SELEN-IXTM: SELENIUM REMOVAL FROM MINING AFFECTED RUNOFF USING ION EXCHANGE BASED TECHNOLOGY

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ABSTRACT

Growing awareness of selenium bioaccumulation has resulted in selenium management becoming an important environmental issue for mining operations. Selen-IXTM is a novel ion exchange based technology developed by BioteQ to provide an effective solution for removing selenium oxyanions from mine impacted water to single-digit μ g/L levels. The technology offers significant potential benefits when compared to incumbent biological treatment processes, including substantially reduced capital and operating costs and significantly reduced production of a selenium-containing sludge for final disposal. This paper reviews the key features of the Selen-IXTM process and presents the results of recent pilot testing on selenium impacted water.

KEYWORDS

Selenium, mine impacted water, ion exchange, environmental regulations, coal mining

INTRODUCTION

Selenium is a naturally occurring element essential to all life in trace amounts. A component of the antioxidant enzyme, glutathione peroxidase, selenium works to protect cell membranes from oxidative damage (Tinggi, 2003). But at higher concentrations, selenium has been found to have health implications for humans, animals and aquatic life. For humans 14+ years of age, the recommended dietary allowance is 55 μ g per day ("ODS", 2013). Chronic high intake (e.g. levels in excess of 400 μ g per day) can lead to issues such as gastrointestinal and neurological problems, respiratory distress, hair and nail loss or brittleness, and fatigue. In animals, a median lethal dose of 1.5 to 6 mg/kg body weight for different animals is reported for most selenium compounds (Hageman, Van der Weijden, Weijma & Buisman, 2013). For fish and aquatic life, selenium can bioaccumulate at nominally higher levels than what is nutritionally required. The impact for animals and aquatic life are deformities, reproductive challenges and mortality (Young et al., 2010).

Selenium enters the environment through natural and anthropogenic sources. Natural sources include the weathering of plant life, soils and bedrocks that leach selenium into water. Anthropogenic sources are many and have had the greatest impact for selenium pollution becoming a worldwide problem (Lemly, 2004). Mining is one such anthropogenic source that can accelerate the release of selenium into the environment. With its similar structure to sulphur, selenium can be found as an impurity in hard rock ores and coal deposits with metal sulphide mineralization (Yudovich & Ketris, 2006). During the smelting and refining of metal concentrates from selenium bearing ores, as well as the oxidation of waste rock from mineral extraction, selenium can be mobilized into process water.

In 2009, the Canadian Council of Ministers of the Environment (CCME) issued guidelines that vary between 1 to 50 μ g/L of selenium, depending on the final use of the water; while the Guidelines for Canadian Drinking Water Quality establishes a maximum of 10 μ g/L selenium for drinking water (approved in 1992). In the US, the Environmental Protection Agency (EPA) has a maximum contaminant level of 50 μ g/L of selenium in water (re-approved in 1992). Bioaccumulative in nature, selenium in excess of biological requirements can affect the food web system. As such, selenium management is becoming an increasingly important environmental issue for mining operations and has created a growing demand for innovative and effective technology solutions for selenium management.

Selenium in Mine Waters

In the mining industry selenium removal is complicated by the fact that flows of mine impacted waters are often high, the selenium concentration is dilute, water temperatures are low, and there may be multiple points of discharge in remote locations, which increases the cost of a centralized treatment facility with the need to install expensive water collection infrastructure. Additionally, selenium laden industrial waters typically contain sulphate, chloride, bicarbonate and nitrate in concentrations that are often orders of magnitude greater than that of selenium. Depending on the water quality and site specific discharge requirements, some of these constituents may not require removal. Yet many existing technologies remove the majority of these constituents along with selenium. This additional removal increases overall treatment and waste disposal costs as these removal technologies produce a waste by-product with specific disposal requirements.

Selenium Speciation

When selenium enters the aquatic environment, it is typically in the form of oxyanions, selenite and selenate, which are both toxic, although to different levels (Torres, Pintos, Domínguez, & Kremer, 2010). Due to their chemical polarity, the structure of selenite is more reactive than selenate and as a result, more responsive to treatment. A number of viable solutions exist (some even applied in commercial scale) for selenium removal from water when it is present as selenite. These solution technologies include chemical

adsorption (Zhang, Lin & Gang, 2008), biological reduction to elemental selenium (Soda, Kashiwa, Kagami, Kuroda, Yamashita & Ike, 2011) and chemical reduction with sulphide (Geoffroy & Demopoulos, 2011).

Selenate is not only more difficult to treat than selenite, but also forms the majority of selenium found in mine waters. Selective removal of selenate poses a challenge partly due to its chemical similarity to sulphate. A key step in many of the existing selenate removal technologies is to reduce selenate to selenite or elemental selenium. Selenate reduction is possible in methanogenic or sulphate reducing bioreactors with selenite or elemental selenium being the product (Lenz, Smit, Binder, Van Aelst & Lens, 2008). The selenate reduction process currently considered to be the best available technology is biological selenate reduction using fluidized bed bioreactors or FBR ("NAMC-SWG", 2013). There are however some significant disadvantages of this process, including:

- Requirement to heat water to ensure proper operation of the system;
- Retention time is a function of selenium removal, higher selenium concentrations require greater retention times;
- Large volume of selenium containing bio-solid waste and there is limited information on its stability;
- Increased phosphorus and Biological Oxygen Demand (BOD) levels in the treated water and its potential impact on the downstream aquatic environment; and
- Relatively high capital and operating costs.

New Selenium Removal Technology

This paper describes Selen-IXTM, a novel integrated process developed by BioteQ for the selective removal of both selenite and selenate from water to concentrations below 5 μ g/L. Selen-IXTM does so with minimal co-removal of other species from a wide range of water compositions. As Selen-IXTM involves minimal pre/post treatment of water, it offers significantly lower capital/operating cost and footprint compared to existing selenium removal technologies. As a result, Selen-IXTM is appropriate for the treatment of large flows of low temperature, mine impacted water in remote sites. In this paper results from laboratory test work and successful pilot plant operation on mine impacted water are presented and discussed. Preliminary capital and operating cost estimates based on the outcomes of latest piloting are also provided and compared to currently available selenium treatment technologies published in a recent review by the North American Metals Council Selenium Working Group ("NAMC-SWG", 2013).

SELEN-IXTM SCHEMATIC FLOWSHEET

The first stage of Selen-IXTM is the removal of selenium oxyanions from water through ion exchange (IX) with a strong base anion exchange resin (SBA), resulting in effluent water containing single digit µg/L of selenite and selenate combined. The IX resin is regenerated with a concentrated sulphate solution to create a concentrated selenium containing stream typically one to two orders of magnitude more concentrated than the influent water. The spent regenerant is then treated to remove selenium with iron as a solid product. The details of the spent regenerant treatment process are outside the scope of this paper; however, the basic chemistry of the selenium removal process will be discussed in the following section. The solid product is separated from the selenium barren solution via flocculated clarification to allow for recycle of the regenerant. The low-volume, high selenium content solids are filtered to produce a solid cake. Meanwhile, the regenerant solution is recycled and re-used in the IX step. As a result, zero liquid waste is generated by the process. This eliminates costs associated with liquid waste disposal/evaporation and minimizes reagent consumption associated with conventional IX without regenerant recycle. The process is shown schematically in Figure 1. The configuration of the "Spent Regenerant Treatment" train depends on the composition of the regenerant solution, which in turn depends on the composition of the water to be treated. The selection of the IX regenerant in combination with the spent regenerant treatment steps allow selenium to be removed selectively from a broad range of mine impacted and industrial waters.



Figure 1 – Simplified block diagram showing sequence of treatment steps in Selen-IXTM (ppb = μ g/L).

BASIC CHEMISTRY OF SPENT REGENERANT TREATMENT IN SELEN-IXTM

Iron is known to react with selenium in a number of different ways including redox reactions, adsorption and co-precipitation. Selen-IXTM takes advantage of these reactions to remove selenium from the concentrated spent regenerant stream. Key redox reactions and their corresponding half-cell standard reduction potentials vs Standard Hydrogen Electrode (SHE) are summarized below for a solution containing iron, selenium and sulphate. It is noteworthy that pKa₁ and pKa₂ values for selenous acid (H₂SeO₃) are 2.46 and 7.3, respectively. Similar to sulphuric acid, selenic acid (H₂SeO₄) has a pKa₂ value of ~2.

$E^0 = +1,150 \text{ mV}$	$HSeO_4^{-} + 2H^{+} + 2e^{-} = HSeO_3^{-} + H_2O$	(1a)
$E^0 = +1,060 \text{ mV}$	$SeO_4^{2-} + 3H^+ + 2e^- = HSeO_3^- + H_2O$	(1b)
$E^0 = +903 \text{ mV}$	$HSeO_{3}^{-}+5H^{+}+4e^{-}=Se+3H_{2}O$	(2a)
$E^0 = +771 \text{ mV}$	$Fe^{3+} + e^{-} = Fe^{2+}$	(3)
$E^0 = +1,060 \text{ mV}$	$H_2SeO_3 + 4H^+ + 4e^- = Se + 3H_2O$	(2b)
$E^0 = -370 \text{ mV}$	$SeO_3^{2-} + 3H_2O + 4e^- = Se + 6OH^-$	(4)
$E^0 = -440 \text{ mV}$	$Fe^{2+} + 2e^{-} = Fe$	(5)
$E^0 = -540 \text{ mV}$	$Fe(OH)_3 + e^- = Fe(OH)_2 + OH^-$	(6)

Reactions that can be held responsible for selenate reduction in a system containing both iron and selenium are a combination of reactions 1a or b and 3 or 5 or 6 (combination of reactions 1b and 3 is shown below):

$$SeO_4^{2-} + 3H^+ + 2Fe^{2+} = HSeO_3^{-} + 2Fe^{3+} + H_2O$$
(7)

In almost all combinations that lead to selenium reduction, protons are part of the reactants and the extent of selenate conversion to selenite and possibly the reaction kinetics is influenced by pH with acidic pH being beneficial. Based strictly on thermodynamic considerations, the values of half-cell potentials indicate that at least a partial reduction of selenate all the way to elemental selenium is possible via several different pathways such as:

$$HSeO_{3}^{-}+5H^{+}+4Fe^{2+} = Se + 3H_{2}O + 4Fe^{3+}$$

$$HSeO_{3}^{-}+5H^{+}+4Fe(OH)_{2} + 4OH^{-} = Se + 3H_{2}O + 4Fe(OH)_{3}$$
(8)
(9)

As noted before, the reaction of elemental or zero valent iron (ZVI) oxidation to ferrous (reaction 5) can also be paired with reactions 1a or b and results in selenate reduction. Thermodynamically, reduction of selenate through this reaction is even more favourable compared to ferrous oxidation reaction (reaction 3). Reaction 6, oxidation of ferrous hydroxide can also be paired with selenate reduction reactions and similarly, thermodynamic considerations suggest a larger driving force is available for selenate reduction if

ferrous hydroxide is present. The pKa₁ of selenous acid and the half-cell potentials indicate that there is more driving force for the production of elemental selenium at a medium pH (5 to 7.3) when most selenite is present as $HSeO_3^{2-}$ and a significant portion of both ferrous and ferric iron is present as hydroxides. There are however, kinetic limitations that play a significant role.

Similar to all other reactions, one of the parameters that affects the kinetics of selenate reduction with iron/ferrous in the bulk of the solution is a function of contact events between the two species. This means that concentrations of iron/ferrous and selenate as well as mixing of the solution affect the kinetics of the reaction. In the case of elemental iron another factor that affects the reaction kinetics is the scaling/passivation of the surface. As soon as the first few layers of the iron particles react with selenate, scaling/passivation significantly reduces the reaction kinetics. In general, the data from the literature and the theory agree that the kinetics of selenate reduction with iron is slow and a method for increasing the number of contact events between the species is required in order to obtain acceptable reaction kinetics.

LABORATORY TESTING RESULTS

The objectives of the Selen-IXTM lab testing were twofold: a) to demonstrate the capacity of Selen-IXTM to remove selenium from samples of mine impacted waters selectively; and b) to achieve efficient removal of selenium from the regenerant and thus allow re-use of the regenerant brine. The experimental lab work was divided into two stages with the results of each stage of lab testing discussed in the following sections:

- a) Ion Exchange (IX) performance for selenium removal; and
- b) Selenium removal and fixation into a solid product.

Ion Exchange (IX) Performance

IX tests were performed in BioteQ's Vancouver, British Columbia laboratory. Tests were performed in columns filled with 500-1,000 mL of resin and used top-down flow. Resins were first conditioned with the appropriate regenerant composition before use – resins were not used as received. Each IX test sequence consisted of load and regeneration followed by wash with de-ionised water (DI). This sequence of load, regeneration and wash was conducted twice for each test in order to yield resin performance data as this form of cyclical loading/regeneration more closely mimics practice. Some of the outcomes of this test work included identification of the optimum regenerant volume, strength and flow rate as well as the loading volume and flow rate.

Table 1 shows the composition of the feed water used for resin screening in batch and column testing configurations. As can be seen in the table, sulphate (SO₄) and nitrate (NO₃) were present in the water at concentrations three orders of magnitude greater than that of selenium (Se). Selenium in this solution was present as 80% selenate Se(VI) and 20% selenite Se(IV).

рН	Conductivity (mS/cm)	Dissolved Se (µg/L)	SO ₄ (mg/L)	NO ₃ (mg/L as N)	Alkalinity (mg/L eq CaCO ₃)
7.64	1.43	363	735	21	306

Table 1 – Laboratory feed water chemistry

Figure 2 shows an example of the selenium loading profile of IX tests in large columns. For this particular test a loading rate of 16.5 BV/h was used with a resin volume of 1 L. The resin bed height was \sim 2 m and the diameter of the column was \sim 4.5 cm. Selenium breakthrough occurred at approximately 66 BV

and selenium concentration in the effluent remained below 5 μ g/L until 82 BV. The very low levels of selenium in the IX effluent indicate that both selenate and selenite were being removed from the influent water.



Figure 2 – Se concentration in spent load as a function of load volume. 1 BV = 1 L, loading rate 16.5 BV/hr. IX resin bed dimensions \sim 2 m by \sim 4.5 cm

Figure 3 provides an example of the selenium regeneration profile for large column IX testing. The resin bed volume was 0.5 L in a column 4.5 cm in diameter for a bed height of 1 m. The regeneration rate was 1.5 BV/h using a concentrated sodium sulphate solution. As illustrated in the graph, regeneration was completed after 3 BV. Peak selenium concentration in the spent regenerant during regeneration was 15.8 mg/L. Selenium regeneration started almost immediately after contacting the fresh regenerant solution with the resin.



Figure 3 – Se concentration in spent regenerant as a function of regenerant volume. 1 BV = 0.5 L, regeneration rate 1.5 BV/h, fresh regenerant was a concentrated solution of Na₂SO₄. IX resin bed dimensions 1 m by 4.5 cm

It can be calculated from the graphs shown in Figure 2 and in Figure 3 that at an effluent selenium concentration target of 5 μ g/L, this column configuration and particular SBA resin resulted in a concentration factor of ~30×. This calculation is done on the basis of 82 BV load and 3 BV regeneration. Across all of

these tests the operational capacity of the resin for selenium was found to be 0.3-0.5 meq/L, depending on the water composition.

As the regenerant was to be recycled, tests were conducted to determine the effect of initial selenium concentration in the regenerant on selenium regeneration. Figure 4 shows the elution results in tests with 0 and 1 mg/L selenium in the fresh regenerant. In both cases, the regeneration is complete within 3 BV, indicating that a small amount of selenium in the fresh regenerant has a negligible impact on the regeneration efficiency. The value of 1 mg/L selenium makes a useful target concentration of selenium in the treated eluate, addressed in the following section.



Figure 4 – Effect of residual selenium on regenerant recycle. 1 BV = 0.5 L, 1.5 BV/h regeneration rate, IX resin bed dimensions 1 m by 4.5 cm

Selenium Removal and Fixation (Batch and Continuous-flow Treatment of Spent Regenerant)

In order to be able to recycle the regenerant it is necessary to remove selenium from the spent regenerant. Selen-IXTM uses a novel series of treatment steps to concentrate selenium into a stable solid product. Several batch and continuous laboratory results are presented in the following section. These tests were carried out to evaluate the efficiency of the selenium removal from spent regenerant under range of different operating conditions such as regenerant composition and hydraulic retention time (HRT) in the reactor. All tests were done at ambient temperature $(18 - 23^{\circ}C)$ in tanks that were open to the atmosphere.

Spent Regen Treatment Duration (min)	Initial [Se] in Spent Regen (mg/L)	% Se Removal	wt% Se in Dried Solids
360	92	98	0.8
180	100	98	0.7
180	84	99	1.1
180	91	100	0.8
90	108	90	1.7
90	108	96	1.2
90	88	100	0.6

Table 2 - Select results from batch tests showing selenium removal from spent regenerant

Table 2 shows the results of batch spent regenerant treatment. In these tests a rather conservative reaction time was used as the starting concentration of selenium was high. As apparent from the table, initial selenium concentrations of up to 108 mg/L were tested in the lab and selenium removals of up to 100% were achieved. The mass percent selenium of the resultant dry solid product was inferred through slurry mass balance, shown in Table 2. The table shows the duration of the treatment for reaction and does not include time spent for solid liquid separation. As can be seen in Table 2, the time necessary for batch reaction ranged from 360 minutes to 90 minutes while keeping selenium removal at or near 100%. The treatment time was reduced by an order of magnitude when the system was operated continuously as presented in Table 3.

Operating Mode	Time (min)	Reactor HRT (min)	Initial [Se] in Spent Regen (mg/L)	[Se] in Treated Regen (mg/L)
Batch	0-45	n/a	8.6	6.2
Continuous	46-69	8	8.6	2.2
Continuous	70-93	8	8.6	1.3
Continuous	94-117	8	8.6	1.6
Continuous	118-141	8	8.6	0.6

Table 3 – Continuous-flow test results showing successful selenium removal from spent regenerant at 8 minutes retention time in the spent regenerant treatment step

Table 3 shows the results of continuous operation of the spent regenerant treatment train in the lab. This time includes the selenium removal reaction and does not include the time necessary for solid/liquid separation. The test was started in batch and after 45 minutes was switched to continuous operation at 8 minute retention time. Each stage of the continuous operation was continued for 24 minutes (3 HRT) to ensure steady state in the circuit was achieved by allowing the circuit to operate for three turn overs at a specific condition before sampling. After approximately 90 minutes of continuous operation, the residual selenium in the treated regenerant was low enough that the treated regenerant could be recycled effectively.

PILOT PLANT & OPERATING RESULTS

Piloting started in the third quarter of 2013 on mine impacted water on a client's site in Canada. The pilot unit is pictured in Figure 5. The unit is a 40 ft long container and can treat up to 2.8 m³/day. The unit is fully instrumented and is automated with process control logic for unattended operation. The pilot plant is self-contained, insulated and can be transported to site for testing on fresh solution. The IX columns used in the pilot plant have an internal diameter of ~10 cm and are ~2 m high. The volume of resin used in each column is ~10 L and the resin bed height is ~1.5 m. At the time of writing piloting operations to date were done using single pass regeneration without recycle of the regenerant. Data presented in this paper thus corresponds to open-circuit operation fresh regenerant being used instead of treated, spent regenerant.



Figure 5 – BioteQ's Selen-IXTM pilot plant in operation

Data from the first 35 days of open-circuit pilot plant operation is shown in Table 4. The first few weeks of operation were dedicated to the IX circuit only and optimizing the operating parameters with the starting conditions being the best operating conditions extracted from the lab data. As apparent from the table, the IX part of the circuit met the piloting target of $< 20 \ \mu g/L$ after the first week of operation once loading/regeneration rates were adapted for the water chemistry. The temperature of the feed water was outdoor ambient of 5-10°C, while regenerant processing was conducted at 8-12°C.

Table 4 - Feed and effluent composition from first 35 days of pilot plant operation using mine impacted
water. Selenium present as ~85% selenate, 15% selenite. IX sequence of 42-50 BV load, 3 BV
regeneration

	Feed				Treated Water			
Day	Se (µg/L)	Alkalinity (as CaCO ₃) (mg/L)	NO ₃ as N (mg/L)	SO ₄ (mg/L)	Se (µg/L)	Alkalinity (as CaCO ₃) (mg/L)	NO3 as N (mg/L)	SO ₄ (mg/L)
1	446	730	55.7	1,960	90	381	36.9	2,210
7	468	433	56.2	1,970	3.78	495	18	2,140
14	456	463	57.5	2,050	2.08	173	29	2,490
21	456	484	57.1	2,030	25.9	357	30.2	2,320
28	446	n/d	n/d	n/d	5.01	n/d	n/d	n/d

	35	456	441	57.5	2,070	6.34	424	35.2	2,120
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Given that the purpose of the pilot program was to test operational variables rather than continuous operation, there were several days where selenium concentration in the effluent was greater than 20 μ g/L. These occassions corresponded with the change from 4 to 3 columns in operation and the beginning of lead-lag configuration. After the first three weeks of operation, selenium concentrations in the effluent consistently met the target. Operational selenium capacity of the resin was found to be similar in the pilot as in the lab, though the overall increase in dissolved salts in the pilot feed water compared to lab feed water necessitated a somewhat shorter load cycle.

Concentrated sodium sulphate was used as a regenerant and thus a net increase in the sulphate concentration was observed across the columns. The increase in sulphate was balanced by all other anions that were removed from the solution such as nitrate and alkalinity. As the moles of equivalent charge of alkalinity and nitrate dwarf the charge equivalence of selenium, the majority of the sulphate gain is due to ion exchange with anions other than selenium. This is a direct result of the open circuit operation of the pilot. In closed loop operation there would be limited removal of alkalinity or nitrate in this system, and thus these anions will build up in the regenerant circuit to a plateau concentrate. Consequently, there will be limited net removal of anions other than selenium and as such the amount of sulphate gain across the circuit would be minimal.

Operation of the downstream circuit including spent regenerant treatment started after the upstream IX circuit was optimized. Therefore, there is limited data available at the time of preparation of this document.

PRELIMINARY COST ANALYSIS

On the basis of data gathered in the laboratory and pilot program to date, capital and operating costs for Selen-IXTM can be estimated. The NAMC-SWG published report in March 2013, Review of Available Technologies for the Removal of Selenium from Water, provides a survey of existing selenium removal technologies compiled by subject matter experts. Through the cost curves presented in the report, the capital and operating costs of Selen-IXTM can be compared to other available technologies on the market. It should be noted that these are considered Class 5 cost estimates, indicating preparation based on limited information with an accuracy range of +100% and -50%. Actual costs will depend on many variable factors such as project scope, site condition/location to implementation schedule.

Figures 6 and 7 outline estimates for capital and operating costs associated with the treatment of $15,000 \text{ m}^3/\text{d}$ feed water on the following basis:

	Selen-IX [™]	IX + Evap/Cryst	ABMet	FBR
	(µg /L)	(µg /L)	(µg /L)	(µg /L)
Influent Selenium	370	20 - 50	20 - 300	20 - 300
Effluent Selenium	< 5	5 - 10	5 - 20	5 - 20



Figure 6 – Comparison of total installed cost of selenium removal technologies (15,000 m³/day capacity)

Capital costs in these figures include equipment, installation, engineering, permitting, commissioning for the main selenium treatment unit operations plus any necessary pre/post treatment, but exclude flow equalization and diversion infrastructure. As indicated in Figure 6, Selen-IXTM can offer capital savings compared to other technologies as the bulk of the treatment occurs on the low volume spent regenerant instead of the high volume feed water. The spent regenerant treatment process itself requires low residence time, meaning reactors and solid liquid separation stages are small in footprint.



Figure 7 – Comparison of per m³ operating cost of selenium removal technologies

Operating costs include maintenance, labour, energy, media replacement, reagent and waste disposal, with the waste assumed to be non-hazardous. The operating cost for Selen-IXTM is shown as a range with projected minimum and maximum costs. A range is presented here as the technology has not yet been optimized. Despite this, results indicate operating costs can be significantly lower than IX + Evaporator/Crystallizer technology and are very competitive with the active biological technologies, primarily due to the recycling of regenerant and the consequent reduction in reagent makeup, low power costs and the generation of low volume, non-hazardous solid by-product.

CONCLUSIONS

Selen-IXTM is a novel ion exchange based technology designed to address the challenges of removing selenium from large streams of water. The technology is applicable to not only selenite but also selenate bearing waters. Unlike other selenium IX technologies, the selenium bearing regenerant brine is treated to remove selenium and allows re-use of the regenerant brine. Results of recent laboratory and pilot studies were presented showing that Selen-IXTM is capable of removing selenium from water to concentrations below 5 μ g/L and deporting it as a low volume solid. Based on results of the pilot, capital and operating costs of the technologies (and currently available information), indicating that Selen-IXTM would be suitable to treat high flows of cold water to achieve the most rigorous selenium discharge requirements.

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