TECHNICAL MEMORANDUM

To:	Robin Campbell, President (Coal Association of Canada)
From:	Guy Gilron, MSc, RPBio, Senior Environmental Scientist (Borealis Environmental Consulting Inc.)
Subject:	Selenium Management Strategies, Selenium Treatment Systems, including Demonstrated Selenium Reductions using Various Treatment Systems
Date:	March 25, 2025

1.0 Introduction and Objective

1.1 Context

Recent environmental concerns related to metallurgical coal mine developments in Canada have focussed on water quality, with an emphasis on the potential for elevated selenium concentrations downstream of mining operations. These concerns are based mainly on challenges of legacy mining operations in particular, in the Elk River Valley region of British Columbia. Based on recent reporting on the topic of coal developments in the media, there appear to be common misunderstandings regarding the progress that has been made in the management, mitigation and treatment of selenium at coal mining operations (Gilron *et al*., 2022).

1.2 Objective of this memorandum

The objective of this technical memorandum is to provide the Coal Association of Canada with an independent, third-party summary updating current selenium management practices in North America. This summary specifically describes the various management measures, addresses the challenges of the efficacy, efficiency, and sustainability of various treatment approaches/systems, with a focus on demonstrated removal efficiencies of treatment systems currently being implemented and operated at various operations.

2.0 Selenium: Ecological Impacts

Selenium is a naturally-occurring metalloid that is essential for living organisms; however, at elevated concentrations in the aquatic environment, it can be harmful to egg-laying vertebrates (*e.g.,* fish, birds). The complex dietary (food chain) transfer of organic selenium from periphyton to benthic invertebrates to fish and aquatic birds can result in reproductive effects in the eggs and in 2nd generation larval fish and aquatic birds (Janz *et al*., 2010).

While selenium occurs naturally in many of the marine shales and coal-bearing rock formations across British Columbia and Alberta. In the mining sector, elevated selenium in aquatic ecosystems can result from seepage from waste rock and tailings. The most common selenium species present in aquatic environments are selenate and selenite. These compounds are soluble in water and have the potential – when converted to organic chemical species (*e.g.,* seleno-methionine, seleno-cysteine) - to bioaccumulate in aquatic organisms (Janz *et al*., 2010).

Bioaccumulation of selenium in aquatic organisms is an environmental concern that has led to the regulation of selenium via the development, publication, and promulgation of environmental monitoring guidance, benchmarks/guidelines/standards, and effluent permit limits.

This has resulted in research, testing and implementation of:

- various selenium mitigation strategies (aimed at minimizing selenium from leaching from waste rock); and,
- treatment technologies (aimed at removing selenium from mine effluent).

3.0 "Multiple Lines of Defence" Strategy – Selenium Management

Modern mining techniques being proposed and adopted recently have employed strategies intended to prevent/avoid/mitigate selenium releases at source, backed up by modern water treatment technologies – passive, semi-passive, and active - using a "multiple lines of defence" approach (Gilron & McKenna, 2022, 2021). This approach is accomplished by using one, or a combination of, various principles and methods, including (but not limited to):

- clean water diversions;
- selective handling and placement of waste rock;
- engineered placement of material to limit exposure to oxygen and water (suboxia); and,
- dry stacking methods that prevent selenium being oxidized and becoming mobile in the aquatic environment.

Implementing these measures during mine planning and design ensures that selenium concentrations remain controlled and strictly monitored. This not only protects water resources, but also reduces long-term financial and regulatory risks. The approach builds on industry experience and commits to responsible, science-based methods of mining, management, and effluent control.

These strategies significantly reduce the risk of selenium leaching into receiving waters, setting a higher environmental standard for responsible coal mining. While significantly reducing the amount of contact water to be treated, the above-mentioned mitigation measures could still result in water requiring treatment; modern water treatment technologies will ensure that selenium concentrations are safe prior to release into the aquatic environment (see Table 1; below).

Table 1. Examples of Treatment Technologies used for Selenium Removal from Industrial Effluents

Treatment type	Examples
Filtration	Active treatment with filters can remove total Se
Membrane Separation	Reverse osmosis (Active)
Resins	Ion Exchange (Active)
Biological Reduction	Biochemical reactors (Active or Semi-passive), "brand name" units: • Suez ABMet™ • Frontier SeHawk® • Envirogen Fluidized Bed Bioreactor • Veolia AnoxKaldnes™
Biological Oxidation	Moving bed bioreactors (Active) Aerated gravel beds (Active)
Chemical Oxidation	Ozonation, peroxide, etc.
Photolysis	Photocatalysis, developmental, for reduction.
Electrochemical Reduction	BQE Water Selen-IX™

4.0 Selenium Treatment Technologies

Treatment technologies to remove selenium can be either natural features or engineered systems – or a combination of the two; these generally remove selenium from effluent, prior to discharge into the receiving environment. These treatment technologies range from passive (capitalizing on natural processes; *e.g.,* wetlands), to semi-passive (a combination of both natural and engineered systems) to active (completely engineered; *e.g.,* a treatment plant) systems. In addition, these systems can use - as their basis - either physical, biological or chemical transformations. Most selenium management programs at mining, and other industrial sector, operations can apply a combination of mitigation measures and treatment technologies, within a broader on-site water management system (McKenna & Gilron, 2021).

There are currently a number of engineered selenium removal treatment systems used at various industrial operations, including metal and coal mines, and hydroelectric facilities. Some examples are provided in Table 1; additional detail pertaining to the range and effectiveness of these

systems is provided in publicly-available documents, including integrative reports (*e.g.,* Golder Associates, 2020).

4.1 Overall suitability and feasibility of implementing a treatment approach for selenium control

Due to the availability of multiple selenium removal technologies, a treatment technology for a mining project is generally selected based on site-specific needs. Although the majority of physico-chemical methods can be used in a wide variety of climates, the same is not true for biological systems. Only some biological treatment technologies that can be used in northern climates and therefore, prior to selecting a treatment system, the feasibility and sustainability of each technology needs to be evaluated and weighed. The following outlines considerations for the evaluation of suitability and feasibility of a treatment system:

- Physico-chemical systems have the advantage of a shorter lag time when starting up the system after a pause of some sort, when comparing to biological treatment systems. Since physico-chemical systems do not involve the use of living organisms, re-starting systems after an unexpected pause is relatively easy when compared to the accommodations required to support the growth of microbes after a delay in operations.
- Bed Bioreactor systems (*e.g.,* FBR) have high maintenance and labor costs. Active biological systems usually need to undergo a significant amount of treatability testing to determine retention times, removal rates, etc. These studies can be time-consuming and expensive to implement (Golder Associates, 2020).
- Some biological treatment systems are available as pre-configured units so they can be installed at mines in shorter time intervals and the systems can be scaled (up or down) depending on site requirements. *In situ* bioreactors (biological treatment) have lower energy consumption and lower maintenance requirements. Moreover, these bioreactors do not usually require the construction of treatment plants and therefore, eliminate costs associated with facility infrastructure and maintenance (Golder, 2020).
- *In situ* biological treatments (*i.e.,* saturated rock fills and biochemical reactors) are better suited for northern sites where resources are limited, so treatments requiring high energy consumption treatments (*i.e.,* non-biological treatments, bed bioreactors) are not as feasible. Active biological treatment systems are the most expensive to implement, while passive systems are the least expensive.

4.2 Evaluation criteria and key considerations for treatment systems

Biological and non-biological treatment systems have both been demonstrated to be effective in the removal of selenium. Every treatment technology type has both advantages and disadvantages. The suitability of the treatment technology is mostly based on alignment with site-specific needs and conditions. When selecting a selenium treatment system, there are many factors to consider, including, but not limited to the following:

- cost and timing to develop and implement the system;
- how weather/climatic conditions can affect the efficacy and operation of the system;
- resource availability to implement the system;
- availability of space to accommodate the system; and,
- energy requirements to operate the system.

No single treatment technology fulfills every requirement for every/any type of mine. Instead, treatment technologies must be selected (and modified, if necessary) based on site-specific needs. Table 2 (below) evaluates and compares the key criteria for the two types of treatment system types.

Table 2. Comparison of key criteria of biological and non-biological systems (relative)

Criteria	Biological Treatment Systems	Non-Biological Treatment Systems
Final effluent concentrations	Higher (*i.e.,* > 10 ppb)	Lower (*i.e.,* <5 ppb)
Climatic condition suitability	Less effective in colder climates	Better in colder climates
Stability of by-product	Less stable	More stable
Cost to implement	Less expensive	More expensive
Flow in different seasons	Less flexible	More flexible
Timing to implement	Variable	Short time to implement
Resource requirements	Variable	High resource requirements
Space availability	Variable	Requires more space
Energy requirements	Variable	Lower energy requirements

5.0 Demonstrated Selenium Reductions at Coal Mining Operations

During the past five years, publicly-available information regarding the efficacy of treatment systems – specifically, the percentage removal of selenium from effluent discharges - has been reported via research papers, conference proceedings papers and commercial documentation; a summary is provided in Table 3, below.

Table 3. Summary of treatment methods employed at coal mines, and associated selenium reductions

Operation (Location)	Selenium Reductions (%)	Treatment Method(s)	Reference
EVR Elk Valley Mines (Southeast BC)	four water treatment facilities removing between **95% and 99%** of selenium from treated water	Treatment Plant and Saturated Rock Fills	Mackie *et al.*, 2022
Conuma Brule Mine (Northeast BC)	removal **up to 94%** (with concentrations decreasing from ~200 µg/L to 20 µg/L).	*In situ* anaerobic bioreactor	Kona & Atuke, 2022; Miller *et al.*, 2019
Simplot Smoky Canyon Mine (Idaho, USA)	removal of **91%** of the influent total selenium load (Simplot 2021)	Water Treatment Plant [Reverse osmosis and flotation bioreactor (aeration reactor)]	Technical memorandum
Confidential (Southwestern USA)	% removal from **≥ ~85% to > 90%** .	Selen-IX™, non-biological	Kratochvil *et al.*, 2022
Trend Mine (Northeast BC)	reduce selenium **up to 96.4%** (with concentrations decreasing from 130 µg/L to 5 µg/L	ABMet	Wastewater Digest article

In addition, the North American Selenium Working Group has, over the past two decades, commissioned white papers on a regular basis, to provide publicly-available state-of-knowledge updates on various technologies, their efficacy, their advantages, disadvantages, and implementation across various industrial sectors, including the metallurgical coal mining sector:

- State-of-Knowledge on Selenium Treatment Technologies – NAMC SWG White Paper Addendum (Golder Associates, 2020)
- Addendum to Review of Available Technologies for the Removal of Selenium from Water (CH2M Hill, 2013)
- Review of Available Technologies for the Removal of Selenium from Water (CH2M Hill, 2010).

These are available on the North American Selenium Working Group website: namc.org/selenium.html.

6.0 Summary

This technical memorandum provides an independent, third-party assessment of current selenium management strategies in the coal mining sector, with a focus on North America. Selenium, while essential for biological functions, can pose ecological risks at elevated concentrations, particularly in aquatic environments. Modern coal mining operations are addressing selenium concerns through a "multiple lines of defence" strategy, incorporating mitigation measures such as selective waste rock handling, clean water diversions, and advanced treatment technologies.

The memorandum outlines various selenium treatment technologies, including biological, chemical, and physical removal methods, categorized as passive, semi-passive, or active systems. The effectiveness of these treatment systems varies based on site-specific factors, with demonstrated selenium reductions at coal mining operations ranging from 85% to 99%. Selection of appropriate treatment methods depends on criteria such as cost, climatic conditions, resource availability, and energy requirements.

By implementing proactive selenium management strategies, coal mining operations can minimize environmental impacts while ensuring regulatory compliance. The findings presented support a science-based approach to selenium mitigation, reinforcing the industry's commitment to sustainable and responsible mining practices.

Closure

I trust that this Technical Memorandum meets your requirements at the present time. Please do not hesitate to contact the undersigned at your convenience to discuss any aspects of this Memorandum.

Sincerely,

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References

Beatty JM, and Russo GA. 2014. Ambient water quality guidelines for selenium technical report update. BC Ministry of Environment, Victoria, BC, Canada, 254 pp. + appendices.

CH2M Hill. 2013. Addendum to Review of Available Technologies for the Removal of Selenium from Water. Prepared for the North American Metals Council - Selenium Working Group. 68 pp. https://www.namc.org/docs/00113597.pdf

CH2M Hill. 2010. Review of Available Technologies for the Removal of Selenium from Water. Prepared for the North American Metals Council - Selenium Working Group. 233 pp. https://www.namc.org/docs/00180231.pdf

Gilron G, Wenning R, Adams WA. 2023. The Implications of Science Communication in Reporting of the Risks Posed by Selenium in Canadian Coal Mine Effluents. *Proceedings of the Canadian Ecotoxicity Workshop 2023*, Ottawa, ON. 14 pp.

Golder Associates. 2020. State-of-Knowledge on Selenium Treatment Technologies. Prepared for the North American Metals Council - Selenium Working Group. 19117343-002-R-Rev0-2000. https://www.namc.org/docs/00300393.pdf

Janz DM, DeForest DK, Brooks ML, Chapman PM, Gilron G, Hoff D, Hopkins WA, McIntyre DO, Mebane CA, Palace VP, Skorupa JP, Wayland M. 2010. Selenium toxicity to aquatic organisms. In: Chapman PM, Adams WJ, Brooks ML, Delos CG, Luoma SN, Maher WA, Ohlendorf HM, Presser TS, Shaw DP, eds, Ecological assessment of selenium in the aquatic environment. SETAC Press, Pensacola, FL, pp. 141-231.

Kona M, Atuke D. 2022. Biogeochemical Attenuation of Selenium and Nitrate in Mine Contact Waters. *Proceedings of Mine Water Solutions 2022,* Vancouver, BC, Canada.

Kratochvil D, Liang HC, Baker B, Sundar V. 2022. Industrial Scale Non-Biological Selenate Removal – Examples of Plants & Criteria behind Process Selection. *Proceedings of Mine Water Solutions 2022*, Vancouver, BC, Canada.

McKenna G, Gilron G. 2022. From the Bottom Up: A Proactive Approach of Landform Design and Source Control. *Canadian Mining Journal,* June-July pp. 17-21.

McKenna G, Gilron G. 2021. Selenium Management: A Crucial Consideration in Coal Policy Development for Alberta, Canada. *Integrated Environmental Assessment and Management,* 17 (5): 1083–1085.

Miller, T, Marshall, M, Gilron, G. 2019. Biochemical Reactor System at the Brule Mine: A semi-passive approach to operational and post closure selenium and nitrate reduction. *Proceedings of the Technical & Research Committee on Reclamation*, Cranbrook, BC.