfall III	129 kg d^{-1}	NA
		October 12		100 kg	Unknown	100 kg d^{-1}	NA
	Zn	December 25	87 kg				
		December 26				177 kg d^{-1} ; 2.2 mg L^{-1}	90 kg d^{-1} ; 0.9 mg L^{-1}
	Slag cooling water/slag, granulated slag	August 20	~25,000 L (slag, Pb, Zn, H_20)	unknown	Outfall II	1.9 m^3	
		October 24	15 min duration	unknown	Unknown	15 min	

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			quantity released	*quantity released*	*location*	*quantity released*	*permit limit**
	Granulated slag/ Barren slag/ slurry	January 9		unknown	Unknown	1-3 m^3	
		April 7	1 tonne	1-1.5 tonnes	05 sewer	1 tonnes	
1999	**Cd**	March 24		3.53 kg d^{-1}; 0.040 mg L^{-1}	Outfall III	3.53 kg d^{-1}; 0.04 mg L^{-1}	3 kg d^{-1}; 0.03 mg L^{-1}
		March 25		4.01 kg d^{-1}; 0.045 mg L^{-1}	Outfall III	4.01 kg d^{-1}; 0.045 mg L^{-1}	3 kg d^{-1}; 0.03 mg L^{-1}
		March 27		3.32 kg d^{-1}; 0.040 mg L^{-1}	Outfall III	3.32 kg d^{-1}; 0.04 mg L^{-1}	3 kg d^{-1}; 0.03 mg L^{-1}
		September 22		6.04 kg d^{-1}; 0.073 mg L^{-1}	Outfall II	6.04 kg d^{-1}; 0.073 mg L^{-1}	2.75 kg d^{-1}; 0.061 mg L^{-1}
		September 24				5.8 kg d^{-1}; 0.06 mg L^{-1}	3 kg d^{-1}; 0.03 mg L^{-1}
		September 25		5.8 kg d^{-1}; 0.061 mg L^{-1}	Outfall III		
		October 7		3.48 kg d^{-1}	Outfall II	3.48 kg d^{-1}	2.75 kg d^{-1}
		October 11		2.86 kg d^{-1}	Outfall II	2.86 kg d^{-1}	2.75 kg d^{-1}
	Tl	April 17				67.2 kg d^{-1}; 0.7 mg L^{-1}	NA
		April 18		67.2 kg	Outfall III		
		April 18		196 kg	Outfall III	196 kg d^{-1}; 2.1 mg L^{-1}	NA
		April 19		201 kg	Outfall III	201 kg d^{-1}; 2.1 mg L^{-1}	NA
		April 20		136 kg	Outfall III	136 kg d^{-1}; 1.5 mg L^{-1}	NA
		April 21		72.7 kg	Outfall III	72.7 kg d^{-1}; 0.8 mg L^{-1}	NA
		April 22		56.0 kg	Outfall III	56 kg d^{-1}; 0.6 mg L^{-1}	NA
		April 23		39.0 kg	Outfall III	39 kg d^{-1}; 0.4 mg L^{-1}	NA
	Zn	October 4		165 kg d^{-1}; 1.90 mg L^{-1}	Outfall II	165 kg d^{-1}; 1.9 mg L^{-1}	75 kg d^{-1}; 1.4 mg L^{-1}
		October 7				106 kg d^{-1}	90 kg d^{-1}
	Fume contaminated water	July 23		unknown	Columbia River		
2000	**Cd**	February 9		3.74 kg d^{-1}	Outfall II	3.7 kg d^{-1}	2.75 kg d^{-1}
		February 18	10.5 kg	10.5 kg d^{-1}; 0.12 mg L^{-1}	Outfall II	10.5 kg d^{-1}; 0.12 mg L^{-1}	2.75 kg d^{-1}; 0.06 mg L^{-1}
	Tl	October 8		43 kg	Outfall III	43 kg d^{-1}	
		October 10		34 kg	Outfall III	34 kg d^{-1}	
		October 11		31 kg	Outfall III	31 kg d^{-1}	
	Zn	February 18	350 kg	349 kg d^{-1}; 4.0 mg L^{-1}	Outfall II	350 kg d^{-1}; 4 mg L^{-1}	75 kg d^{-1}; 1.4 mg L^{-1}
		March 31				693 µg L^{-1}	900 µg L^{-1}
		April 4				1810 µg L^{-1}	900 µg L^{-1}
	NH_3/ NH_3-N	March 28		up to 1.9 tonnes	Outfall IV	1.9 tonnes	
	Flow rate	July 25		> 125,000 m^3 d^{-1}	Outfall II		
		July 26		> 125,000 m^3 d^{-1}	Outfall II		
		July 29		> 125,000 m^3 d^{-1}	Outfall II		
		July 30		> 125,000 m^3 d^{-1}	Outfall II		
	Low pH alarm	April 18				NA	
2001	**Hg**	May 8				1.42 kg d^{-1}	0.55 kg d^{-1}
	Zn	January 31		529.7 kg d^{-1}	Outfall II	529.7 kg d^{-1}; 6.6 mg L^{-1}	75 kg d^{-1}; 1.4 mg L^{-1}
		November 26		unknown	Unknown	NA	90 kg d^{-1}
	Oil	May 27	10 L			22 L	
	LC50 bioassay	December 3		failed	Outfall II		
2002	**Cd**	October 21		5.4 kg d^{-1}	Outfall II		
	LC50 bioassay	February 19		failed	Outfall IV		
		June 19		failed	Outfall II		
	pH	January 15		8.3	Outfall IV		
2003	**Zn**	January 8		99.5 kg d^{-1}	Outfall II	99.5 kg d^{-1}	75 kg d^{-1}
2004							
2005							

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			quantity released	*quantity released*	*location*	*quantity released*	*permit limit*[*]
2006			▨	▨	▨	▨	▨
2007			▨	▨	▨	▨	▨

*The assumption is that the permit limits given in the Work Plan apply to the values reported in the CCT Briefing Document. In most cases, where data are available for both sources the values are the same. However, different permit limits for the same constituent during the same year implies that the spill location may be different, information that was not provided in the Work Plan.

[†]1 tonne = 1000 kg (also known as a short ton)

[**] = surface spills, potential for groundwater contamination

[††] pond = slag collection pond; cooling water = slag furnace cooling water

▨	No information provided
░	Highlighted difference between sources. Many differences appear to be transcription errors, that is values are off by an order of magnitude, units are partially missing, or date for which data are reported varies by one day.

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EXPERT OPINION OF PAUL B. QUENEAU
PAKOOTAS, ET AL. v. TECK COMINCO METALS ET AL.

May 12, 2011

Paul B. Queneau

Paul B. Queneau