



Achieving less than 1 ppb Se – Results of pilot demonstration for the KSM project

BC MEND ML/ARD Workshop | December 3, 2015

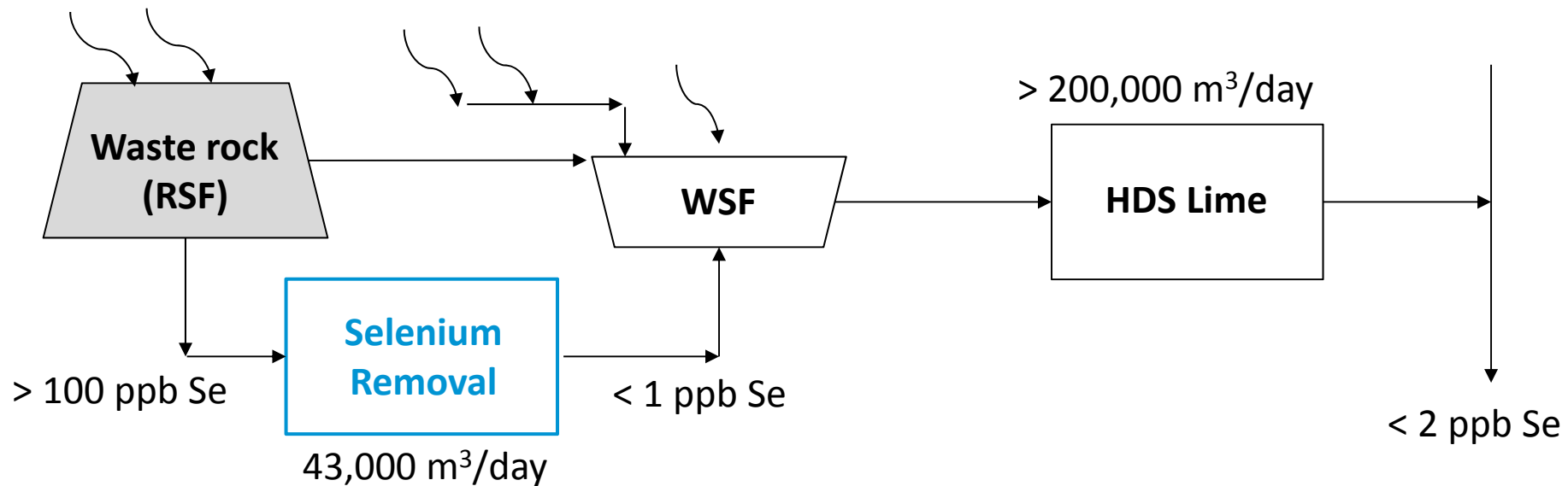
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KSM project requirements

- Compliance with BC WQG < 2 ppb Se sets the requirements
- Total flow of mine impacted water up to $200,000 \text{ m}^3/\text{day}$
- Selenium management plan key principles
 - Intersect stream with the highest selenium load
 - Treat this stream in a plant to < 1 ppb



Selection of Selenium Removal Process

KSM Project Challenge	Impact on Process Selection
< 1 ppb Se discharge target	Cannot use biological process
ARD nature of wasterock seepage – cocktail of constituents	Membrane pre-treatment requirements costly, water recovery reduced
Variable loads (flow and mass)	Process should be adaptable to variations caused by seasons/mine plan
Quantity and long term stability of residues	Brine management from membranes cost prohibitive, permitting of biosolids disposal complicated
Cold water temperature	Process performance and cost not sensitive to temperature

Feed Water Quality

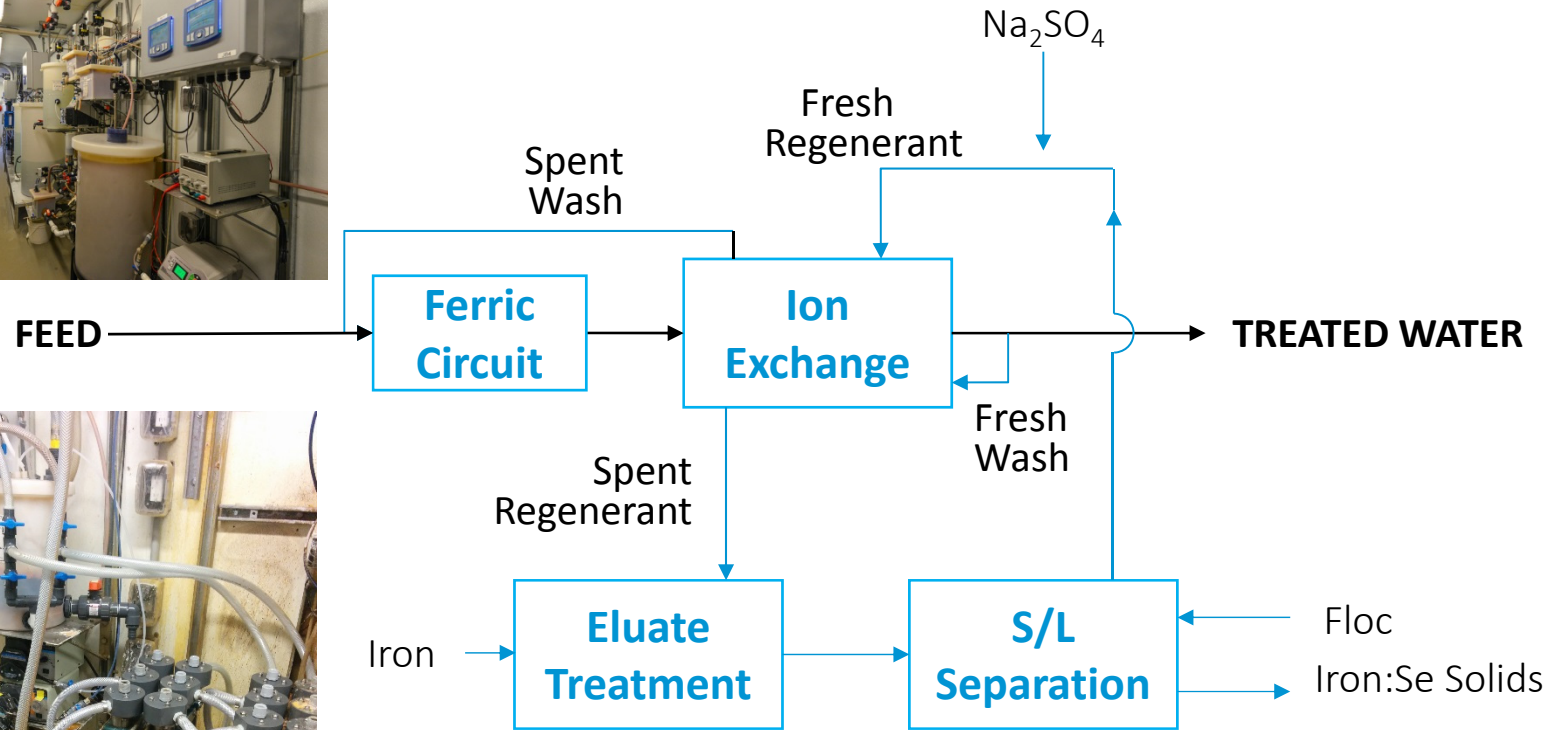
Rock Storage
Facility (RSF)
Estimated
Values

	Minimum	Median	Mean	95th P	Maximum
Anions and Nutrients					
Chloride	0.756	4.63	5.52	13.1	25.2
Nitrite	0.001	0.842	1.11	2.99	4.64
Nitrate	0.032	36.7	48.3	130	202
Ammonia	0.006	4.63	6.11	16.5	25.5
Sulphate	288	1227	1259	2284	2765
Phosphorous	0.028	0.188	0.349	1.21	1.94
Dissolved Metals					
Aluminum	2.78	20.4	20.7	39.0	50.3
Cadmium	0.0100	0.0440	0.0452	0.0828	0.0933
Calcium	87.1	138	136	164	168
Chromium	0.0017	0.0135	0.0137	0.0261	0.0371
Cobalt	0.137	0.190	0.190	0.221	0.224
Copper	18.3	25.5	25.4	29.6	30.1
Iron	17.5	152	162	326	535
Lead	0.139	0.195	0.195	0.227	0.234
Magnesium	6.74	20.8	20.3	34.5	41.4
Manganese	7.98	11.3	11.2	13.1	13.3
Molybdenum	0.0148	0.0995	0.109	0.243	0.357
Nickel	0.0310	0.0441	0.0439	0.0514	0.0522
Potassium	2.68	18.2	18.1	33.1	42.0
Selenium	0.0115	0.0836	0.0829	0.0978	0.0988
Silicon	6.93	37.5	37.8	70.8	91.2
Sodium	2.75	10.2	10.2	17.6	20.7
Strontium	0.527	1.91	2.05	3.69	6.55
Vanadium	0.0025	0.0213	0.0222	0.0425	0.0646
Zinc	1.00	5.05	4.98	6.20	6.40

	Batch 1	Batch 2
Anions and Nutrients		
Chloride	8.0	8.0
Nitrite	1.7	1.7
Nitrate	72	72
Ammonia	9.1	9.1
Sulphate	1800	1800
Phosphorous	0.9	0.9
Dissolved Metals		
Aluminum	30	30
Cadmium	0.06	0.06
Calcium	147	147
Chromium	0.02	0.02
Cobalt	0.19	0.19
Copper	26	26
Iron	236	236
Lead	0.20	0.20
Magnesium	27	27
Manganese	11	11
Molybdenum	0.16	0.16
Nickel	0.05	0.05
Potassium	26	26
Selenium	0.120	0.320
Silicon	54	54
Sodium	14	14
Strontium	2.8	2.8
Vanadium	0.03	0.03
Zinc	5.3	5.3

Selenium
Removal Plant
Feed Solution
Targets

Selen-IX™ KSM Initial Flowsheet



Selen-IX™ Mobile Pilot Unit

- **Objective:** Continuous operation & demonstration at customer's sites
- **Hydraulic Capacity:** 2 - 4 L/min



Pilot Campaign Objectives

- Demonstrate capacity to remove to < 1 ppb in a continuous process
- Demonstrate capacity to adapt to sudden changes in Se loading
- Characterize solids residue

Selen-IX™ KSM Pilot



Project Phase	Volume of water treated
Process Commissioning/Calibration	65 m ³
Demonstration Closed Loop	32 m ³

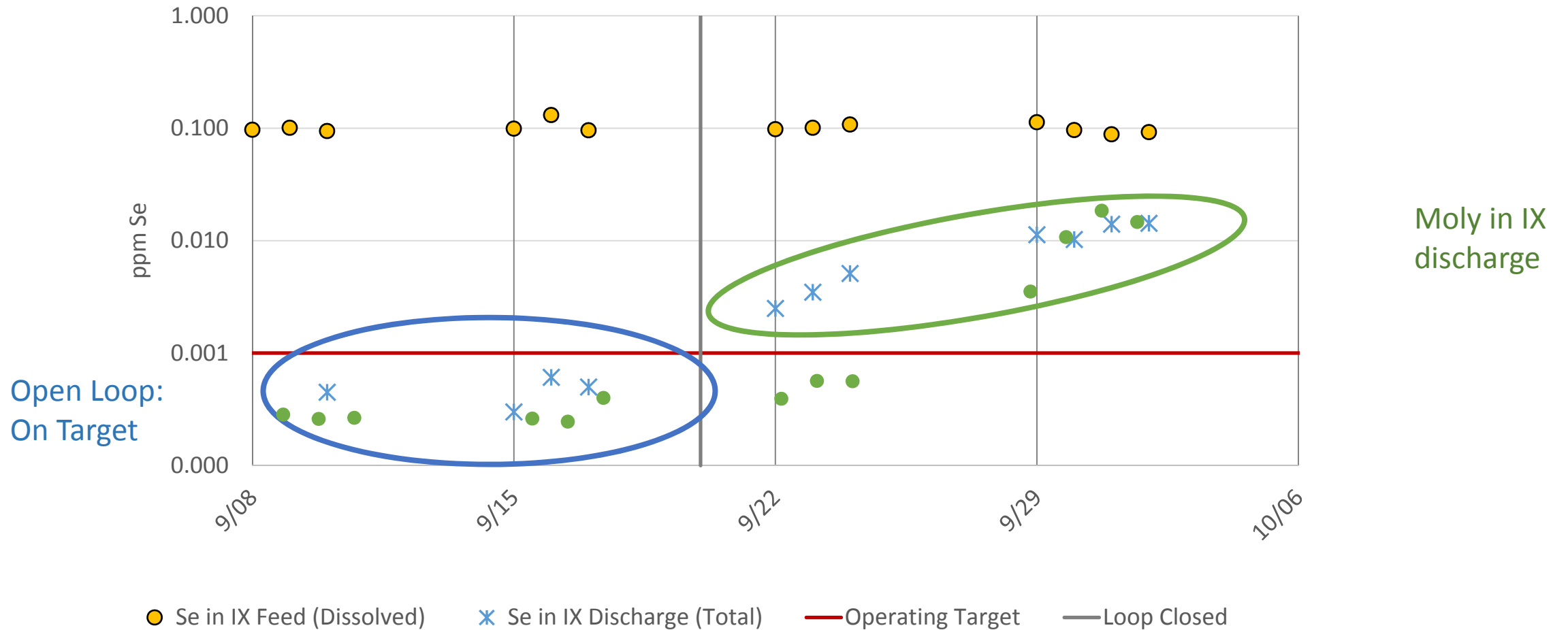


Average Chemistry of Selen-IX™ Plant Feed

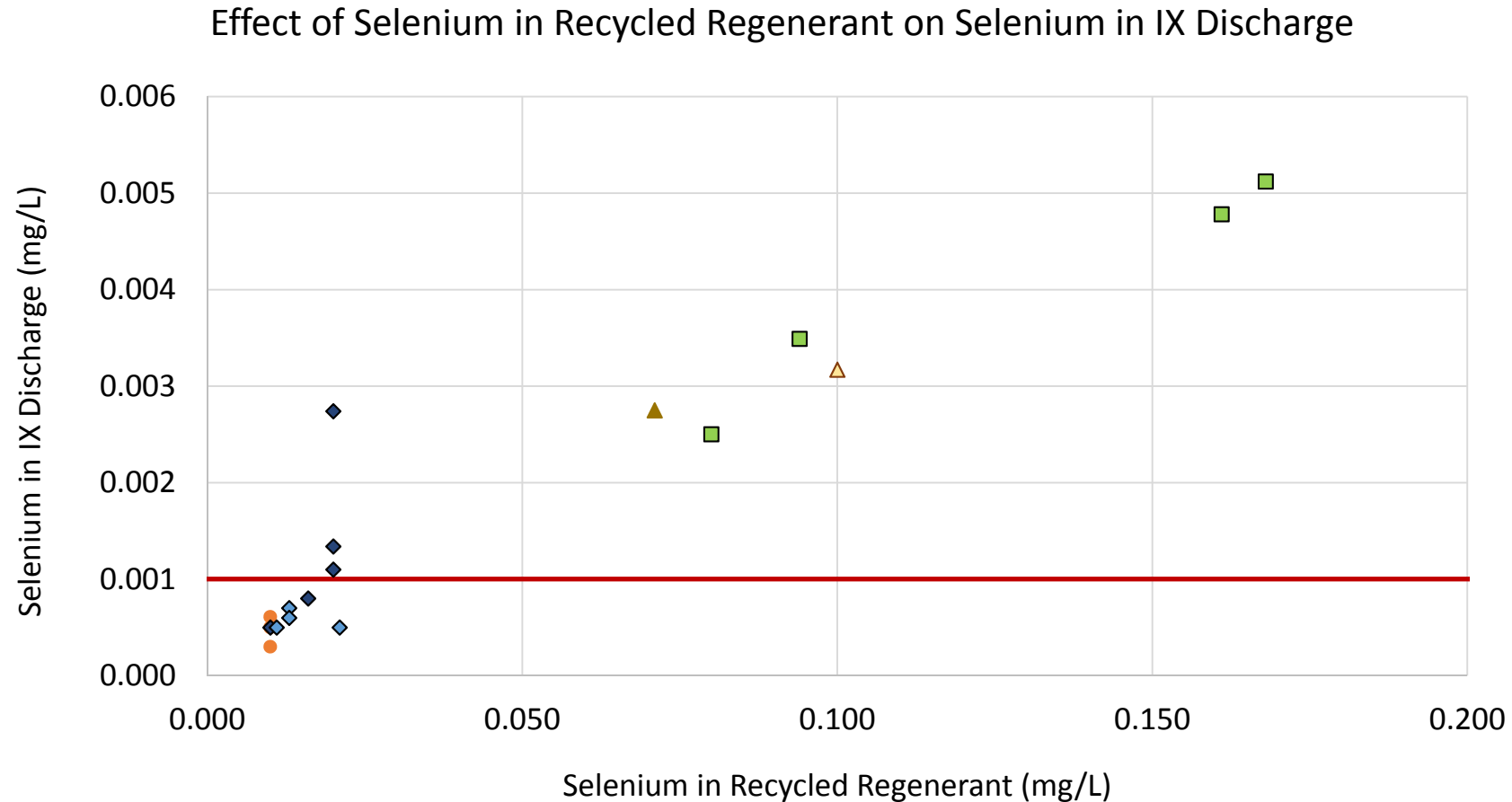
	Plant Feed Campaign Average	
	120 ppb feed	320 ppb feed
pH	4.3	4.3
Selenium (Se) – Se6	0.097	0.277
Ammonia (as N)	6.3	5.4
Nitrate (as N)	30	28
Sulphate (SO₄)	1950	1900
Aluminum (Al)	9.4	12
Calcium (Ca)	661	615
Copper (Cu)	15	17
Manganese (Mn)	9.1	9.7
Nickel (Ni)	0.14	0.06
Silicon (Si)	18	18
Strontium (Sr)	4.2	3.9
Uranium (U)	0.0013	0.0012
Zinc (Zn)	4.7	4.6

Initial Pilot Operations – IX Data

Selenium Removal Across IX Circuit



Inter-dependency of IX and Eluate Treatment

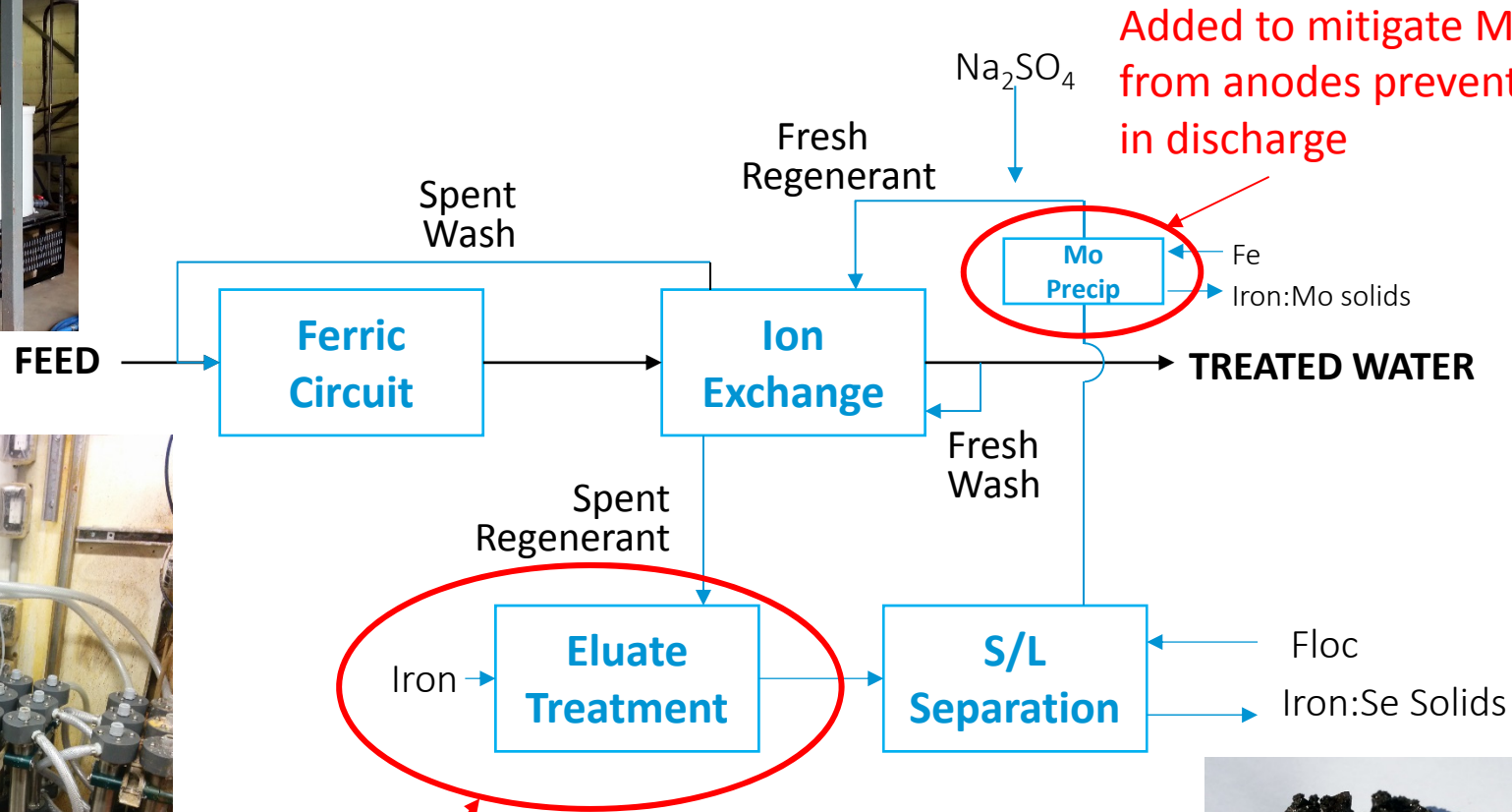


Reaching < 1 ppb effluent selenium requires high degree of selenium removal from regenerant

Summary of Initial Challenges During Piloting

- < 1 ppb target not achieved when we started to recycle brine in closed loop operation
- Data analysis revealed to reach < 1 ppb in plant effluent, selenium removal from recycled brine had to exceed initial pilot design (initial design of 200 ppb, to less than 10 ppb)
 - Requirement for additional electrocells (from 6 to 12)
 - Change from constant EC flow to batch treatment
 - Resulted in significant piping rework
- Molybdenum released from iron anodes reduced selenium removal by ion exchange
 - Secondary molybdenum precipitation system was implemented

Selen-IX™ KSM Revised Pilot Flowsheet



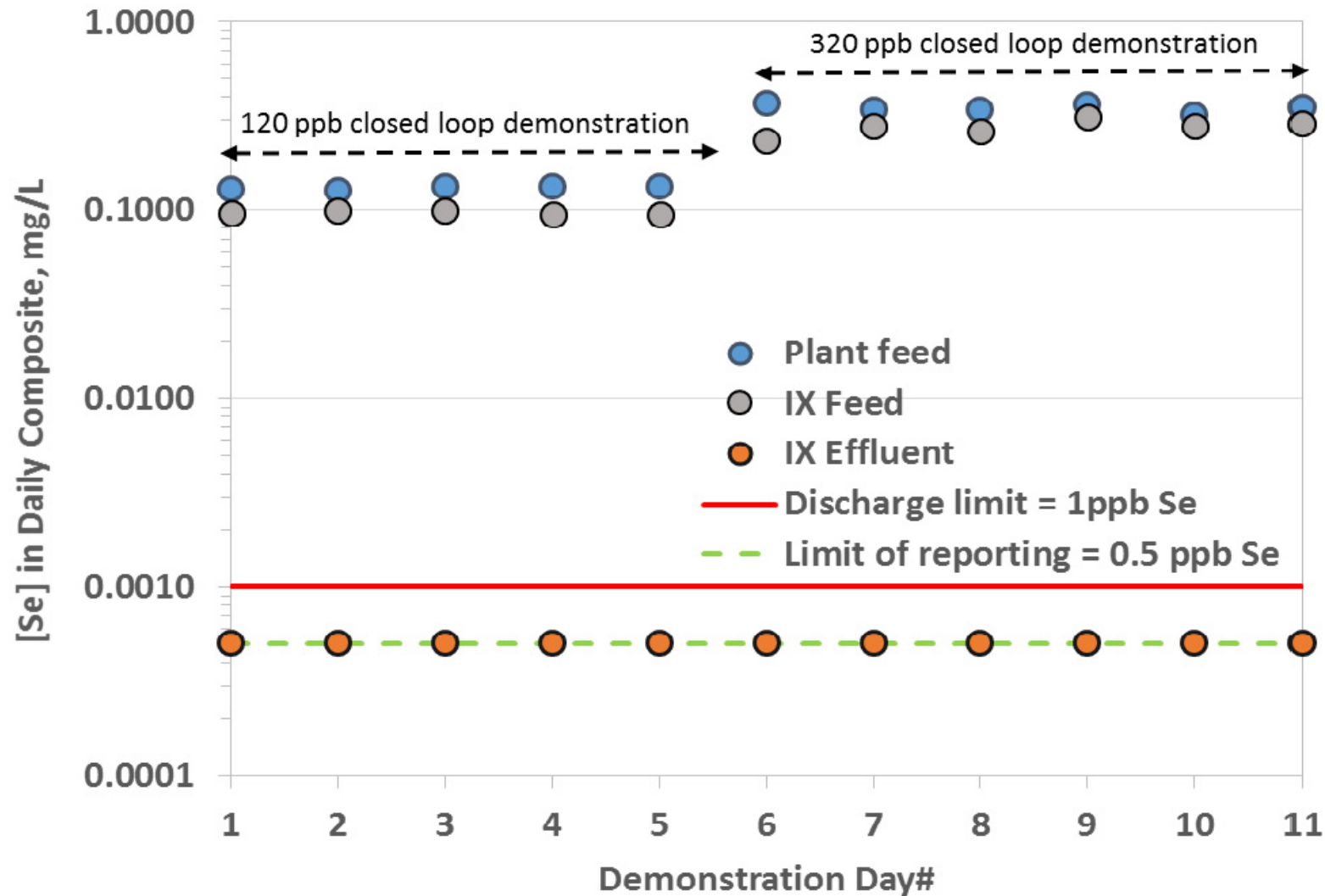
Added to mitigate Mo released from anodes preventing < 1 ppb in discharge



6 additional electrocells



Summary of Selen-IX™ Demonstration



**IX resin
regeneration 3 x
per day**

Plant Feed & Discharge During Demonstration

	120 ppb		320 ppb	
	IX Feed (mg/L)	IX Effluent (mg/L)	IX Feed (mg/L)	IX Effluent (mg/L)
Ammonia (as N)	6.34	6.6	5.44	5.52
Nitrate (as N)	29.6	23.6	27.9	29.4
Sulphate (SO₄)	1,950	1,890	1,900	1,810
Aluminum (Al)	9.4	10.2	12.0	12.1
Calcium (Ca)	661	655	615	628
Copper (Cu)	14.5	15.5	16.9	17.5
Nickel (Ni)	0.135	0.138	0.064	0.068
Selenium (Se) – Se6	0.097	< 0.0005	0.277	0.0005
Silicon (Si)	18.1	18.4	18.2	18.7
Uranium (U)	0.0013	0.0002	0.0012	0.0002
Zinc (Zn)	4.74	4.79	4.56	4.73

Solids Dewatering & Characterisation



Solids Residue Assay

Element	Units	Solids Residue (120 ppb Se feed)
Fe	% dwb	43.8
S	% dwb	4.3
Na	% dwb	2.0
Se	% dwb	< 0.1

With O & H making up the remaining

Semi-Quantitative Phase Analysis -XRD

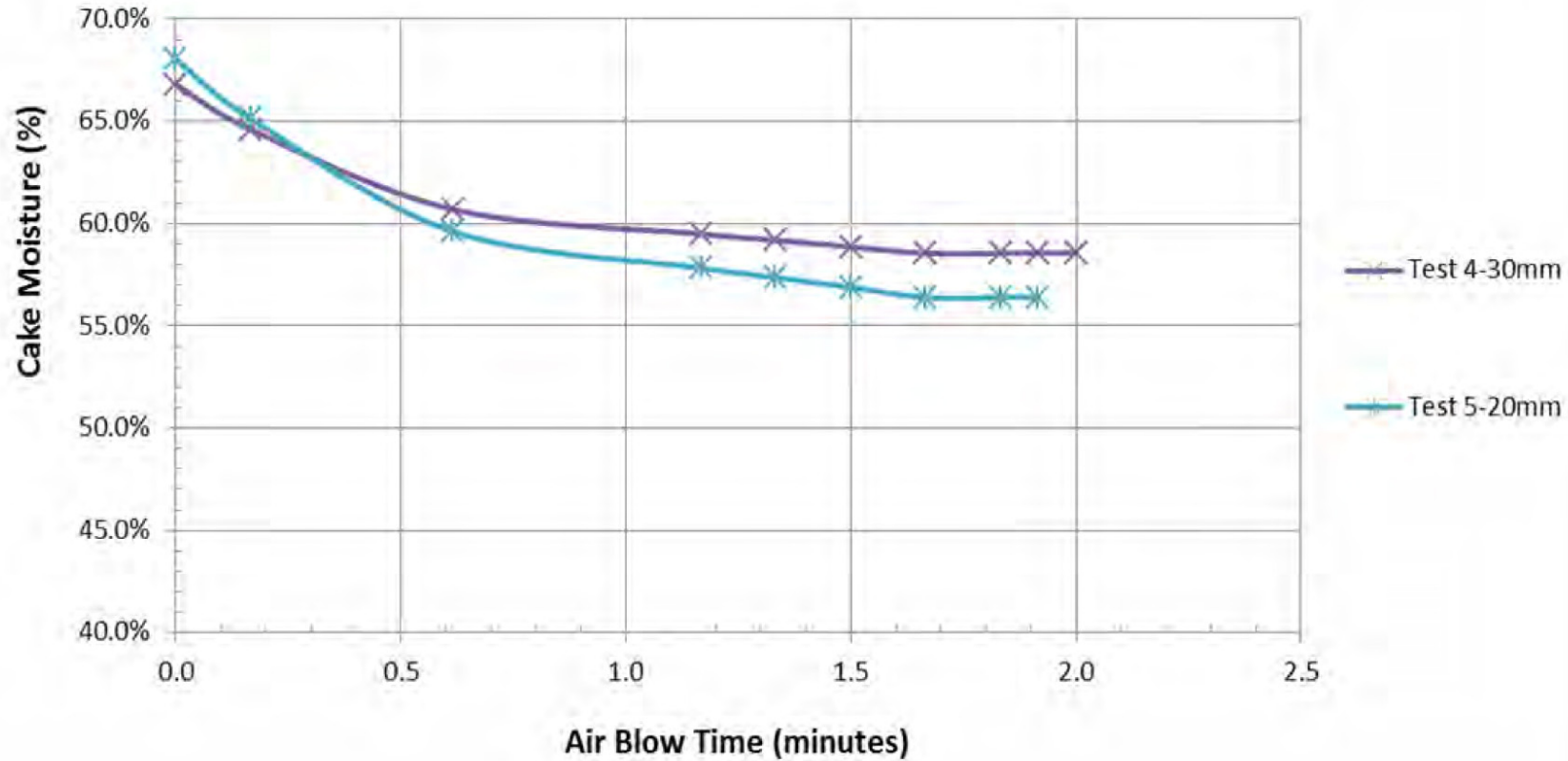
- Estimates based on analysis of XRD diffractogram analysis by International Centre for Diffraction Database

Mineral	Ideal Formula	Estimated %
Goethite	$\alpha\text{-Fe}^{3+}\text{O(OH)}$	57.0
Lepidocrocite	$\gamma\text{-Fe}^{3+}\text{O(OH)}$	35.5
Magnetite / Maghemite	$\text{Fe}_3\text{O}_4 / \gamma \text{Fe}_2\text{O}_3$	4.1
Bloedite	$\text{Na}_2\text{Mg(SO}_4)_2 \cdot 4\text{H}_2\text{O}$	1.9
Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	1.5
Total		100.0

TCLP Results of Solids Residue

Element	TCLP Reg. Limit (mg/L)	Result (mg/L)
Cd	10	< 0.050
Cr	50	< 0.25
Cu	250	0.071
Ni	250	5.18
Pb	50	< 0.25
Zn	250	< 0.50
Hg	1	< 0.0010
Sb	150	< 1.0
As	50	< 1.0
Be	10	< 0.025
Tl	50	< 1.0
V	250	< 0.15
Se	1	< 1.0
Ba	1,000	< 2.5

Air Blow – Iron Selenium Cake

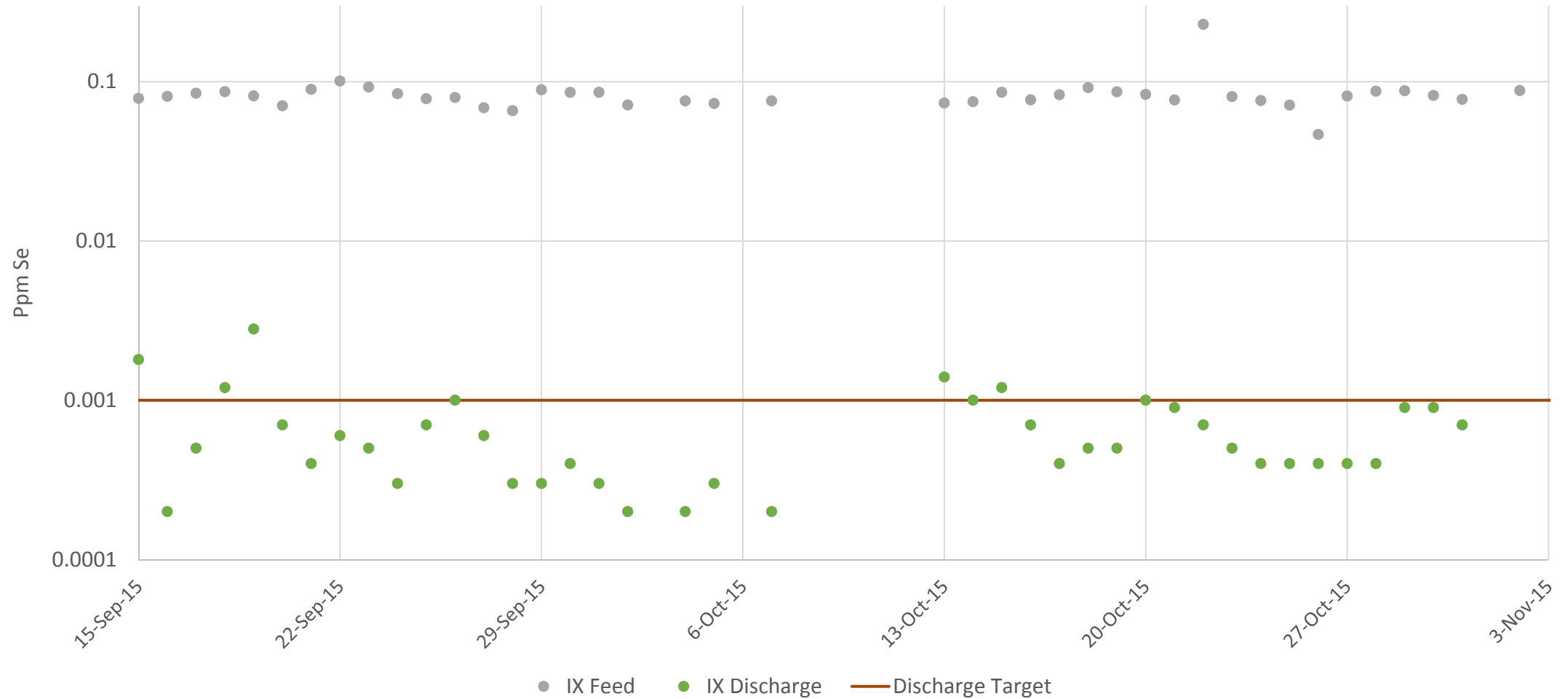


KSM Pilot Campaign Summary

- Selen-IX™ can remove Se < 1 ppb selectively from waste rock seepage
- Selen-IX™ is robust and readily adaptable to Se load fluctuations
- Solid residue is mostly iron oxide
 - Solids are non-hazardous/pass TCLP
 - Off-take of iron residue is possible
 - Additive to cement or steel production

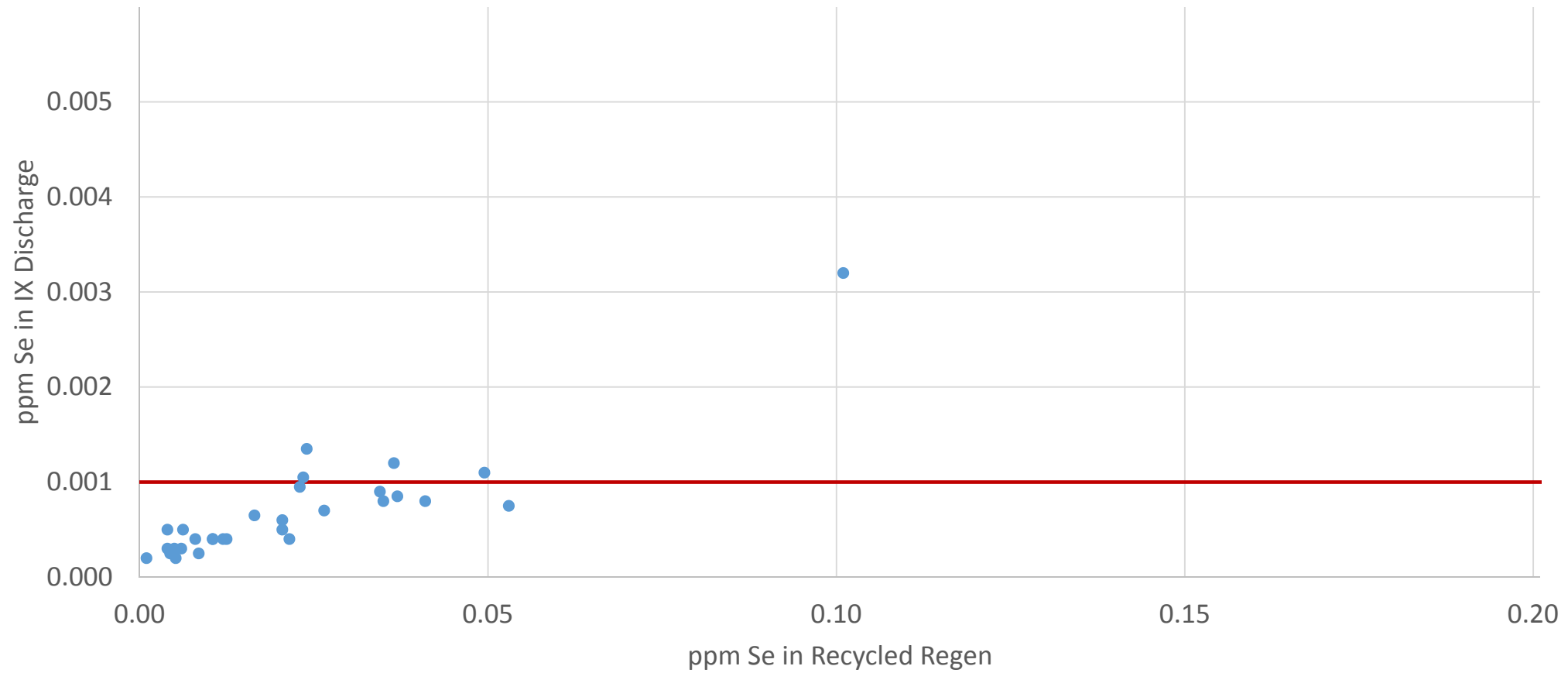
Subsequent Selen-IX™ Pilot Treating Mine Impacted Water From Northern BC Project

Closed Loop IX Data



Se Interdependency

Effect of Selenium in Recycled Regenerant on Selenium in IX Discharge



Main Takeaways from Latest Pilot

- Entered straight into closed loop operations with the same system as Seabridge
- Consistently attained 1 ppb at end of pipe
- Operated 24/7 for ~2 months
- A full presentation on this latest pilot will occur in the near future

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