

Rook I Project

Environmental Impact Statement

TSD XVII: Waste Rock and Underground Wall Rock Source
Term Predictions Report

FINAL

Waste Rock and Underground Wall Rock Source Term Predictions – Rook 1 Project

Rook I, Saskatchewan, Canada
NexGen Energy Ltd.



FINAL

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Rook 1, Saskatchewan, Canada

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Useful Definitions

This list contains definitions of symbols, units, abbreviations, and terminology that may be unfamiliar to the reader.

ABA	Acid-base accounting
AG	Acid generating
EA	Environmental assessment
EIS	Environmental impact statement
HCT	Humidity cell test
INT	Intrusive
ML/ARD	Metal Leaching/Acid Rock Drainage
NPAG	Non-potentially acid generating
PAG	Potentially acid generating
SFE	Shake flask extraction test
SPGN	Semi-pelitic gneiss
SPR	Source pathway receptor
UGTMF	Underground tailings management facility
WRSA	Waste rock storage area

1 Introduction

The Rook I Project (the Project) is a proposed uranium mining and milling operation in northern Saskatchewan that is 100% owned by NexGen Energy Ltd. NexGen is preparing an Environmental Assessment (EA) for the Project

The development of the mine will require management of various mine waste materials, which include waste rock and underground wall rock. NexGen proposes to store the waste rock produced from development of the proposed underground mine workings and the underground tailings management facility (UGTMF) at surface in waste rock storage area(s) (WRSA(s)). In addition, the development of the underground mine and UGTMF will produce exposed wall rock. These materials will produce mine affected drainage which may require management as part of site-wide water management. Additionally, potential effects of the drainage need to be considered in the EA. Accordingly, source terms were derived for input into solute transport models for the Project.

NexGen retained SRK Consulting (Canada) Inc. to characterize the geochemical properties of waste rock and to evaluate the drainage chemistry from the WRSA and underground wall rock. This included development of source term water quality predictions (source terms) for the WRSAs and underground mine workings. This report presents the inputs, assumptions and methods used to develop source terms for the WRSAs, as well as the source term results.

2 Background and Conceptual Geochemical Model

2.1 Deposit Geology

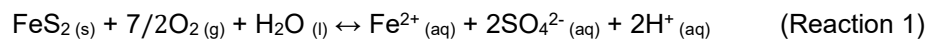
The geological description for the Project is summarized from RPA (2016).

The Arrow uranium deposit is located within the western margins of the Athabasca Basin in northern Saskatchewan. The geology of the Project area is underlain by the Proterozoic Talston Magmatic Zone, which is composed of granitic, granodioritic, tonalitic, dioritic and local gabbroic gneisses. The Arrow uranium deposit occurs within the Proterozoic basement rocks. Overall, the dominant lithology at the Project is semi-pelitic gneiss (SPGN) with lesser intrusive (INT). Other minor lithologies are recognized, including pelitic gneiss and pegmatite. The Proterozoic basement units are covered by thin Devonian mudstone, Cretaceous sandstone and overburden. The majority of the development is planned within the basement Proterozoic rocks (SPGN and INT).

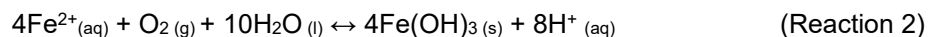
Uranium mineralization at the Arrow deposit is closely associated with narrow, strongly graphitic pelitic, and graphitic semi-pelitic gneiss lithologies thought to represent discrete shear zones. High grade uranium zones often occur immediately adjacent to heavily sheared and strongly graphitic zones, but not within them. Uranium is predominantly present as uraninite (UO₂).

2.2 Geochemical Weathering Concepts

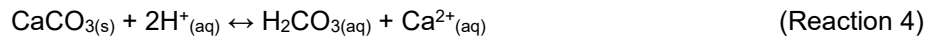
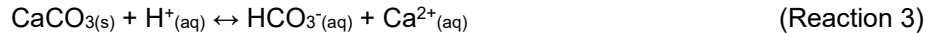
Mining of the Arrow deposit will produce a component of pyrite (FeS₂) bearing potentially acid generating (PAG) waste rock. Mineralogical testing indicates pyrite is the main sulfide mineral at the Arrow deposit. Under natural conditions, the pyrite is stable in bedrock where it is isolated from atmospheric oxygen. However, following blasting of the bedrock, pyrite in the waste rock will be exposed to atmospheric oxygen prior to and after being placed in a WRSA. Pyrite within the waste rock is expected to oxidize in the presence of oxygen and water according to the following reaction:



As seen in Reaction 1, pyrite oxidation produces sulfate, iron and acidity. The iron liberated from the sulfide can subsequently oxidize to ferric iron in neutral pH water to produce additional acidity according to the following reaction:



In waste materials, the onset of acidic conditions will depend on the balance of acid generated and neutralization potential (NP) available. However, acidic conditions will not occur until carbonate minerals are consumed. Based on static geochemical testing, the overall sulfur concentrations associated with pyrite in waste rock are generally low (<0.2%). However, the dominant waste rock units are deficient in carbonate minerals and therefore contain limited buffering capacity. The available carbonate is expected to buffer acid formed early from oxidation of sulfide according to the following reactions:



Acidity can also be neutralized through dissolution of oxyhydroxide and aluminosilicate minerals; however, due to the dissolution kinetics of these minerals, they often produce insufficient neutralization potential to produce neutral drainage.

Similarly, some metal carbonates (e.g., siderite and ankerite) offer limited buffering potential, since during dissolution, oxidation of the metal cation produces acidity, which offsets the neutralization produced from the carbonate ion. Given the limited neutralizing capacity of these minerals, they were conservatively assumed not to provide buffering capacity in source terms.

Release mechanisms from the materials at Rook 1 are assumed to be governed by two main processes. Oxidation of sulfide is assumed to be the dominant mechanism of constituent release for parameters associated with sulfides (e.g., sulfate, copper, cobalt, arsenic). Conversely, dissolution is assumed to be the dominant mechanism of constituent release from oxide, sulfate, and carbonate minerals. As uranium occurs as the oxide species uraninite at the Arrow deposit, uranium and radionuclide release (e.g., radium-226) is expected to result primarily from dissolution. Release from these minerals can also be influenced by pH and redox conditions. Based on this conceptual model, source terms for uranium and radionuclides are derived differently from most other species, as described in this report.

2.3 Unsaturated Waste Rock

All waste rock placement options under consideration will be unsaturated WRSAs with waste rock disposed on surface. Waste rock stored in the WRSA will oxidize according to Reaction 1, and acid production will be neutralized through Reactions 3 and 4. Dissolution of uraninite is expected to be the dominant mechanism for release of uranium and radionuclides into contact water from WRSAs.

The development of acidic conditions of the PAG waste rock will form when carbonate is depleted. Results from ongoing kinetic testing on waste rock samples show that a delay to onset of acidic conditions is expected in PAG waste rock with low sulfide content (below approximately 1% sulfide). Geochemical depletion calculations from ongoing laboratory based kinetic testing indicate that this delay is on the order of decades. These results were used to frame the approach to developing distinct sets of source terms for the conditions during operations (year 0 to 28) and closure (year 28 onward). During operations, the low sulfide PAG waste rock is expected to have near neutral pH with acidic conditions forming at or after closure, if not otherwise mitigated.

Once the predicted acidic conditions form in the PAG waste rock following closure, the mobility of cation species, which are sensitive to pH conditions, will increase (e.g., Cu and Co), resulting in higher concentrations and loadings of these constituents. The conceptual source control being considered for some placement method options (described in Section 2.4) will limit ingress of oxygen available for sulfide oxidation (Reaction 1 and Reaction 2). By limiting oxygen ingress, the reduction in waste rock mass exposed to oxic conditions will have the net effect of reducing loadings of parameters released from sulfide oxidation.

2.4 Waste Rock Management

NexGen is considering different waste rock placement methods to mitigate metal leaching and acid rock drainage (ML/ARD) from PAG materials. To inform the waste rock management multiple accounts analysis completed for the Project, SRK developed source terms for each of the WRSAs representing placement methods being considered. The different WRSA options are presented by Okane Consultants Ltd. (Okane) in an Options Analysis of waste rock placement strategies (Okane 2020a).

The conventional placement methods considered in the Options Analysis includes placement of waste rock by end-dumping. The WRSAs constructed by conventional end-dumping are expected to have a high degree of advective oxygen transport for sulfide oxidation due to the high degrees of particle size segregation and low water contents, allowing oxygen to freely move through the WRSA (Okane 2020a). WRSA placement options considered included both co-mingling and segregation of PAG and NPAG (non-potentially acid generating) material placed by conventional end-dumping.

The placement methods include segregation and co-placement of PAG and NPAG waste rock and using engineered source controls with design of horizontal layering to limit oxygen ingress into the WRSA (engineering layering). The engineered control was designed by Okane. For this design, the waste rock dumps are constructed from the bottom up, with a sequence of 5 m lifts of waste rock followed by 0.5 m thick engineered layers of fine-textured material (Okane 2020b). Okane modelled O₂ transport in this design, which indicated O₂ ingress would be limited to a surficial “skin” in the WRSA. As described previously, limiting O₂ ingress will reduce the reactive mass and in turn reduce geochemical loadings.

The placement methods considered combining or segregating PAG and NPAG material, use of the engineered layering design and use of a liner to capture leachate. These combinations result in five separate WRSAs with source terms developed for each so that each placement method can be evaluated with respect to its runoff water quality (Table 2-1). Note that one or two WRSAs are necessary, depending on the placement method selected.

Table 2-1: Source Terms Modelled

Source Term	Placement Method	Design	Liner
Source Term 1	Combined (conventional co-placement) PAG & NPAG	Conventional waste rock placement	Yes
Source Term 2	Combined (conventional co-placement) PAG & NPAG	Engineer layering	Yes
Source Term 3	Segregated PAG	Conventional waste rock placement	Yes
Source Term 4	Segregated NPAG	Conventional waste rock placement	No
Source Term 5	Segregated PAG	Engineer layering	Yes

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2.5 Underground Wall Rock

Underground wall rock will be exposed to oxic conditions prior to back-filling during operations or flooding in closure and will weather according to the reactions outlined in Section 2.2. Therefore, water contacting underground wall rock represents a source which may require management.

For the development of underground wall rock source terms, wall rock is expected to produce geochemical loading when the wall is exposed to oxic conditions resulting in the oxidation of sulfide. Additionally, the geochemical loading is expected to be stored as secondary mineral precipitates such as sulfate or oxyhydroxides produced from the oxidation reactions that precipitate on the exposed wall rock and fracture surfaces (e.g., ferrihydrite produced in Reaction 2).

During operations, oxygen availability will be limited as underground developments are backfilled with paste-tailings, cave rock or inundated with groundwater. When the exposed face is backfilled or inundated with groundwater, oxygen is limited, and the exposed face no longer accumulates stored geochemical loading.

During closure, the ingress of groundwater into underground workings will return to static conditions, and the accumulated stored geochemical load will be released into the underground mine pool by simple dissolution of readily soluble oxidation products such as sulfates, or by reductive dissolution of oxyhydroxides.

3 Methods

3.1 Model Constituents

The following constituents were modelled in the waste rock and underground wall rock models:

General Chemistry: pH (waste rock only), alkalinity;

Major Ions: calcium, magnesium, sulfate;

Trace Elements: aluminum, antimony, arsenic, barium, boron, cadmium, cobalt, chloride, chromium, copper, iron, lead, lithium, manganese, mercury, molybdenum, nickel, potassium, selenium, silver, sodium, strontium, tin, uranium, vanadium, zinc; and

Radionuclides: radium-226, lead-210, polonium-210, thorium-230.

3.2 Waste Rock Source Term

Waste rock source terms were developed to represent predicted water quality of contact water during operations and closure. The approach and inputs used to develop the waste rock source terms are detailed in the following section.

The source terms are developed for different management options including segregation PAG and NPAG materials, and the use of a liner to capture and manage contact water.

3.2.1 Method Overview

Waste rock source terms were developed by numerical modelling using inputs derived from ongoing laboratory-based kinetic geochemical testing with humidity cell tests (HCTs), available mine plans and water balances provided by BGC Engineering (BGC) and Okane. In general, the model was initially set up as a mass balance model where loadings from HCTs were scaled to field conditions and combined with estimated waste rock tonnages and precipitation infiltration rates. The predicted concentrations were subsequently equilibrated using the geochemical speciation and mass transfer code PHREEQC developed by the USGS (Parkhurst and Appelo 1999) to evaluate if the mass balanced concentrations would be constrained through precipitation of relevant mineral species.

Humidity Cell Test Input

Humidity cell tests (HCTs) on samples collected from the Project have been operating since 2019 at SGS Canada Inc. in Lakefield, Ontario using the standard HCT operation method ASTM D 5744-18 (ASTM 2018).

Average loading rates in milligrams per kilogram per week (mg/kg/week) were calculated from the last eight (8) weekly cycles (up to week 56) in HCTs at the time of model development. Representative HCT loading rates were then assigned to each lithology (SPGN or INT) from each location of the

development (the UGTMF and the Mine area). Criteria to select the representative HCTs included a review of sulfur content, ARD classification, lithology and development location. Input loading rates were then prorated based on their relative compositions for each of the placement methods being considered according to the expected lithological distribution in the WRSA(s). The prorated loading rates were then scaled from laboratory to field conditions to account for differences in temperature, grain size and channelization. The total load from the WRSA was estimated by multiplying the scaled loading rates by the total tonnage stored in the WRSA at the end of the mine life.

Consideration of Liner

The source term models also considered if a liner was used in the waste rock placement method, which determines where contact water is predicted to be released. For Source Term 4 (Table 3-2), representing NPAG material placed with no liner, all contact water reports directly to shallow groundwater as basal seepage. For Source Terms 1, 2, 3 and 5, which represent placement methods of waste rock containing a component of PAG material and use a liner, the majority of the WRSA load was assumed to drain to the toe of the WRSA(s) where it will be captured for treatment with a minor component reporting to shallow groundwater from leakage through the liner during operations. The liner is assumed to fail following closure with the WRSA drainage then reporting to shallow groundwater. Therefore, the modelled closure scenario assumes the liner no longer functions. The total WRSA load on an annual basis is assumed to dissolve in the estimated volume of water in contact with waste rock annually providing a source term in milligrams per litre (mg/L). The use of liner is described in more detail in the following section.

Equilibration Modelling

The predicted concentrations were equilibrated using the geochemical speciation and mass transfer code PHREEQC to evaluate if the mass balanced concentrations would be constrained through precipitation of relevant mineral species. Predicted WRSA water qualities were equilibrated with relevant mineral phases (Table 3-1) using the MinteqV4 library in PHREEQC to provide a final source term (mg/L).

Redox conditions in the PHREEQC model input reflected the predicted conditions of leachate leaving the WRSA. For the source terms representing placement methods using a liner (Source Term 1, 2, 3 and 5), the majority of the seepage will exit at the toe of the WRSA(s) during operations. It is expected that during operations, seepage will be in equilibrium with atmospheric gases. For the unlined placement method (Source Term 4), the seepage is modelled to recharge groundwater at the base of the pile under more reducing conditions. For source terms 1, 2, 3 and 5, a minor component of the contact water is expected to leak through the liner and report to shallow groundwater under more reducing conditions. To account for the different redox conditions in the source terms, the solution oxygen partial pressure was controlled by fixing the oxidation reduction potential (ORP) to oxic conditions for drainage exiting at the toe of the WRSA and to more reducing conditions for water infiltrating at the base of the WRSA. An ORP of 300 millivolts (mV) was assumed for water draining to the toe of the WRSA and 100 mV for WRSA drainage recharging shallow groundwater as basal seepage from the WRSA. The value of 300 mV was used as an assumed redox condition for surface

waters. As there is no data available for ORP from shallow groundwater at the site, a value of 100 mV was used to represent shallow groundwater for leachate released as basal seepage. It is assumed that the shallow groundwater is more reducing than surface waters however there will be some interaction with the atmosphere, and therefore a low oxidizing value was used.

Geochemical modelling requires consideration of temperature. All model equilibrations using PHREEQC were conducted using a reaction temperature of 5°C. This temperature was selected based on SRK project experience from a northern Saskatchewan uranium mine with recorded temperature from instrument bore hole in a waste rock pile which ranged from -3 °C to 0.3°C and near surface temperature recorded at site which ranged from 3°C to 6°C. Colder temperatures in the pile will limit geochemical kinetics; therefore, a conservative value of 5°C was used in the modelling to account for seasonal warming of the upper areas in the pile.

The pH conditions will influence element mobility and stability of secondary mineral phases. For the equilibration modelling using PHREEQC, pH was fixed based on anticipated conditions described in the conceptual model (Section 2.3) which assumes low-sulfide PAG waste rock will maintain neutral pH during operations and will be acid generating in closure. The following pH values were assumed for the operations and closure scenarios for each WRSA option:

Operations

All Source Terms: pH = 6.5

Closure

Source Term 1, 2, 3 and 5: pH = 3.5

Source Term 4: pH = 6.5

Geochemical models require input solutions to be electrically neutral. Charge imbalances can occur through prorating and mixing loading rates from multiple HCTs that have different individual ionic proportions. Charge imbalances were corrected in the model by adding potassium (K^+) to solutions with negative imbalance or sulfate (SO_4^{2-}) to solutions with positive imbalances. Sulfate was selected because it is expected to be the most abundant anion as a result of sulfide oxidation. Potassium is a relatively inert cation, and addition of this ion is not anticipated to change the outcomes of the geochemical model.

Table 3-1: Mineral Phases used in Equilibration (from PHREEQC Minteq.v4)

Phase Name	Formula
Al(OH) _{3(am)}	Al(OH) ₃
Gibbsite	Al(OH) ₃
Otavite	CdCO ₃
Barite	BaSO ₄
Brochantite	Cu ₄ SO ₄ (OH) ₆
Cu(OH) ₂	Cu(OH) ₂
Malachite	Cu ₂ CO ₃ (OH) ₂
Azurite	Cu ₃ (CO ₃) ₂ (OH) ₂
Chalcanthite	CuSO ₄ ·5H ₂ O.
Ferrihydrite	Fe(OH) ₃
Melanterite	FeSO ₄ ·7H ₂ O
Anglesite	PbSO ₄
Birnessite	MnO ₂
Manganite	MnOOH
PbMoO ₄	PbMoO ₄
CaMoO ₄	CaMoO ₄
Ni(OH) ₂	Ni(OH) ₂
Co(OH) ₂	Co(OH) ₂
Zn(OH) _{2(am)}	Zn(OH) ₂
Smithsonite	ZnCO ₃
Goslarite	ZnSO ₄ ·7H ₂ O
UO ₂ (OH) _{2(beta)}	UO ₂ (OH) ₂
Gypsum	CaSO ₄ ·2H ₂ O
Calcite	CaCO ₃

Model Scenarios

Multiple source terms were developed to account for variability in the water quality model. For each of the five source terms, a unique water quality prediction was modelled to represent the expected (base case) and upper case. The base and upper case predictions represent different laboratory-to-field scaling factors which were outlined in Section 3.2.2 (Scaling Factors).

A summary of each of the modelled source terms is provided in Table 3-2.

Table 3-2: Summary of Modelled Source Term Scenarios

Source Term	WRSA Description	Liner	Modelled Source Term
Source Term 1	Single WRSA - Mixed PAG and NPAG – Conventional Construction and Waste Rock Placement	Yes	Operations - Base Case
			Operations - Upper Case
			Closure - Base Case
			Closure - Upper Case
Source Term 2	Single WRSA - Mixed PAG and NPAG with Engineered Layering	Yes	Operations - Base Case
			Operations - Upper Case
			Closure - Base Case
			Closure - Upper Case
Source Term 3	Segregated PAG WRSA – Conventional Construction and Waste Rock Placement	Yes	Operations - Base Case
			Operations - Upper Case
			Closure - Base Case
			Closure - Upper Case
Source Term 4	Segregated NPAG WRSA – Conventional Construction and Waste Rock Placement	No	Operations - Base Case
			Operations - Upper Case
			Closure - Base Case
			Closure - Upper Case
Source Term 5	Segregated PAG WRSA - Engineered Layering	Yes	Operations - Base Case
			Operations - Upper Case
			Closure - Base Case
			Closure - Upper Case

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3.2.2 Model Inputs & Assumptions

The information used to derive the source terms is described in the following sections.

ARD Classification

The waste rock tonnage modelling included calculations to estimate waste rock by ARD classification (PAG or NPAG). The distribution of PAG and NPAG material was estimated through modelling sulfur content of the assay database and using a low sulfur cutoff criteria provided by SRK. In this criteria, PAG is defined as material having over 0.1% sulfur (total) and NPAG defined as material with less than 0.1% sulfur.

The low-sulfur cut-off criteria to define ARD potential was developed from results of geochemical characterization of drill core samples representing waste rock from the Project. ARD potential was assessed using the results of acid-base accounting (ABA) which were used to calculate the

neutralization potential ratio (NPR). The NPR represents the ratio of neutralization potential (NP), which is determined through the Modified NP analysis, to acid potential (AP), which is calculated based on sulfide content. Samples with an NPR greater than 3 were classified as NPAG, and samples with an NPR less than 1 were classified as PAG. Samples with NPR between 1 and 3 were classified as uncertain (UC). Further details on the ARD classification will be provided in a baseline geochemistry report currently in draft. The geochemical testing results also indicated that the majority of the samples of waste rock with a sulfide concentration greater than 0.1% (equivalent to AP of 0.31 kg CaCO₃/t) resulted in an NPR less than 1 and were classified as PAG (Figure 3-1 and Figure 3-2).

The geochemical release rates of the lower sulfur samples are still being evaluated (i.e., it has not yet been determined if low sulfur PAG samples will become acidic in the long-term). As the low sulphur cut-off criteria for the classification has not yet been developed for the Project, a value of 0.1% sulphur has been intermittently used for the classification of ARD potential of waste rock. The use of a low sulfide cut-off of 0.1% to classify all material as NPAG is supported by work conducted by Day and Kennedy (2015) which demonstrated that in many carbonate-deficient systems, the rate of acid generation from low sulfide geological material is sufficiently buffered by bicarbonate produced through meteoric weathering of silicate minerals. Furthermore, Day and Kennedy (2015) also demonstrate that the Modified NP method underestimates the silicate mineral reservoir potentially available to neutralize acidity generated by low sulfide geological materials. NexGen applied the sulfur cut-off of 0.1% to estimate the total tonnage of PAG and NPAG waste rock in the block model for the underground workings.

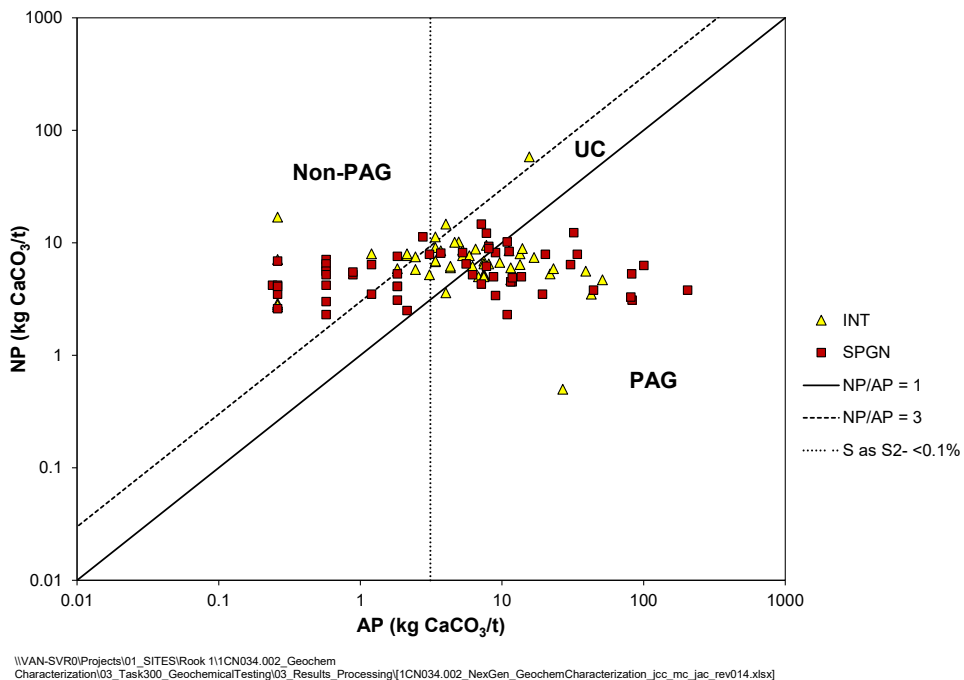
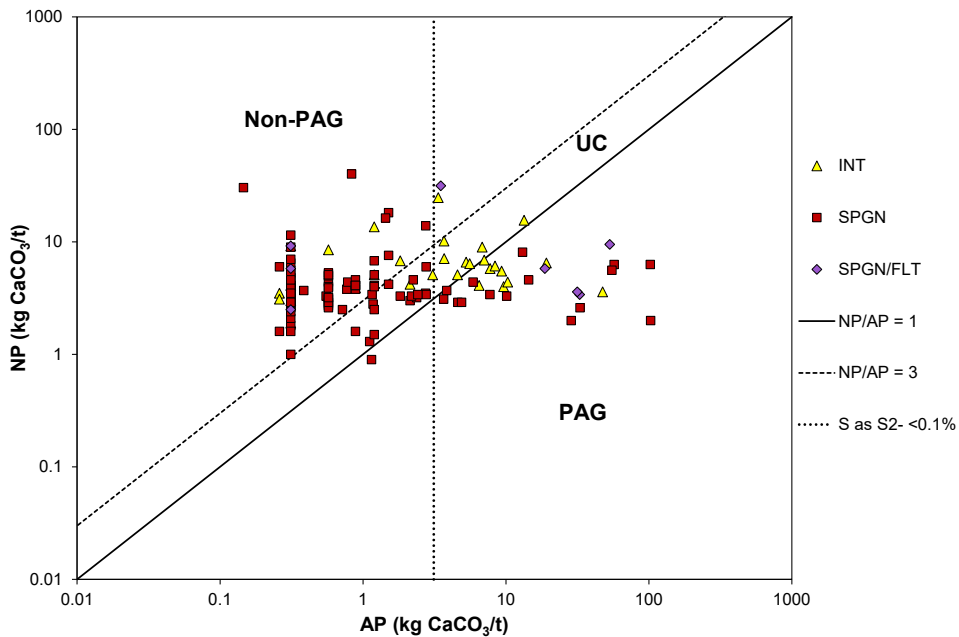


Figure 3-1: NP versus AP – UGTMF



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 Characterization\03_Task300_GeochemicalTesting\03_Results_Processing\1CN034.002_NexGen_GeochemCharacterization_jcc_mc_jac_rev014.xlsx]

Figure 3-2: NP vs. AP – Mine Workings

Waste Rock Tonnages

Waste rock tonnage was used as an input in the source term model along with the ARD classification criteria. The waste rock tonnages for the Project were calculated by Roscoe Postle Associates Inc. (RPA; now SLR Consulting Inc.) and provided as an Excel sheet in March 2020 (RPA 2020). The summary provided by RPA included a breakdown of waste rock tonnage by lithology, location (UGTMF or Mine), and ARD potential. For the 28-year mine life, RPA estimated the total waste rock tonnage at 25,378,277 tonnes (t), with 20,588,544 t (81%) being produced from the UGTMF and the remaining 4,789,731 t (19%) from the mine development area (RPA 2020).

The modelled tonnage for each of the waste rock groupings (location, lithology, ARD potential) were used to calculate tonnages representing lithologic grouping. In the context of the source term development, lithologic groupings are defined as groupings of waste rock by location, lithology and ARD potential (e.g., PAG SPGN from the UGTMF). A tonnage representing lithologic grouping was calculated for each WRSA in Source Terms 1 to 5 (Table 3-3).

Table 3-3: Waste Rock Tonnages by Lithological Domain Grouping for Each Source Term for Operations Scenario

Source Term	Placement Method	Lithology Domain Grouping (Location-Lithology-ARD Classification) during Operations								Total
		UGTMF-INT-PAG	UGTMF-INT-NPAG	UGTMF-SPGN-PAG	UGTMF-SPGN-PAG	Mine-INT-PAG	Mine-INT-NPAG	Mine-SPGN-PAG	Mine-SPGN-NPAG	
Source Term 1	Combined (conventional co-placement) PAG & NPAG	4,436,074	4,940,108	5,304,811	5,907,552	109,832	416,525	889,616	3,373,759	25,378,277
Source Term 2	Combined PAG & NPAG with engineered layering	4,436,074	4,940,108	5,304,811	5,907,552	109,832	416,525	889,616	3,373,759	25,378,277
Source Term 3	Segregated PAG with conventional placement	4,436,074	-	5,304,811	-	109,832	-	889,616	-	10,740,333
Source Term 4	Segregated NPAG with conventional placement	-	4,940,108	-	5,907,552	-	416,525	-	3,373,759	14,637,945
Source Term 5	Segregated PAG with engineered layering	4,436,074	-	5,304,811	-	109,832	-	889,616	-	10,740,333

Source: \\VAN-SVR0\Projects\01_SITES\Rook 1\1CN034.002_Geochem Characterization\04_Task400_SourceTerms\Final Source Terms\Waste Rock Source Terms\{Rook1_SourceTerms_No_Sorbtion_No_Liner_1CN034.002_MKH_JAC_Rev07.xlsx

Water Balance

Modelled water balances for each of the WRSAs were used to generate infiltration rates, which are inputs in the source term development model. The water balance modelling was completed by Okane for the conventional co-placement of PAG and NPAG waste rock and engineered placement methods (Source Term 1, 2, 5) and by BGC for the segregated PAG and NPAG WRSAs (Source Term 3, 4). The infiltration rates provided by BGC were modelled using a range of cover types with varying permeability.

Golder Associates (Golder) completed a multiple accounts analysis (MAA) to determine a preferred WRSA option for the Project which would be assessed in the EA (see the EIS, Section 4). The segregated PAG and NPAG WRSA with “Option A ablation till infiltration” scenario was carried forward into the source term solute transport model for the EA and was represented by Source Term 3 and 4.

The modelled infiltration rates were combined with the WRSA footprint area provided by Wood (2020) to calculate infiltration volumes through each WRSA (m³/year). The WRSA areas were generated from the WRSA designs provided by Wood (2020) (Table 3-4).

For the placement methods which would use a liner (Source Term 1, 2, 3 and 5) 5% of the total precipitation is assumed to report to shallow groundwater as basal seepage leaking through the liner during operations (Okane 2020c, *pers. comm.*), with the remaining volume reporting as toe seepage. For the placement method that does not use a liner (Source Term 4) infiltration will report to shallow groundwater. As the liner used in the lined placement methods (Source Term 1, 2, 3 and 5) is eventually expected to fail, all closure scenarios are modelled assuming all contact water reports to shallow groundwater as basal seepage. A summary of the infiltration rates, surface area and annual flows rates for each Source Term are provided in Table 3-4.

Table 3-4: Source Term Model Water Balance Inputs

Source Term	Placement Method	Operations or Closure	Net Infiltration (mm/yr)	Pad Footprint (m ²)	Flow Rate (m ³ /yr)	Seepage (based on total precipitation)
Source Term 1	Combined (conventional co-placement) PAG & NPAG	Operations	210	1,029,378	216,169	95% toe seepage / 5% basal seepage
		Closure	75	1,029,378	77,203	100% basal seepage
Source Term 2	Combined PAG & NPAG with engineered layering	Operations	120	1,029,378	123,525	95% toe seepage / 5% basal seepage
		Closure	75	1,029,378	77,203	100% basal seepage
Source Term 3	Segregated PAG	Operations	220	457,329	100,612	95% toe seepage / 5% basal seepage
		Closure	75	457,329	32,013	100% basal seepage
Source Term 4	Segregated NPAG	Operations	220	572,049	125,851	100% basal seepage
		Closure	70	572,049	40,043	100% basal seepage
Source Term 5	Segregated PAG with engineered layering	Operations	120	457,329	54,879	95% toe seepage / 5% basal seepage
		Closure	70	457,329	32,013	100% basal seepage

Source: \\VAN-SVR0\Projects\01_SITES\Rook 1\1CN034.002_Geochem Characterization\05_Reporting\03_Final Source Terms_Approach\020_Tables\[Source_Term_Scenario_Compilation_1CN034.002_JAC_REV01.xlsx]Sheet

Oxygen Transport Modelling

Oxygen transport modelling was completed by Okane to assess oxygen availability for sulfide oxidation in the waste rock pile. This was used in the source term development to account for the amount of reactive mass which would be exposed to oxic conditions. The oxygen transport modelling was completed by Okane as a one-dimensional, numerical model of oxygen transport for both operations (no cover system) and closure (with cover system) conditions and for both the waste rock placement methods represented by Source Term 1 and 2 (co-mingled PAG and NPAG material) (Okane 2020b).

The modelling results for the placement method of combined PAG and NPAG material without engineered layering (Source Term 1) indicated that the potential for advective gas transport is greater than oxygen consumption by sulfide; therefore, it is assumed that the entire WRSA will be reactive for both the operations and closure scenarios that have a constant supply of oxygen.

For the engineered layer design (Source Term 2 and 5) during operations (while the waste rock is being placed and the engineered layering is being progressively constructed) it is assumed that the WRSAs have full reactive thickness with oxygen available in the entire WRSA.

The model results for the placement method of combined PAG and NPAG material with horizontal engineered layering (Source Term 2 and 5) indicated the engineered layering will effectively act as a barrier to advective gas transport during closure with oxygen consumption being greater than the rate of advective oxygen supply, which will lead to a diffusion-dominated system. Therefore, only the areas where diffusive gas transport can reach are considered reactive materials in the source term model. The modelling suggests diffusive oxygen transport through the WRSA plateau and slopes will create a reactive zone of approximately 3 m in thickness in the waste rock pile which averages 16 m in height (Okane 2020b). Thus, the reactive waste rock tonnage was scaled using the ratio of 3/16, representing the ratio of reactive thickness to overall average waste rock pile thickness. A summary of the reactive masses at closure for all scenarios is summarized in Table 3-5.

Source terms 1, 3 and 4 are for designs with no engineered layer design, and therefore oxygen ingress is assumed not to be restricted.

Table 3-5: Reactive Waste Rock Tonnages by Lithological Grouping for Each Source Term for Closure Scenario

Source Term	WRSA	Lithology Domain Grouping (Location-Lithology-ARD Classification) at Closure								Total
		UGTMF-INT-PAG	UGTMF-INT-NPAG	UGTMF-SPGN-PAG	UGTMF-SPGN-PAG	Mine-INT-PAG	Mine-INT-NPAG	Mine-SPGN-PAG	Mine-SPGN-NPAG	
Source Term 1	Combined (conventional co-placement) PAG & NPAG	4,436,074	4,940,108	5,304,811	5,907,552	109,832	416,525	889,616	3,373,759	25,378,277
Source Term 2	Combined PAG & NPAG with engineered layering	831,764	926,270	994,652	1,107,666	20,594	78,098	166,803	632,580	4,758,427
Source Term 3	Segregated PAG	4,436,074	-	5,304,811	-	109,832	-	889,616	-	10,740,333
Source Term 4	Segregated NPAG	-	4,940,108	-	5,907,552	-	416,525	-	3,373,759	14,637,945
Source Term 5	Segregated PAG with engineered layering	831,764	-	994,652	-	20,594	-	166,803	-	2,013,812

Source: \\VAN-SVR0\Projects\01_SITES\Rook 1\1CN034.002_Geochem Characterization\04_Task400_SourceTerms\Final Source Terms\Waste Rock Source Terms\[Rook1_SourceTerms_No_Sorption_No_Liner_1CN034.002_MKH_JAC_Rev07.xlsx

Waste Rock Loading Rates

Geochemical loading rates from HCTs were used as inputs in the source term modelling to represent waste rock lithological groupings. The HCTs represent waste rock material from the different locations, lithologies and classification of ARD potential. Representative HCTs or mixtures of representatives HCTs were selected to provide geochemical loading rate inputs for each of the lithological groupings for both the operation and closure scenarios and for WRSA (Table 3-6 to Table 3-8)

Each of the WRSAs that were modelled in the source term development were represented by different proportions of the lithological groupings. The HCT mixtures used to represent the lithological groupings were developed to represent both operations and closure scenarios for each placement method. For the operations scenario, each lithological grouping was generally represented by a single HCT (primary HCT) with typical sulfide content.

To account for variability in the geochemical characteristics of the lithological groupings, smaller proportions of other HCTs were selected to be mixed in with the primary HCT to represent a range of leachate characteristics. Typically, the additional HCTs mixed with the primary HCTs were represented by a minor component of samples with high proportions of acid-generating (AG) material (samples 39137, 39010 and 39140). These HCTs were selected and mixed with the primary HCT to represent high sulfide material in each lithological grouping.

The proportions of HCT sample representing AG material used in each of the HCT mixtures representing the operations scenario were determined through a review of the static geochemical results. The three samples with acidic pH (pH<5) (sample 39137, 39010 and 39140) all have solid phase sulfide content above 1.06% (Figure 3-3). Results from the static geochemical analysis over 1.06% sulfide were classified as AG, with the proportion of samples in each lithological grouping with sulfide values above this cut-off used to represent the proportion of AG material in the HCT mixtures.

Wherever two HCTs were considered to be representative of the primary lithological grouping, the HCTs were prorated using a 50/50 proportion.

For the WRSAs represented by placement methods containing PAG material (i.e., Source Terms 1, 2, 3 and 5), acidic conditions are expected to form in the closure scenario. During this period, loading rates from HCTs that had become acid generating during the testing period were used as input. For the segregated PAG placement method, this resulted in using only the AG HCT loading rates to represent each lithological grouping, whereas for the co-mingled PAG and NPAG WRSA, the proportion of AG HCTs used in the mixtures was proportional to the amount of PAG material for each lithological grouping.

For the segregated NPAG placement method (Source Term 4), the same HCT mixtures were used to represent the operations and closure scenarios because neutral pH conditions are predicted to persist through operations and closure.

Source terms were iteratively defined and updated as more information and data became available. At the time this iteration of the source term modelling was completed, 56 weeks of HCT results were

available. For each HCT, the average value of the loading rate (mg/kg/week) for each parameter was calculated from the last three cycles of the elemental analysis (analyzed on weeks 48, 52 and 56). The model input loading rates for each lithological grouping generated from the HCT mixtures are provided for operations (Table 3-9) and closure (Table 3-10).

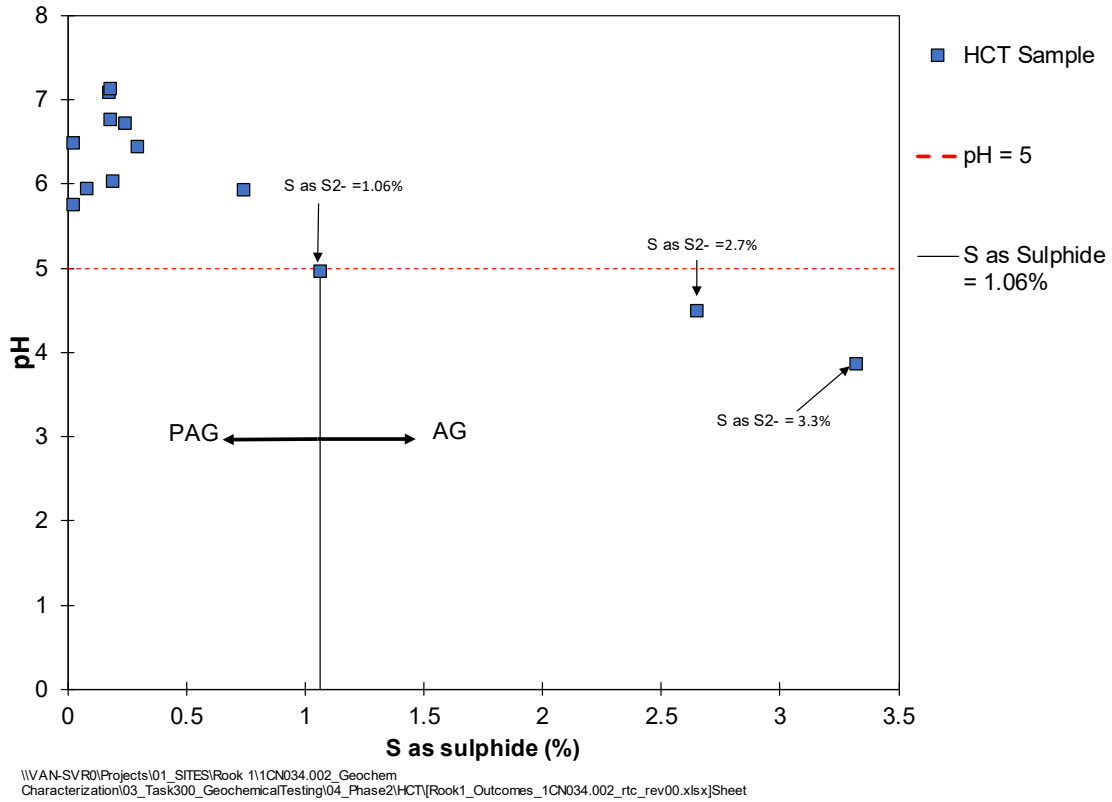


Figure 3-3: Solid phase sulfide content vs. HCT pH (at week 56)

Table 3-6: HCT Mixtures for Co-mingled PAG and NPAG Placement Method (Source Term 1 and 2) for Operations and Closure

	Lithology	Location	HCT Sample	Solid Phase Sulfide (%)	INT - UGTMF	INT - Mine	SPGN - UGTMF	SPGN - Mine
Operations	INT	UGTMF	39032	0.17	52.7%	-	-	-
	INT	UGTMF	39003	0.24	44.8%	-	-	-
	INT	Mine	39186	0.18	-	98.8%	-	-
	SPGN	UGTMF	39023	0.18	-	-	52.7%	-
	SPGN	UGTMF	39015	0.29	-	-	35.1%	-
	SPGN	UGTMF	39010	2.65	2.6%	-	12.2%	-
	SPGN	Mine	39140	1.06	-	1.2%	-	3.3%
	SPGN	Mine	39181	0.02	-	-	-	39.6%
	SPGN	Mine	39076	0.19	-	-	-	53.9%
	SPGN	Mine	39137	3.32	-	-	-	3.3%
	Total					100%	100%	100%
Closure	INT	UGTMF	39032	0.17	52.7%	-	-	-
	INT	UGTMF	39003	0.24	-	-	-	-
	INT	Mine	39186	0.18	-	79.1%	-	-
	SPGN	UGTMF	39023	0.18	-	-	52.7%	-
	SPGN	UGTMF	39015	0.29	-	-	-	-
	SPGN	UGTMF	39010	2.65	47.3%	-	47.3%	-
	SPGN	Mine	39140	1.06	-	20.9%	-	19.5%
	SPGN	Mine	39181	0.02	-	-	-	39.6%
	SPGN	Mine	39076	0.19	-	-	-	39.6%
	SPGN	Mine	39137	3.32	-	-	-	1.4%
	Total					100%	100%	100%

Source: \\VAN-SVR0\Projects\01_SITES\Rook 1\1CN034.002_Geochem Characterization\04_Task400_SourceTerms\Final Source Terms\Waste Rock Source Terms\|Rook1_SourceTerms_No_Sorbtion_No_Liner_1CN034.002_MKH_JAC_Rev07.xlsx

Table 3-7: HCT Mixtures for Segregated PAG WRSA Placement Method (Source Term 3 and 5) for Operations and Closure

	Lithology	Location	HCT Sample	Solid Phase Sulfide (%)	INT - UGTMF	INT - Mine	SPGN - UGTMF	SPGN - Mine
Operations	INT	UGTMF	39032	0.17	-	-	-	-
	INT	UGTMF	39003	0.24	94.6%	-	-	-
	INT	Mine	39186	0.18	-	94.1%	-	-
	SPGN	UGTMF	39023	0.18	-	-	-	-
	SPGN	UGTMF	39015	0.29	-	-	74.2%	-
	SPGN	UGTMF	39010	2.65	5.4%	-	25.8%	-
	SPGN	Mine	39140	1.06	-	5.9%	-	15.6%
	SPGN	Mine	39181	0.02	-	-	-	-
	SPGN	Mine	39076	0.19	-	-	-	68.8%
	SPGN	Mine	39137	3.32	-	-	-	15.6%
	Total					100.0%	100.0%	100.0%
Closure	INT	UGTMF	39032	0.17	-	-	-	-
	INT	UGTMF	39003	0.24	-	-	-	-
	INT	Mine	39186	0.18	-	-	-	-
	SPGN	UGTMF	39023	0.18	-	-	-	-
	SPGN	UGTMF	39015	0.29	-	-	-	-
	SPGN	UGTMF	39010	2.65	100.0%	-	100.0%	-
	SPGN	Mine	39140	1.06	-	100.0%	-	93.2%
	SPGN	Mine	39181	0.02	-	-	-	-
	SPGN	Mine	39076	0.19	-	-	-	-
	SPGN	Mine	39137	3.32	-	-	-	6.8%
	Total					100.0%	100.0%	100.0%

Source: \\VAN-SVR0\Projects\01_SITES\Rook 1\1CN034.002_Geochem Characterization\04_Task400_SourceTerms\Final Source Terms\Waste Rock Source Terms\Rook1_SourceTerms_No_Sorbtion_No_Liner_1CN034.002_MKH_JAC_Rev07.xlsx

Table 3-8: HCT Mixtures for Segregated NPAG WRSA Placement Method (Source Term 4) for Operations and Closure

	Lithology	Location	HCT Sample	Solid Phase Sulfide (%)	INT - UGTMF	INT - Mine	SPGN - UGTMF	SPGN - Mine
Operations and Closure	INT	UGTMF	39032	0.17	100%	-	-	-
	INT	UGTMF	39003	0.24	-	-	-	-
	INT	Mine	39186	0.18	-	100%	-	-
	SPGN	UGTMF	39023	0.18	-	-	100%	-
	SPGN	UGTMF	39015	0.29	-	-	-	-
	SPGN	UGTMF	39010	2.65	-	-	-	-
	SPGN	Mine	39140	1.06	-	-	-	-
	SPGN	Mine	39181	0.02	-	-	-	50%
	SPGN	Mine	39076	0.19	-	-	-	50%
	SPGN	Mine	39137	3.32	-	-	-	-
Total					100.00%	100.00%	100.00%	100.00%

Source: \\VAN-SVR0\Projects\01_SITES\Rook 1\1CN034.002_Geochem Characterization\04_Task400_SourceTerms\Final Source Terms\Waste

Table 3-9: Model Input Loading Rates for Operations by Lithological Grouping

Parameter	Units	Co-mingled (conventional placement) PAG and NPAG on single WRSA (with engineered layer design and as conventional placement) Source Term 1 & 2				Segregated PAG (with engineered layer design and as conventional placement) Source Term 3 & 5				Segregated NPAG Source Term 4 (conventional placement)			
		INT – UGTMF	INT – Mine	SPGN – UGTMF	SPGN – Mine	INT – UGTMF	INT – Mine	SPGN – UGTMF	SPGN – Mine	INT – UGTMF	INT – Mine	SPGN – UGTMF	SPGN – Mine
pH	s.u.	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Alkalinity	mg CaCO ₃ /kg/wk	3.1	2	2.5	1.9	2.8	2	1.9	1.9	3.4	2	3.1	1.9
SO ₄	mg/kg/wk	2.4	2.8	4.5	4	3	3.4	7.5	11	1.9	2.6	1.9	2
Cl	mg/kg/wk	0.96	1.5	0.96	1.2	0.96	1.5	0.96	0.95	0.96	1.5	0.96	1.2
Ag	mg/kg/wk	0.000048	0.000056	0.000048	0.000051	0.000048	0.000056	0.000048	0.000049	0.000048	0.000056	0.000048	0.000051
Al	mg/kg/wk	0.049	0.2	0.14	0.085	0.077	0.19	0.28	0.36	0.023	0.2	0.019	0.012
As	mg/kg/wk	0.00056	0.00029	0.0003	0.00062	0.00019	0.00028	0.00021	0.0004	0.00089	0.00029	0.00038	0.00068
Ba	mg/kg/wk	0.00038	0.00086	0.00048	0.00035	0.00046	0.00093	0.00042	0.00075	0.00032	0.00084	0.00054	0.00025
B	mg/kg/wk	0.002	0.012	0.0026	0.007	0.0022	0.012	0.0033	0.01	0.0019	0.012	0.0019	0.0062
Ca	mg/kg/wk	0.73	0.99	0.54	0.6	0.61	1	0.36	1.1	0.84	0.97	0.71	0.47
Cd	mg/kg/wk	0.0000044	0.0000089	0.00001	0.000066	0.0000061	0.00003	0.000018	0.00031	0.0000029	0.0000034	0.0000029	0.0000031
Co	mg/kg/wk	0.00067	0.0024	0.0031	0.041	0.0014	0.011	0.0066	0.2	0.000025	0.00023	0.000041	0.00013
Cr	mg/kg/wk	0.000078	0.00059	0.000086	0.00024	0.000081	0.00057	0.000097	0.00084	0.000077	0.0006	0.000077	0.000084
Cu	mg/kg/wk	0.0018	0.002	0.0077	0.081	0.0035	0.0057	0.016	0.39	0.00019	0.001	0.00019	0.00024
Fe	mg/kg/wk	0.022	0.43	0.079	0.33	0.039	0.41	0.16	1.2	0.0073	0.43	0.0067	0.092
Hg	mg/kg/wk	0.0000092	0.0000094	0.0000094	0.0000091	0.0000092	0.0000093	0.0000093	0.0000088	0.0000092	0.0000095	0.0000094	0.0000091
K	mg/kg/wk	0.69	0.39	0.48	0.33	0.7	0.38	0.49	0.46	0.69	0.39	0.46	0.29
Li	mg/kg/wk	0.0003	0.00085	0.00096	0.00063	0.00052	0.00097	0.0019	0.0021	0.000096	0.00082	0.000096	0.00025
Mg	mg/kg/wk	0.12	0.38	0.4	0.26	0.19	0.41	0.8	0.71	0.048	0.37	0.045	0.14
Mn	mg/kg/wk	0.0018	0.0016	0.008	0.0027	0.0034	0.0037	0.015	0.0097	0.00041	0.001	0.0015	0.00086
Mo	mg/kg/wk	0.00016	0.0038	0.00021	0.002	0.000077	0.0037	0.00012	0.0051	0.00023	0.0039	0.00029	0.0012
Na	mg/kg/wk	0.035	0.29	0.038	0.029	0.035	0.28	0.048	0.034	0.035	0.29	0.029	0.027
Ni	mg/kg/wk	0.00081	0.0018	0.0035	0.011	0.0016	0.0068	0.0073	0.053	0.000096	0.00054	0.000096	0.00018
Pb	mg/kg/wk	0.000041	0.0003	0.00015	0.000066	0.000069	0.0003	0.0003	0.00017	0.000016	0.00031	0.0000096	0.000038
Sb	mg/kg/wk	0.00086	0.001	0.00086	0.00091	0.00086	0.001	0.00086	0.00085	0.00086	0.001	0.00086	0.00092
Se	mg/kg/wk	0.000051	0.00062	0.000099	0.0011	0.000065	0.0015	0.00017	0.0049	0.000038	0.00039	0.000038	0.000091
Sr	mg/kg/wk	0.0023	0.016	0.0045	0.0088	0.0026	0.016	0.0063	0.018	0.0021	0.016	0.0028	0.0064
Sn	mg/kg/wk	0.000057	0.00026	0.000057	0.00014	0.000057	0.00025	0.000057	0.000059	0.000057	0.00026	0.000058	0.00016
U	mg/kg/wk	0.0011	0.002	0.00031	0.29	0.00089	0.0024	0.00021	0.24	0.0018	0.0019	0.0004	0.3
V	mg/kg/wk	0.00022	0.00047	0.000078	0.00022	0.00022	0.00045	0.000034	0.00021	0.00022	0.00048	0.00012	0.00022
Zn	mg/kg/wk	0.000036	0.000068	0.00016	0.00017	0.0029	0.0036	0.0067	0.019	0.0019	0.0029	0.0019	0.002

Source: \\VAN-SVR0\Projects\01_SITES\Rook 1\1CN034.002_Geochem Characterization\05_Reporting\03_Final Source Terms_Approach\020_Tables\Compiled_HCT>Loading_inputs_1CN034.002_JAC_REV01.xlsx\Sheet

Table 3-10: Model Input Loading Rates for Closure by Lithological Grouping

Parameter	Units	Co-mingled (conventional placement) PAG and NPAG on single WRSA (with engineered layer design and as conventional placement) Source Term 1 & 2				Segregated PAG (with engineered layer design and as conventional placement) Source Term 3 & 5				Segregated NPAG Source Term 4 (conventional placement)			
		INT – UGTMF	INT – Mine	SPGN – UGTMF	SPGN – Mine	INT – UGTMF	INT – Mine	SPGN – UGTMF	SPGN – Mine	INT – UGTMF	INT – Mine	SPGN – UGTMF	SPGN – Mine
pH	s.u.	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	6.5	6.5	6.5	6.5
Alkalinity	mg CaCO ₃ /kg/wk	2.7	2	2.5	1.9	1.9	1.9	1.9	1.9	3.4	2	3.1	1.9
SO ₄	mg/kg/wk	12	5.4	12	5	23	16	23	16	1.9	2.6	1.9	2
Cl	mg/kg/wk	0.96	1.4	0.96	1.2	0.95	0.96	0.95	0.97	0.96	1.5	0.96	1.2
Ag	mg/kg/wk	0.000048	0.000055	0.000048	0.00005	0.000048	0.000048	0.000048	0.000047	0.000048	0.000056	0.000048	0.000051
Al	mg/kg/wk	0.53	0.17	0.53	0.036	1.1	0.073	1.1	0.12	0.023	0.2	0.019	0.012
As	mg/kg/wk	0.00056	0.00027	0.00029	0.00059	0.00019	0.00019	0.00019	0.00026	0.00089	0.00029	0.00038	0.00068
Ba	mg/kg/wk	0.00066	0.0012	0.00078	0.00067	0.001	0.0024	0.001	0.0023	0.00032	0.00084	0.00054	0.00025
B	mg/kg/wk	0.0045	0.011	0.0045	0.0062	0.0073	0.0064	0.0073	0.0064	0.0019	0.012	0.0019	0.0062
Ca	mg/kg/wk	0.81	1.2	0.74	0.77	0.78	2	0.78	1.9	0.84	0.97	0.71	0.47
Cd	mg/kg/wk	0.000031	0.000096	0.000031	0.000091	0.000062	0.00045	0.000062	0.00042	0.000029	0.000034	0.000029	0.000031
Co	mg/kg/wk	0.012	0.038	0.012	0.038	0.025	0.18	0.025	0.18	0.000025	0.00023	0.000041	0.00013
Cr	mg/kg/wk	0.00011	0.00049	0.00011	0.00011	0.00016	0.000077	0.00016	0.00022	0.000077	0.0006	0.000077	0.000084
Cu	mg/kg/wk	0.029	0.018	0.029	0.019	0.062	0.081	0.062	0.092	0.00019	0.001	0.00019	0.00024
Fe	mg/kg/wk	0.29	0.37	0.29	0.17	0.6	0.12	0.6	0.47	0.0073	0.43	0.0067	0.092
Hg	mg/kg/wk	0.0000092	0.0000088	0.0000093	0.0000086	0.0000092	0.0000061	0.0000092	0.0000063	0.0000092	0.0000095	0.0000094	0.0000091
K	mg/kg/wk	0.72	0.38	0.6	0.3	0.75	0.34	0.75	0.32	0.69	0.39	0.46	0.29
Li	mg/kg/wk	0.0033	0.0013	0.0033	0.00087	0.0069	0.0033	0.0069	0.0033	0.000096	0.00082	0.000096	0.00025
Mg	mg/kg/wk	1.3	0.53	1.3	0.34	2.7	1.1	2.7	1.1	0.048	0.37	0.045	0.14
Mn	mg/kg/wk	0.027	0.01	0.028	0.0097	0.057	0.046	0.057	0.043	0.00041	0.001	0.0015	0.00086
Mo	mg/kg/wk	0.00027	0.0033	0.0003	0.0013	0.00031	0.0012	0.00031	0.0017	0.00023	0.0039	0.00029	0.0012
Na	mg/kg/wk	0.032	0.23	0.029	0.025	0.028	0.019	0.028	0.019	0.035	0.29	0.029	0.027
Ni	mg/kg/wk	0.013	0.023	0.013	0.021	0.028	0.11	0.028	0.1	0.000096	0.00054	0.000096	0.00018
Pb	mg/kg/wk	0.00053	0.00029	0.00053	0.000097	0.0011	0.00022	0.0011	0.00032	0.000016	0.00031	0.0000096	0.000038
Sb	mg/kg/wk	0.00086	0.00098	0.00086	0.00091	0.00086	0.00086	0.00086	0.00084	0.00086	0.001	0.00086	0.00092
Se	mg/kg/wk	0.00027	0.0043	0.00028	0.0038	0.00054	0.019	0.00054	0.018	0.000038	0.00039	0.000038	0.000091
Sr	mg/kg/wk	0.0084	0.017	0.0088	0.0096	0.015	0.023	0.015	0.022	0.0021	0.016	0.0028	0.0064
Sn	mg/kg/wk	0.000057	0.00022	0.000057	0.00014	0.000057	0.000057	0.000057	0.000069	0.000057	0.00026	0.000058	0.00016
U	mg/kg/wk	0.001	0.0036	0.00029	0.26	0.00016	0.01	0.00016	0.11	0.0018	0.0019	0.0004	0.3
V	mg/kg/wk	0.00012	0.00038	0.000068	0.0002	0.000013	0.000013	0.000013	0.00014	0.00022	0.00048	0.00012	0.00022
Zn	mg/kg/wk	0.011	0.0055	0.011	0.0047	0.021	0.015	0.021	0.015	0.0019	0.0029	0.0019	0.002

Source: \\VAN-SVR01\Projects\01_SITES\Rook 1\1CN034.002_Geochem Characterization\05_Reporting\03_Final Source Terms_Approach\020_Tables\Compiled_HCT_Loading_inputs_1CN034.002_JAC_REV01.xlsx\Sheet

Scaling Factors

Scaling factors were applied to the geochemical loading rates from the HCTs to scale from laboratory to field conditions. Mixed loading rates were scaled to field conditions by applying the following scaling factors:

Temperature – Applied to scale from laboratory-based test (HCTs at 25°C) to field conditions of waste rock pile (assumed to be at 5°C). The rate constant for laboratory and field conditions was calculated using the Arrhenius equation (Equation 1) to correct for temperature differences between the lab and the field. The resulting scaling factor was 0.08.

Equation 1 -

$$\frac{k_{field}}{k_{lab}} = e^{-\frac{E}{R} \left(\frac{1}{T_{lab}} - \frac{1}{T_{field}} \right)}$$

k Daily rate constant at temperature T , d^{-1}

E Activation energy (assumed to be 88,000 J mol^{-1}) (Nicholson et al. 1988)

R Gas constant (8.31 J $K^{-1} mol^{-1}$)

T_{field} Field Temperature (degrees Kelvin)

T_{lab} Laboratory Temperature (degrees Kelvin)

Grain size – Applied to differences in water to waste rock contact from laboratory-based test with grain size of <1/4” to field-scale (mix of fine and coarse material). In the absence of field data to develop site-specific grain size scaling factors, conventional scaling factors developed from project experience at other sites, which are supported by both laboratory and field results, were used for the base case (scaling factor of 0.2). For the upper-case scenario, the grain size scaling factor was increased to 0.3, which assumes there is a greater degree of WRSA drainage in contact with waste rock.

Channelization – Applied to account for difference in water to waste rock contact from fully saturated, laboratory-based tests to field-scale WRSA(s) where preferential flow pathways are expected to form. A channelization factor of 0.5 was used in the both the base and upper cases. Like the grain size scaling factors, the channelization scaling represents a factor developed from other project experience.

3.2.3 Uranium and Radionuclide Source Term Calculations

As outlined in the conceptual geochemical model (Section 2.2) uranium is primarily hosted in the oxide form as uraninite, and therefore the release of uranium is controlled by dissolution as opposed to oxidation. Subsequently, radionuclides on the uranium decay chain are also assumed to be released

by dissolution of uraninite. As the mechanism for release is different than most other constituents, a different approach is used to develop uranium and radionuclide source term predictions.

Elements that are released through dissolution will deplete from their solid phase sources. As the depletion of geochemical constituents from dissolution in a waste rock source is difficult to predict, the model was developed with a conservative assumption that the initial peak concentrations are representative of waste rock over the long term.

It is observed that the peak concentration of source terms occurred in the early period of HCT testing. This provides a conservative representation of leachate characteristics from constituents which are primarily released by dissolution from oxides. However, this approach is not suitable for modelling parameters associated with sulfide release, as oxidation of those phases prior to the initiation of kinetic testing can lead to artificially high concentrations. Therefore, the source term development for these constituents uses stable HCT rates as the primary geochemical input as described in Section 3.2.2.

Uranium mobility is also sensitive to pH conditions. Therefore a HCT sample with acidic pH (Sample 39137) was used to generate a uranium source term for placement methods with PAG material at closure when acidic conditions are expected to form (Source Term 1, 2, 3 and 5) (Figure 3-4). In contrast, a NPAG HCT sample with neutral pH and elevated uranium solid phase content (Sample 39181) was used to generate a source term for waste rock placement methods with non-acidic leachate (all Source Terms during operations and Source Term 4 at closure) (Figure 3-5).

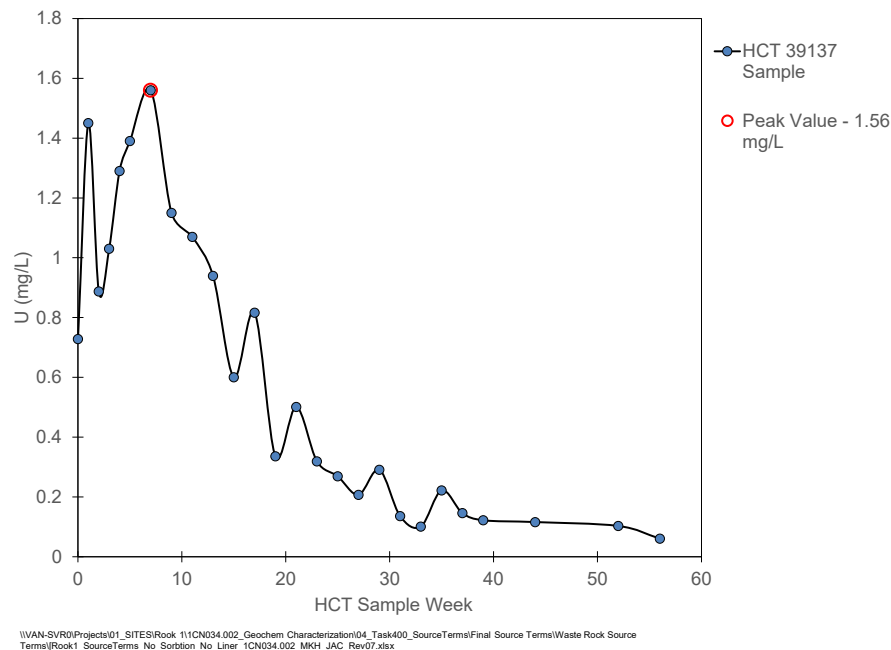


Figure 3-4: Uranium concentration time series from acidic sample 39137

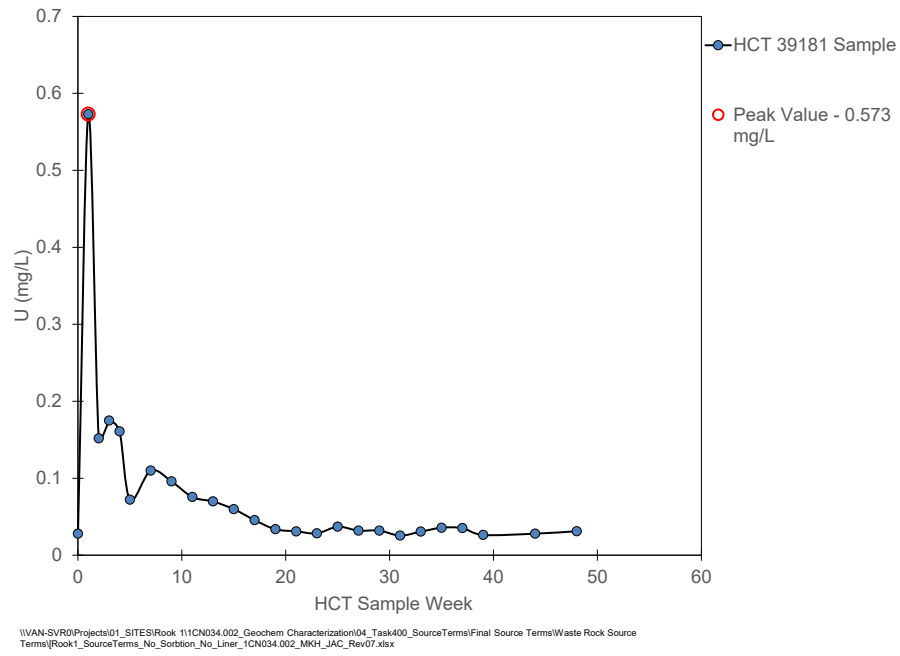


Figure 3-5: Uranium Concentration Time Series from Non-acidic Sample 39181

The radionuclide analysis requires a larger leachate sample size that is generated by monthly composites from the HCTs. Therefore, no initial concentration at 0 weeks is analyzed in the HCT program. To calculate the initial concentration (C_0) of radium-226 (in Bq/L), the test concentrations are plotted on a timeseries, with first-order exponential curve-fitting used to estimate C_0 . Radium-226 analysis has been conducted on 4-week composites in three HCTs representing waste rock with elevated solid-phase uranium and radionuclide content (39137, 39181 and 39140), and less frequently in all other HCTs representing waste rock with low solid-phase uranium and radionuclide content. Radium-226 (Bq/L) values from 39137 were highest relative to all other HCTs and were used to generate the radium-226 source term (Figure 3-6).

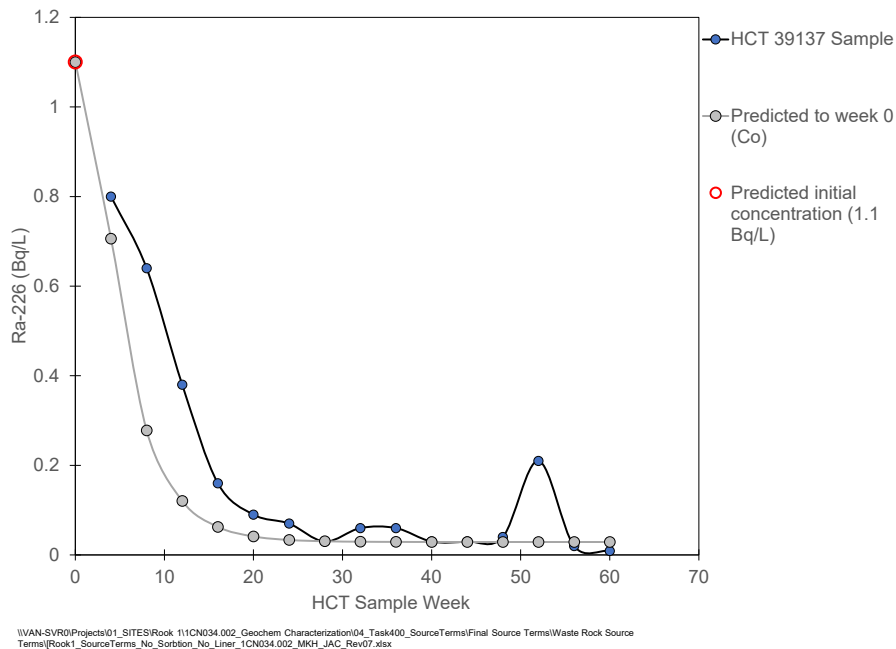


Figure 3-6: Measured Radium-226 (Bq/L) Results and Predicted Concentration to 0 Weeks for Sample 39137

Radionuclide analysis from the HCT and shake-flask extraction testing also included radium-228, thorium-228, thorium-230, thorium-232, lead-210 and polonium-210. Of these, lead-210, polonium-210 and thorium-230 occur on the uranium decay chain and are evaluated in the Environmental Impact Statement (EIS); therefore, source terms were developed for these parameters.

The majority of the results for lead-210, polonium-210 and thorium-230 were reported at or below detection limit, so all HCT and Shake Flask Extraction (SFE) data were pooled for these parameters with the maximum value for each selected to represent the source term.

3.2.4 Conservatism in Model

Conservative assumptions and approaches were applied to different facets of the model development. These are described in the following sections.

Scaling Factors

To address uncertainty in the model, the source term modelling included both a base case and upper-case scenario for each WRSA placement option. The difference in the base and upper-case is based on the scaling factors for grain size applied to scale the HCT data from lab to field conditions described in Section 3.2.2.

Surface Sorption

For the source term scenarios modelled at near neutral pH conditions, the formation of secondary iron-oxhydroxide (e.g., ferrihydrite) is expected which will provide sites for surface adsorption. Surface sorption has the effect of reducing concentrations of parameters which sorb to ferrihydrite. Modelling the effects of surface sorption to constituent concentrations can be conducted using PHREEQC. The commonly used default values in the double diffusive layer model (Dzombak and Morel 1990) included in PHREEQC are based on laboratory experiments. While this provides a powerful mechanism for modelling sorption to ferrihydrite, in the absence of site specific data, it is unknown if these default values are applicable at the field scale. In the initial setup of the source term model, it was identified that several constituents were highly sensitive when sorption was included in the predictions. To provide a conservative estimate of source term concentrations, sorption was not included in the model. Therefore, actual concentrations for constituents that would sorb to ferrihydrite (such as arsenic, cobalt, copper and selenium) are likely to be lower for scenarios that favour the formation of ferrihydrite than what is predicted in the model.

Input HCT Mixtures

The geochemical loadings derived from the HCTs used as input in the source term model are sensitive to the proportion of high sulfide HCT sample used in the representative HCT mixtures. As acidic conditions have not yet occurred in low sulfide PAG HCTs, AG HCTs were included in the input loading rates. These HCTs all have greater than 1% sulfur, and therefore are representative of leaching characteristics of high sulfide (>1% sulfur) AG material. Enrichment of chalcophile elements (e.g., copper, cobalt, nickel, iron) is higher in the AG HCTs. Therefore, basing the predicted leaching characteristics of PAG material using high sulfide (>1% sulfur) AG HCTs will overestimate concentrations of several constituents. Revising the HCT mixtures using AG waste rock with lower sulfide concentrations can be considered if an HCT representing low-sulfide material (<1% sulfur) becomes acidic.

The geochemical loadings derived from the HCT mixtures are particularly sensitive to the proportion of sample 39137. This HCT is representative of the highest sulfide sample for the mine area and has loading rates over an order of magnitude higher for many elements in comparison to all other HCTs. The proportion of this sample in the HCT mixtures used to represent the SPGN lithology from the mine

in placement methods with PAG material (Source Terms 1, 2, 3 and 5) ranged from 3.4 to 15.6%. This is considered a conservative estimate as the model input assumes between 3.4 to 15.6% of the bulk rock has high sulfide equivalent to the highest sulfide sample from the static geochemical data set.

Modelled pH

Conservatism is also introduced in the predicted pH conditions of WRSAs with PAG material at closure. The co-mingled placement methods (Source Term 1 and 2) will include a mix of PAG and NPAG material. At closure, the PAG material is expected to become acidic with equilibration modelling using PHREEQC for these scenarios modelled using an acidic pH of 3.5. This pH was selected based on observed pH in the HCT results for AG sample material. It is therefore representative of leachate characteristics in high sulfide material. However, the NPAG material in the co-mingled placement method has the potential to provide some alkalinity to maintain higher pH values than that used in the model. The effect of alkalinity provided by NPAG material to maintain higher pH will also be dependent on the effectiveness of mixing the PAG and NPAG material during placement. As there is no experimental or field data to confirm what this pH would be or direct data from a co-mingled HCT, a conservative approach is used that assumes the pH conditions of the WRSA as whole are representative of high sulfide material.

Radionuclide Data

As described in the previous section, radionuclide data were largely non-detect, but were pooled and maximum values were used to represent the radionuclide source term.

3.3 Underground Wall Rock Methods

Source terms were developed to estimate loadings from exposed wall rock during the development of the underground workings. The source terms were developed to represent geochemical loadings produced from oxidation of the wall rock from the start of exposure to final backfilling or inundation of the workings with groundwater.

The approach and inputs used to develop the underground wall rock source terms are detailed in the following subsections.

3.3.1 Method Overview

The source term loadings for the underground wall rock were derived using laboratory-based kinetic geochemical testing with HCTs and the underground mine plan and schedule. Like the waste rock source term development, the underground wall rock source terms were generated as a mass balance model where loadings from HCTs were scaled to field conditions. The underground mine plan was used to estimate exposed wall rock area by lithological group in each of the mine and UGTMF throughout the period of development. The exposed wall rock by lithological grouping was combined with the representative HCT loading rates and an assumption on reactive thickness of wall rock to

generate the source term predictions. The source terms were derived as a mass load for each parameter.

At the time of source term development, the underground water balance model did not include details of the locations of underground wall rock which will be in contact with waters during operations. Therefore, the underground wall rock is assumed to be unsaturated during operations, with all stored load released when the workings are inundated with groundwater post closure. However, this assumption is conservative because a component of the stored load is expected to be released during operations from wet areas in the underground with leachate treated at the effluent treatment plant.

3.3.2 Model Input and Assumptions

Mine Plan

The mine plan formed the bases of estimating the amount of reactive surface area in the underground walls throughout the life of mine. To account for exposure of special waste and ore, a lithological grouping was calculated to represent these materials exposed in the underground wall rock. RPA (2020) provided the distribution of wall rock surface areas for each development year and by mine development level for the following:

- Lithology type (SPGN or INT);
- Material type: waste rock (<0.03% U_3O_8), special waste (U_3O_8 between 0.03-0.3%) and ore (U_3O_8 >0.3%); and
- ARD classification (using sulfur modelling and criteria detailed in Section 3.2.2).

The exposed wall rock surface area figures provided by RPA (2020) were used to calculate surface area by lithological grouping. Surface area for the lithology groupings were calculated by mine level and production year during operations (Year 1 to 28). A summary of the total exposed wall rock area by lithological grouping and by development year is provided for the UGTMF (Table 3-11) and mine development area (Table 3-12). The total exposed wall rock summarized in these tables incorporates information from the mine groundwater inundation rate, where inundation of workings with groundwater will eliminate exposure. Details of the rate of groundwater inundation to the mine in used in the source term model is summarized in Section 3.3.2.

Table 3-11: Cumulative Surface Area Exposure by Lithological Grouping for the UGTMF

Status	Development Year	UGTMF Development - Summary of Cumulative Exposed Surface Area by Lithological Grouping (m ²)				
		INT-PAG	INT-NPAG	SPGN-PAG	SPGN-NPAG	Total
Operations	Year 1	0	0	0	0	0
	Year 2	0	0	0	0	0
	Year 3	2,849	11,780	258	1,065	15,952
	Year 4	24,209	17,453	2,293	1,784	45,740
	Year 5	48,679	23,539	30,436	9,489	112,143
	Year 6	59,509	23,539	51,152	9,489	143,689
	Year 7	77,261	28,331	57,924	11,316	174,832
	Year 8	81,747	28,895	63,751	12,049	186,442
	Year 9	93,670	28,895	73,301	12,049	207,915
	Year 10	93,670	28,895	73,301	12,049	207,915
	Year 11	93,670	28,895	73,301	12,049	207,915
	Year 12	93,670	28,895	73,301	12,049	207,915
	Year 13	93,670	28,895	73,301	12,049	207,915
	Year 14	94,155	53,681	73,525	72,303	293,664
	Year 15	104,101	60,844	80,504	77,715	323,164
	Year 16	107,004	80,964	88,050	102,096	378,114
	Year 17	107,004	80,964	88,050	103,146	379,164
	Year 18	107,004	80,964	88,050	103,146	379,164
	Year 19	107,004	80,964	88,050	103,146	379,164
	Year 20	107,004	80,964	88,050	103,146	379,164
	Year 21	107,004	80,964	88,050	103,146	379,164
	Year 22	107,004	80,964	88,050	103,146	379,164
	Year 23	107,004	80,964	88,050	103,146	379,164
	Year 24	107,004	80,964	88,050	103,146	379,164
	Year 25	122,947	91,331	99,409	118,548	432,236
	Year 26	138,889	101,699	110,769	133,951	485,308
	Year 27	154,831	112,067	122,128	149,353	538,380
	Year 28	166,475	119,352	130,128	160,608	576,562
Post Closure	Year 29	144,836	37,473	107,317	15,889	305,515
	Year 30	104,779	17,298	72,699	7,886	202,662
	Year 31	104,779	17,298	72,699	7,886	202,662
	Year 32	54,352	8,194	34,774	4,336	101,656
	Year 33	0	0	0	0	0
	Year 34	0	0	0	0	0

Source: \\VAN-SVR0\Projects\01_SITES\Rook 1\1CN034.002_Geochem Characterization\04_Task400_SourceTerms\Final Source Terms\Underground Source Terms\UG_Source_Terms_1CN034.002_JAC_REV07.xlsx]Sheet

Table 3-12: Cumulative Surface Area Exposure Summary by Lithological Grouping for the Mine Development

Status	Development Year	Mine Development - Summary of Cumulative Exposed Surface Area by Lithological Grouping (m ²)					
		INT-PAG	INT-NPAG	SPGN-PAG	SPGN-NPAG	Special Waste + Ore	Total
Operations	Year 1	2,081	5,047	3,343	8,106	-	18,577
	Year 2	9,770	15,811	5,953	10,356	-	41,889
	Year 3	10,032	27,753	6,325	39,365	1,215	84,691
	Year 4	11,015	40,014	11,962	132,866	11,823	207,680
	Year 5	12,446	44,018	26,193	197,610	45,432	325,699
	Year 6	23,652	65,107	38,106	270,312	93,053	490,229
	Year 7	30,060	79,623	49,319	342,783	118,358	620,144
	Year 8	40,415	98,201	70,920	389,680	161,092	760,309
	Year 9	42,106	99,312	75,173	390,643	196,405	803,639
	Year 10	42,201	99,382	76,822	394,601	207,274	820,280
	Year 11	42,201	99,382	76,822	394,601	207,274	820,280
	Year 12	42,201	99,382	76,822	394,601	207,274	820,280
	Year 13	43,521	99,799	78,245	395,030	208,507	825,103
	Year 14	43,521	100,959	86,725	459,136	219,656	909,996
	Year 15	43,889	102,203	104,961	504,938	268,697	1,024,688
	Year 16	43,975	102,278	110,497	520,056	324,673	1,101,480
	Year 17	44,127	102,442	119,346	545,159	378,326	1,189,400
	Year 18	44,127	102,442	121,476	550,992	424,408	1,243,445
	Year 19	44,127	102,442	123,215	553,135	456,158	1,279,078
	Year 20	44,127	102,442	123,215	553,135	456,158	1,279,078
	Year 21	44,127	102,442	123,215	553,135	456,158	1,279,078
	Year 22	44,127	102,442	123,215	553,135	456,158	1,279,078
	Year 23	44,127	102,442	123,215	553,135	456,158	1,279,078
	Year 24	46,944	111,763	141,545	609,432	477,190	1,386,875
	Year 25	49,762	121,084	159,875	665,729	498,222	1,494,672
	Year 26	52,579	130,405	178,205	722,025	519,254	1,602,469
	Year 27	55,396	139,727	196,535	778,322	540,286	1,710,266
	Year 28	58,213	149,048	214,865	834,619	561,318	1,818,063
Post Closure	Year 29	37,895	104,717	57,954	320,276	184,070	704,911
	Year 30	31,905	58,860	45,475	213,420	144,789	494,449
	Year 31	26,446	47,796	38,297	177,721	106,588	396,848
	Year 32	21,514	35,555	31,829	140,416	74,772	304,087
	Year 33	1,306	1,536	4,103	39,374	20,259	66,578
	Year 34	0	0	0	0	0	0

Source: \\VAN-SVR0\Projects\01_SITES\Rook 1\1CN034.002_Geochem Characterization\04_Task400_SourceTerms\Final Source Terms\Underground Source Terms\UG_Source_Terms_1CN034.002_JAC_REV07.xlsx\Sheet

Reactive Wall Thickness

The reactive surface area by lithological grouping from the mine plan was used to calculate a reactive mass in the underground wall rock. The calculation of reactive mass from the exposed wall rock surface area requires an estimate of the density and thickness of fracturing in the wall rock that will be exposed to oxygenated conditions during development. A value of 2,400 kg/m³ was used for the density in the reactive mass calculations. Fractures in the wall rock will be created by blast-induced fracturing during development of the workings.

Published literature on blast-induced fracturing shows that there is a significant range in both the density of fracturing and the depth of fracture penetration. In general, the depth of fracture propagation is typically in the range of 0.6 to 1.8 meters, with a typical fracture density of 10%; however, this will depend on factors such as lithological composition and blast methods used. In the absence of any site-specific information relating to the depth of future wall fracturing, an estimated extent of damage zone of 1 m and fracture density of 10% is used for the underground wall rock source term model. This is consistent with published information (e.g., Siskind and Fumanti, 1974; Kelsall et al., 1984).

The reactive mass was calculated as per Equation 2.

Equation 2 -

$$\text{Reactive Mass (kg)} = A \times DRZ \times Fd \times \rho$$

$$A = \text{Wall rock surface area (m}^2\text{)}$$

$$DRZ = \text{Damaged Rock Zone (1 m)}$$

$$Fd = \text{Fracture density (10\%)}$$

$$\rho = \text{Average rock density (2,400 kg/m}^3\text{)}$$

Wall Rock Loading Rates

Geochemical loading rates from HCTs were used as input in the source term modelling to represent the wall rock lithology groupings. These HCTs represent waste rock material from the different locations, lithology types and classification of ARD potential. Representative HCTs or mixtures of representatives HCTs were selected to provide geochemical loading rate inputs for each of the lithological groupings (e.g., PAG SPGN from the UGTMF).

The selection of representative HCTs and HCT mixtures used as geochemical loading rates input in the underground source term model followed the same procedure as detailed in the waste rock source term model (Section 3.2.2). Average loading rates in mg/kg/week were calculated from the last eight weekly cycles (weeks 48 to 56) in HCTs at the time of underground source term model development. The prorated loading rates were then scaled from laboratory to field conditions to account for differences in temperature.

A lithological grouping representing special waste (0.03 to 0.3% U₃O₈) was also used in the underground source term model to represent special waste and ore exposed in the wall rock. Following

guidance from RPA, the exposed surface area of ore material in wall rock derived from the mine plan is likely overestimated as it is assumed that the ore material will be removed from the wall rock. The majority of ore development representing undercuts in the stopes will be shotcreted and backfilled and therefore will not be exposed. To account for the potential of some ore remaining exposed in the final wall rock, the geochemical loading rates representing special waste were also used to represent all surface area of ore in the mine as detailed in the RPA mine plan.

A summary of the HCT mixtures representing the lithological groupings used to generate the geochemical loading inputs is summarized in Table 3-13.

Table 3-13: Summary of HCT Mixtures Representing Lithological Groupings for Geochemical Loading Rates used in the Underground Wall Rock Source Term Model

Lithology Group	HCT Sample	Solid Phase Sulfide (%)	UGTMF				Mine				Special Waste + Ore
			NPAG		PAG		NPAG		PAG		
			INT - UGTMF	SPGN - UGTMF	INT - UGTMF	SPGN - UGTMF	INT - Mine	SPGN - Mine	INT - Mine	SPGN - Mine	
INT - UGTMF	39032	0.17	100%	-	96.9%	-	-	-	-	-	-
INT - Mine	39186	0.18	-	-	-	-	100%	-	96.2%	-	-
SPGN - UGTMF	39023	0.18	-	100%	-	-	-	-	-	-	-
SPGN - UGTMF	39015	0.29	-	-	-	86%	-	-	-	-	-
SPGN - UGTMF	39010	2.65	-	-	3.1%	14%	-	-	-	-	-
SPGN - Mine	39140	1.06	-	-	-	-	-	3.8%	3.4%	-	-
SPGN - Mine	39181	0.02	-	-	-	-	50%	-	46.6%	-	-
SPGN - Mine	39076	0.19	-	-	-	-	50%	-	46.6%	-	-
SPGN - Mine	39137	3.32	-	-	-	-	-	-	3.4%	-	-
SW - Mine	39130	0.02	-	-	-	-	-	-	-	-	75%
SW - Mine	39172	0.08	-	-	-	-	-	-	-	-	25%

Notes: SW = Special Waste

Source: \\VAN-SVR0\Projects\01_SITES\Rook 1\1CN034.002_Geochem Characterization\04_Task400_SourceTerms\Final Source Terms\Underground Source Terms\UG_Source_Terms_1CN034.002_JAC_REV08.xlsx\Sheet

Scaling Factors

The geochemical loading rates from the HCTs were scaled to account for the difference in field to laboratory temperature. The approach to scaling for temperature was the same as used in the waste rock source term model (Section 3.2.2). The laboratory temperature conditions were assumed to be 25°C and field conditions representing underground wall rock were assumed to be 15°C. The ratio of laboratory to field rate constant from the Arrhenius equation provides a temperature scaling factor of 0.29.

As estimates of the reactive tonnage are based on the reactive wall thickness in the wall rock, the HCTs are not scaled for grain size or channelization.

Mine Decommissioning and Closure

The rate at which groundwater inundates the mine workings following closure was used in the source term model to determine which levels of the mine were inundated in the years following operations. In the source term models, mine workings which are inundated with groundwater will no longer accumulate load. The rate of groundwater inundation of the mine workings following completion of production were provided by Golder (Golder 2020, *pers. comm.*). The summary provided by Golder included time for groundwater to inundate specific mine levels following decommissioning and closure. The summary indicates complete inundation of the workings in 5.6 years following closure (years 29 to 34). This information was used to identify the mine levels that are inundated annually following the completion of production (Table 3-14).

Table 3-14: Summary of Groundwater Inundation Rate

Upper Mine Level (m elev)	Lower Mine Level (m elev)	Simulated Inflow Rate (m ³ /d)	Time to Groundwater Inundation (yrs)	Cumulative Time (yrs)	Post Closure Year	Inundated Mine Levels
530	>210	150	0.66	5.6	5-6	170-320
210	160	1019	0.12	4.91	4-5	350
160	120	1154	1.32	4.79	4-5	380-410
120	80	1414	1.10	3.47	3-4	440
80	40	1638	1.06	2.38	2-3	470.00
40	0	1715	0.58	1.32	1-2	500-530
0	-40	1780	0.27	0.74	0-1	560-890
-40	-80	1875	0.25	0.47	0-1	590-890
-80	-120	1964	0.18	0.22	0-1	590-890
<-120	-	1964	0.04	0.04	0-1	590-890

Source: \\VAN-SVR0\Projects\01_SITES\Rook 1\1CN034.002_Geochem Characterization\04_Task400_SourceTerms\Final Source Terms\Underground Source Terms\UG_Source_Terms_1CN034.002_JAC_REV07.xlsx\Sheet

3.3.3 Uranium and Radionuclide Source Term Calculations

As outlined in the conceptual geochemical model (Section 2.2) uranium is presumed to be hosted in the oxide form as uraninite, and therefore the release of uranium is controlled by dissolution as opposed to oxidation. Subsequently, radionuclides on the uranium decay chain are also released by dissolution of uraninite. As the mechanism for release is different than most other constituents, a different approach is used to develop uranium and radionuclide source term predictions.

The same approach used to develop uranium and radionuclide source terms outlined in the waste rock modelling was used for the underground wall rock source terms (Section 3.2.3) which assumes the peak concentration early in the HCT testing or SFE provides a representation of leachate characteristics from metal release by dissolution from oxides such as uraninite. As the underground wall rock will include exposed special waste material, HCTs representative of special waste were also included in the data set used to generate the uranium and radionuclide source terms.

The uranium source term is represented by the peak value from all testing. The peak value is from the SFE test result on special waste sample 39130 (4.67 mg/L).

Radionuclide analysis from the HCT and shake-flask extraction testing also included radium-228, thorium-228, thorium-230, thorium-232, lead-210 and polonium-210. Of these, lead-210, polonium-210 and thorium-230 occur on the uranium decay chain and are evaluated in the EIS, therefore source terms were developed for these parameters. The development of the source terms for the underground wall rock followed a similar procedure used for the waste rock source term described in Section 3.2.3 where all SFE and HCT data were pooled from all waste rock and special waste samples with the maximum value for each radionuclide selected as the source term.

3.3.4 Conservatism in Model

Conservative assumptions were used in the development of the underground source term model. These include the following assumptions:

- The model assumes the geochemical loading will be stored in the wall face throughout operations prior to being inundated by groundwater, with all stored load released when the underground workings are inundated. In reality, a portion of the load will be mobilized by groundwater flowing into the mine and pumped from the underground during dewatering throughout operations. The mass released to mine waters during operations will be collected, treated and discharged, reducing the mass that could be released at closure compared to the assumed mass that accumulates and is released in totality at closure.
- In the absence of a detailed water balance showing wet and dry areas in the underground mine, no equilibrium modelling has been completed to assess if secondary mineral phases are predicted to form. The formation of secondary mineral phases would constrain water quality concentrations of some constituents to solubility limits.

The modelled surface area for the underground workings includes a component of ore present in undercuts of stopes which will likely be backfilled or shotcreted soon after exposure which would limit oxidation of the ore exposed in wall rock. Despite this a source term for exposed ore was developed using the HCTs representing special waste as the primary geochemical input.

4 Results

4.1 Waste Rock

The objective of the source term development was to compare the WRSA(s) drainage water quality for each of the proposed waste rock placement method(s)) carried forward in the EIS solute transport models. Predicted seepage concentrations and loadings for all WRSAs representing the different placement methods during operations are provided in Table 4-1 and Table 4-2. Predicted seepage concentrations and loadings for all WRSAs during closure are provided in Table 4-3 and Table 4-4. A discussion of the results from each of the waste rock source term models are discussed in Section 5.

Table 4-1: Predicted WRSA(s) Concentrations – Operations

Parameter	Units	Source Term 1 - Base Case (toe seepage)	Source Term 1 - Upper Case (toe seepage)	Source Term 1 - Base Case (basal seepage)	Source Term 1 - Upper Case (basal seepage)	Source Term 2 - Base Case (toe seepage)	Source Term 2 - Upper Case (toe seepage)	Source Term 2 - Base Case (basal seepage)	Source Term 2 - Upper Case (basal seepage)	Source Term 3 - Base Case (toe seepage)	Source Term 3 - Upper Case (toe seepage)	Source Term 3 - Base Case (basal seepage)	Source Term 3 - Upper Case (basal seepage)	Source Term 4 - Base Case (basal seepage)	Source Term 4 - Upper Case (basal seepage)	Source Term 5 - Base Case (toe seepage)	Source Term 5 - Upper Case (toe seepage)	Source Term 5 - Base Case (basal seepage)	Source Term 5 - Upper Case (basal seepage)
General Chemistry																			
pH	s.u.	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Alkalinity	mg CaCO ₃ /L	1.4	1.4	3.8	3.9	1.4	1.4	3.9	4	1.4	1.4	3.8	3.9	3.8	3.8	1.4	1.5	4	4.1
SO ₄	mg/L	170	260	170	260	300	450	300	450	260	380	260	380	92	140	470	700	470	700
Cl	mg/L	110	170	110	170	190	290	200	310	64	96	73	110	140	210	120	170	140	210
pe	s.u.	5.4	5.4	1.8	1.8	5.4	5.4	1.8	1.8	5.4	5.4	1.8	1.8	1.8	1.8	5.4	5.4	1.8	1.8
Dissolved Metals																			
Ag	mg/L	0.0023	0.0035	0.0023	0.0035	0.004	0.006	0.004	0.006	0.0021	0.0031	0.0021	0.0031	0.0023	0.0035	0.0038	0.0057	0.0038	0.0057
Al	mg/L	0.0038	0.0038	0.0038	0.0038	0.0039	0.0039	0.0039	0.0039	0.0038	0.0039	0.0038	0.0039	0.0038	0.0038	0.0039	0.004	0.0039	0.004
As	mg/L	0.021	0.032	0.021	0.032	0.038	0.056	0.038	0.056	0.0095	0.014	0.0095	0.014	0.029	0.044	0.017	0.026	0.017	0.026
Ba	mg/L	0.0099	0.0078	0.01	0.0079	0.0071	0.0058	0.0073	0.0059	0.007	0.0055	0.0071	0.0056	0.017	0.013	0.0049	0.004	0.0051	0.0042
B	mg/L	0.16	0.24	0.16	0.24	0.28	0.41	0.28	0.41	0.15	0.23	0.15	0.23	0.15	0.23	0.28	0.42	0.28	0.42
Ca	mg/L	30	45	30	45	52	79	52	79	23	34	23	34	33	50	42	63	42	63
Cd	mg/L	0.00083	0.0012	0.00083	0.0012	0.0014	0.0022	0.0014	0.0022	0.0016	0.0024	0.0016	0.0024	0.00014	0.00021	0.0029	0.0044	0.0029	0.0044
Co	mg/L	0.41	0.61	0.41	0.61	0.71	1.1	0.71	1.1	0.87	1.3	0.87	1.3	0.0029	0.0044	1.6	2.4	1.6	2.4
Cr	mg/L	0.0057	0.0086	0.0057	0.0086	0.01	0.015	0.01	0.015	0.0068	0.01	0.0068	0.01	0.0044	0.0066	0.012	0.019	0.012	0.019
Cu	mg/L	0.57	0.63	0.84	1.3	0.66	0.75	1.5	2.2	0.61	0.68	1.8	2.7	0.011	0.016	0.72	0.83	3.3	4.9
Fe	mg/L	0.012	0.013	5.1	7.6	0.014	0.015	8.9	13	0.013	0.014	8.7	13	1.8	2.7	0.015	0.016	16	24
Hg	mg/L	0.00044	0.00066	0.00044	0.00066	0.00077	0.0012	0.00077	0.0012	0.0004	0.0006	0.0004	0.0006	0.00044	0.00066	0.00073	0.0011	0.00073	0.0011
K	mg/L	160	240	160	240	280	410	280	410	150	230	150	230	150	220	280	420	280	420
Li	mg/L	0.031	0.047	0.031	0.047	0.055	0.082	0.055	0.082	0.058	0.087	0.058	0.087	0.0071	0.011	0.11	0.16	0.11	0.16
Mg	mg/L	13	19	13	19	23	34	23	34	23	35	23	35	3.7	5.5	42	64	42	64
Mn	mg/L	0.22	0.34	0.22	0.34	0.39	0.59	0.39	0.59	0.42	0.64	0.42	0.64	0.046	0.069	0.78	1.2	0.78	1.2
Mo	mg/L	0.025	0.037	0.025	0.037	0.044	0.066	0.044	0.066	0.02	0.03	0.02	0.03	0.027	0.04	0.037	0.055	0.037	0.055
Na	mg/L	1.9	2.9	1.9	2.9	3.4	5	3.4	5	1.9	2.8	1.9	2.8	1.8	2.7	3.4	5.2	3.4	5.2
Ni	mg/L	0.18	0.27	0.18	0.27	0.31	0.47	0.31	0.47	0.38	0.56	0.38	0.56	0.0061	0.0091	0.69	1	0.69	1
Pb	mg/L	0.00013	0.00011	0.00013	0.00011	0.0001	0.000087	0.0001	0.000089	0.00018	0.00016	0.00019	0.00016	0.0001	0.000084	0.00014	0.00013	0.00015	0.00013
Sb	mg/L	0.041	0.062	0.041	0.062	0.073	0.11	0.073	0.11	0.037	0.056	0.037	0.056	0.041	0.062	0.068	0.1	0.068	0.1
Se	mg/L	0.012	0.019	0.012	0.019	0.022	0.033	0.022	0.033	0.023	0.035	0.023	0.035	0.0028	0.0043	0.042	0.063	0.042	0.063
Sr	mg/L	0.22	0.33	0.22	0.33	0.39	0.58	0.39	0.58	0.25	0.38	0.25	0.38	0.18	0.27	0.46	0.69	0.46	0.69
Sn	mg/L	0.0036	0.0054	0.0036	0.0054	0.0063	0.0094	0.0063	0.0094	0.0026	0.0038	0.0026	0.0038	0.0041	0.0062	0.0047	0.0071	0.0047	0.0071
U	mg/L	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
V	mg/L	0.0077	0.012	0.0077	0.012	0.013	0.02	0.013	0.02	0.0056	0.0083	0.0056	0.0083	0.0088	0.013	0.01	0.015	0.01	0.015
Zn	mg/L	0.18	0.27	0.18	0.27	0.31	0.47	0.31	0.47	0.26	0.4	0.26	0.4	0.093	0.14	0.48	0.73	0.48	0.73
Ra-226	Bq/L	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Po-210	Bq/L	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Pb-210	Bq/L	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Th-230	Bq/L	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Table 4-2: Predicted WRSA(s) Loadings – Operations

Parameter	Units	Source Term 1 - Base Case - (toe seepage)	Source Term 1 - Upper Case - (toe seepage)	Source Term 1 - Base Case - (basal seepage)	Source Term 1 - Upper Case - (basal seepage)	Source Term 2 - Base Case - (toe seepage)	Source Term 2 - Upper Case - (toe seepage)	Source Term 2 - Base Case - (basal seepage)	Source Term 2 - Upper Case - (basal seepage)	Source Term 3 - Base Case - (toe seepage)	Source Term 3 - Upper Case - (toe seepage)
General Chemistry											
pH	s.u.	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Alkalinity	kg CaCO3/yr	270	270	85	87	140	150	88	90	130	130
SO ₄	kg/yr	33000	50000	3900	5800	31000	46000	6800	10000	23000	35000
Cl	kg/yr	21000	32000	2600	3900	20000	29000	4500	6800	5800	8600
pe	s.u.	5.4	5.4	1.8	1.8	5.4	5.4	1.8	1.8	5.4	5.4
Dissolved Metals											
Ag	kg/yr	0.45	0.67	0.052	0.077	0.41	0.61	0.09	0.14	0.19	0.28
Al	kg/yr	0.73	0.74	0.085	0.086	0.39	0.4	0.086	0.088	0.35	0.35
As	kg/yr	4.2	6.2	0.48	0.72	3.8	5.7	0.84	1.3	0.86	1.3
Ba	kg/yr	1.9	1.5	0.22	0.18	0.72	0.59	0.16	0.13	0.63	0.5
B	kg/yr	31	46	3.5	5.3	28	42	6.2	9.3	14	21
Ca	kg/yr	5800	8700	670	1000	5300	8000	1200	1800	2100	3100
Cd	kg/yr	0.16	0.24	0.019	0.028	0.15	0.22	0.032	0.049	0.15	0.22
Co	kg/yr	79	120	9.1	14	72	110	16	24	79	120
Cr	kg/yr	1.1	1.7	0.13	0.19	1	1.5	0.22	0.34	0.61	0.92
Cu	kg/yr	110	120	19	28	67	76	33	50	55	62
Fe	kg/yr	2.4	2.6	110	170	1.4	1.5	200	300	1.2	1.3
Hg	kg/yr	0.085	0.13	0.0099	0.015	0.078	0.12	0.017	0.026	0.036	0.054
K	kg/yr	31000	46000	3500	5300	28000	42000	6200	9300	14000	21000
Li	kg/yr	6	9.1	0.7	1	5.5	8.3	1.2	1.8	5.3	7.9
Mg	kg/yr	2500	3800	290	430	2300	3400	510	760	2100	3100
Mn	kg/yr	43	65	5	7.5	40	59	8.8	13	38	58
Mo	kg/yr	4.8	7.3	0.56	0.84	4.4	6.6	0.98	1.5	1.8	2.7
Na	kg/yr	370	560	43	64	340	510	75	110	170	260
Ni	kg/yr	35	52	4	6	32	47	7	10	34	51
Pb	kg/yr	0.025	0.021	0.003	0.0025	0.01	0.0088	0.0023	0.002	0.017	0.014
Sb	kg/yr	8	12	0.93	1.4	7.3	11	1.6	2.4	3.4	5.1
Se	kg/yr	2.4	3.6	0.28	0.42	2.2	3.3	0.49	0.73	2.1	3.1
Sr	kg/yr	43	64	4.9	7.4	39	59	8.6	13	23	34
Sn	kg/yr	0.7	1	0.081	0.12	0.64	0.96	0.14	0.21	0.23	0.35
U	kg/yr	110	110	13	13	58	58	13	13	52	52
V	kg/yr	1.5	2.2	0.17	0.26	1.4	2	0.3	0.45	0.5	0.76
Zn	kg/yr	34	52	4	6	31	47	6.9	10	24	36
Ra-226	Bq/yr	21000000	21000000	2500000	2500000	11000000	11000000	2500000	2500000	10000000	10000000
Po-210	Bq/yr	17000000	17000000	2000000	2000000	9100000	9100000	2000000	2000000	8200000	8200000
Pb-210	Bq/yr	39000000	39000000	4500000	4500000	20000000	20000000	4500000	4500000	18000000	18000000
Th-230	Bq/yr	58000000	58000000	6700000	6700000	30000000	30000000	6700000	6700000	27000000	27000000

Table 4 2: Predicted WRSA(s) Loadings – Operations (con't)

Parameter	Units	Source Term 3 - Base Case - (basal seepage)	Source Term 3 - Upper Case - (basal seepage)	Source Term 4 - Base Case - (basal seepage)	Source Term 4 - Upper Case - (basal seepage)	Source Term 5 - Base Case - (toe seepage)	Source Term 5 - Upper Case - (toe seepage)	Source Term 5 - Base Case - (basal seepage)	Source Term 5 - Upper Case - (basal seepage)	Combined Source Term 3 and 4 - Base Case	Combined Source Term 3 and 4 - Upper Case	Combined Source Term 4 and 5 - Base Case	Combined Source Term 4 and 5 - Upper Case
General Chemistry													
pH	s.u.	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5				
Alkalinity	kg CaCO3/yr	38	39	470	480	65	67	40	41	640	650	580	590
SO ₄	kg/yr	2500	3800	12000	17000	21000	32000	4700	7000	37000	56000	37000	56000
Cl	kg/yr	730	1100	17000	26000	5200	7900	1400	2000	24000	36000	24000	36000
pe	s.u.	1.8	1.8	1.8	1.8	5.4	5.4	1.8	1.8				
Dissolved Metals													
Ag	kg/yr	0.021	0.031	0.29	0.43	0.17	0.26	0.038	0.057	0.5	0.75	0.5	0.75
Al	kg/yr	0.038	0.038	0.47	0.48	0.17	0.18	0.039	0.039	0.86	0.87	0.69	0.7
As	kg/yr	0.095	0.14	3.7	5.5	0.79	1.2	0.17	0.26	4.6	7	4.6	7
Ba	kg/yr	0.071	0.056	2.2	1.7	0.22	0.18	0.05	0.041	2.9	2.2	2.4	1.9
B	kg/yr	1.5	2.3	19	28	12	19	2.8	4.1	34	51	34	51
Ca	kg/yr	230	340	4200	6300	1900	2800	420	630	6500	9700	6500	9700
Cd	kg/yr	0.016	0.024	0.017	0.026	0.13	0.2	0.029	0.044	0.18	0.27	0.18	0.27
Co	kg/yr	8.7	13	0.37	0.55	72	110	16	24	88	130	88	130
Cr	kg/yr	0.067	0.1	0.55	0.83	0.56	0.84	0.12	0.18	1.2	1.8	1.2	1.8
Cu	kg/yr	18	27	1.3	2	33	37	33	49	74	91	67	88
Fe	kg/yr	86	130	230	340	0.66	0.73	160	240	320	470	390	580
Hg	kg/yr	0.004	0.006	0.055	0.082	0.033	0.049	0.0073	0.011	0.095	0.14	0.095	0.14
K	kg/yr	1500	2300	19000	28000	13000	19000	2800	4200	34000	51000	34000	51000
Li	kg/yr	0.58	0.87	0.89	1.3	4.8	7.2	1.1	1.6	6.7	10	6.7	10
Mg	kg/yr	230	340	470	700	1900	2900	420	630	2800	4200	2800	4200
Mn	kg/yr	4.2	6.3	5.8	8.7	35	52	7.7	12	48	73	48	73
Mo	kg/yr	0.2	0.3	3.4	5.1	1.6	2.5	0.36	0.54	5.4	8.1	5.4	8.1
Na	kg/yr	19	28	230	340	150	230	34	51	410	620	410	620
Ni	kg/yr	3.7	5.6	0.76	1.1	31	46	6.9	10	39	58	39	58
Pb	kg/yr	0.0019	0.0016	0.013	0.011	0.0065	0.0057	0.0015	0.0013	0.032	0.026	0.021	0.018
Sb	kg/yr	0.37	0.55	5.2	7.8	3.1	4.6	0.68	1	9	13	9	13
Se	kg/yr	0.23	0.34	0.36	0.54	1.9	2.9	0.42	0.63	2.7	4	2.7	4
Sr	kg/yr	2.5	3.8	22	33	21	31	4.6	6.9	48	72	48	72
Sn	kg/yr	0.026	0.038	0.52	0.78	0.21	0.32	0.047	0.07	0.78	1.2	0.78	1.2
U	kg/yr	5.7	5.7	72	72	26	26	5.7	5.7	130	130	100	100
V	kg/yr	0.055	0.083	1.1	1.7	0.46	0.69	0.1	0.15	1.7	2.5	1.7	2.5
Zn	kg/yr	2.6	3.9	12	18	22	33	4.8	7.2	38	57	38	57
Ra-226	Bq/yr	11000000	11000000	60000000	60000000	49000000	49000000	11000000	11000000	170000000	170000000	120000000	120000000
Po-210	Bq/yr	900000	900000	11000000	11000000	4000000	4000000	900000	900000	20000000	20000000	16000000	16000000
Pb-210	Bq/yr	2000000	2000000	25000000	25000000	9000000	9000000	2000000	2000000	45000000	45000000	36000000	36000000
Th-230	Bq/yr	3000000	3000000	38000000	38000000	13000000	13000000	3000000	3000000	68000000	68000000	54000000	54000000

Table 4-3: Predicted WRSA(s) Seepage Concentrations – Closure

Parameter	Units	Source Term 1 - Base Case	Source Term 1 - Upper Case	Source Term 2 - Base Case	Source Term 2 - Upper Case	Source Term 3 - Base Case	Source Term 3 - Upper Case	Source Term 4 - Base Case	Source Term 4 - Upper Case	Source Term 5 - Base Case	Source Term 5 - Upper Case
General Chemistry											
pH	s.u.	3.5	3.5	3.5	3.5	3.5	3.5	6.5	6.5	3.5	3.5
Alkalinity	mg CaCO ₃ /L	0	0	0	0	0	0	3.9	3.9	0	0
SO ₄	mg/L	1400	2100	260	400	3000	4500	160	240	530	790
Cl	mg/L	380	570	82	120	330	480	240	370	68	95
pe	s.u.	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Dissolved Metals											
Ag	mg/L	0.0064	0.0096	0.0012	0.0018	0.0064	0.0095	0.004	0.006	0.0011	0.0017
Al	mg/L	58	87	11	16	130	200	0.0038	0.0039	24	36
As	mg/L	0.059	0.088	0.011	0.017	0.026	0.039	0.051	0.077	0.0046	0.007
Ba	mg/L	0.0034	0.0029	0.0078	0.0062	0.0023	0.002	0.012	0.01	0.005	0.0041
B	mg/L	0.65	0.98	0.12	0.18	0.97	1.4	0.26	0.39	0.17	0.26
Ca	mg/L	100	160	19	29	120	180	58	87	21	31
Cd	mg/L	0.0056	0.0085	0.0011	0.0016	0.013	0.019	0.00024	0.00036	0.0023	0.0034
Co	mg/L	2.2	3.4	0.42	0.63	5.4	8	0.0051	0.0076	0.95	1.4
Cr	mg/L	0.016	0.024	0.003	0.0045	0.022	0.032	0.0077	0.012	0.0038	0.0057
Cu	mg/L	3.6	5.5	0.68	1	8.7	13	0.019	0.028	1.5	2.3
Fe	mg/L	36	54	6.7	10	78	120	3.2	4.8	14	21
Hg	mg/L	0.0012	0.0018	0.00023	0.00034	0.0012	0.0018	0.00076	0.0011	0.00021	0.00032
K	mg/L	530	800	100	150	700	1100	260	390	120	180
Li	mg/L	0.38	0.57	0.071	0.11	0.88	1.3	0.012	0.019	0.16	0.23
Mg	mg/L	150	220	28	42	340	510	6.5	9.7	60	91
Mn	mg/L	3.2	4.8	0.6	0.9	7.5	11	0.08	0.12	1.3	2
Mo	mg/L	0.044	0.064	0.011	0.015	0.009	0.0097	0.047	0.071	0.0066	0.0071
Na	mg/L	4.5	6.7	0.84	1.3	3.7	5.5	3.1	4.7	0.65	0.98
Ni	mg/L	2	3	0.37	0.56	4.7	7	0.011	0.016	0.83	1.2
Pb	mg/L	0.0042	0.0036	0.0074	0.0066	0.031	0.038	0.000079	0.000066	0.016	0.018
Sb	mg/L	0.12	0.17	0.022	0.033	0.11	0.17	0.072	0.11	0.02	0.03
Se	mg/L	0.13	0.19	0.024	0.036	0.29	0.44	0.005	0.0074	0.051	0.077
Sr	mg/L	1.2	1.8	0.22	0.34	2.2	3.2	0.31	0.46	0.38	0.57
Sn	mg/L	0.01	0.015	0.0019	0.0028	0.0078	0.012	0.0072	0.011	0.0014	0.0021
U	mg/L	1.6	1.6	1.6	1.6	1.6	1.6	0.57	0.57	1.6	1.6
V	mg/L	0.016	0.023	0.0029	0.0044	0.0032	0.0047	0.015	0.023	0.00056	0.00084
Zn	mg/L	1.3	1.9	0.24	0.36	2.7	4	0.16	0.24	0.48	0.71
Ra-226	Bq/L	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Po-210	Bq/L	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Pb-210	Bq/L	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Th-230	Bq/L	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Table 4-4: Predicted WRSA(s) Seepage Loadings – Closure

Parameter	Units	Source Term 1 - Base Case	Source Term 1 - Upper Case	Source Term 2 - Base Case	Source Term 2 - Upper Case	Source Term 3 - Base Case	Source Term 3 - Upper Case	Source Term 4 - Base Case	Source Term 4 - Upper Case	Source Term 5 - Base Case	Source Term 5 - Upper Case	Combined Source Term 3 and 4 - Base Case	Combined Source Term 3 and 4 - Upper Case	Combined Source Term 4 and 5 - Base Case	Combined Source Term 4 and 5 - Upper Case
General Chemistry															
Alkalinity	kg CaCO ₃ /yr	0	0	0	0	0	0	150	160	0	0	150	160	150	160
SO ₄	kg/yr	110000	160000	20000	31000	96000	140000	6400	9700	18000	27000	100000	150000	25000	37000
Cl	kg/yr	30000	44000	6300	9000	11000	15000	9700	15000	2300	3300	20000	30000	12000	18000
Dissolved Metals															
Ag	kg/yr	0.5	0.74	0.093	0.14	0.2	0.31	0.16	0.24	0.039	0.058	0.37	0.55	0.2	0.3
Al	kg/yr	4500	6700	840	1300	4300	6400	0.15	0.16	810	1200	4300	6400	810	1200
As	kg/yr	4.5	6.8	0.85	1.3	0.84	1.3	2	3.1	0.16	0.24	2.9	4.3	2.2	3.3
Ba	kg/yr	0.26	0.23	0.6	0.48	0.075	0.065	0.49	0.4	0.17	0.14	0.57	0.46	0.67	0.54
B	kg/yr	50	75	9.4	14	31	46	11	16	5.9	8.8	42	62	16	25
Ca	kg/yr	8000	12000	1500	2300	3800	5700	2300	3500	720	1100	6100	9200	3000	4600
Cd	kg/yr	0.44	0.65	0.082	0.12	0.41	0.62	0.0097	0.014	0.078	0.12	0.42	0.63	0.088	0.13
Co	kg/yr	170	260	33	49	170	260	0.2	0.31	32	49	170	260	33	49
Cr	kg/yr	1.2	1.9	0.23	0.35	0.69	1	0.31	0.46	0.13	0.2	1	1.5	0.44	0.66
Cu	kg/yr	280	420	53	79	280	410	0.74	1.1	52	78	280	410	53	80
Fe	kg/yr	2800	4100	520	780	2500	3800	130	190	470	710	2600	3900	600	900
Hg	kg/yr	0.094	0.14	0.018	0.026	0.039	0.058	0.031	0.046	0.0073	0.011	0.069	0.1	0.038	0.057
K	kg/yr	41000	62000	7700	12000	23000	34000	10000	15000	4200	6300	33000	49000	15000	22000
Li	kg/yr	29	44	5.5	8.2	28	42	0.5	0.74	5.3	8	29	43	5.8	8.7
Mg	kg/yr	12000	17000	2200	3200	11000	16000	260	390	2100	3100	11000	17000	2300	3500
Mn	kg/yr	250	370	46	70	240	360	3.2	4.8	45	68	240	360	48	73
Mo	kg/yr	3.4	5	0.87	1.1	0.29	0.31	1.9	2.8	0.23	0.24	2.2	3.1	2.1	3.1
Na	kg/yr	350	520	65	97	120	180	130	190	22	34	240	370	150	220
Ni	kg/yr	150	230	29	43	150	220	0.42	0.64	28	43	150	230	29	43
Pb	kg/yr	0.32	0.28	0.57	0.51	0.99	1.2	0.0031	0.0027	0.56	0.63	0.99	1.2	0.56	0.63
Sb	kg/yr	8.9	13	1.7	2.5	3.7	5.5	2.9	4.3	0.69	1	6.6	9.8	3.6	5.4
Se	kg/yr	9.8	15	1.8	2.7	9.3	14	0.2	0.3	1.8	2.6	9.5	14	2	2.9
Sr	kg/yr	92	140	17	26	69	100	12	19	13	20	82	120	25	38
Sn	kg/yr	0.77	1.2	0.14	0.22	0.25	0.37	0.29	0.43	0.047	0.071	0.54	0.81	0.34	0.5
U	kg/yr	120	120	120	120	49	49	23	23	53	53	72	72	76	76
V	kg/yr	1.2	1.8	0.23	0.34	0.1	0.15	0.61	0.92	0.019	0.029	0.71	1.1	0.63	0.95
Zn	kg/yr	99	150	19	28	86	130	6.5	9.8	16	24	93	140	23	34
Ra-226	Bq/yr	85000000	85000000	85000000	85000000	35000000	35000000	44000000	44000000	60000000	60000000	79000000	79000000	82000000	82000000
Po-210	Bq/yr	6900000	6900000	6900000	6900000	2900000	2900000	3600000	3600000	3100000	3100000	6500000	6500000	6700000	6700000
Pb-210	Bq/yr	15000000	15000000	15000000	15000000	6400000	6400000	8000000	8000000	6900000	6900000	14000000	14000000	15000000	15000000
Th-230	Bq/yr	23000000	23000000	23000000	23000000	9600000	9600000	12000000	12000000	10000000	10000000	22000000	22000000	22000000	22000000

Source: \\VAN-SVR0\Projects\01_SITES\Rook 1\1CN034.002_Geochem Characterization\04_Task400_SourceTerms\Final Source Terms\Waste Rock Source Terms\Compiled_WR_Source_Terms-Issue_to_NexGen_1NC034.002_JAC_REV13-DRAFT.xlsx

4.2 Underground Wall Rock

The underground wall rock source terms are presented in Table 4-5. The source terms are provided as a mass of stored load released for each of the years following the operations when the underground workings are inundated (years 29 to 34). The source terms for uranium and radionuclides are provided as concentrations (mg/L and Bq/L respectively) in Table 4-6.

Table 4-5: Summary of Stored Loading for each Post-closure by Development Year

Development Year		29	30	31	32	33	34
Parameter	Units						
General Chemistry							
Alkalinity	kg CaCO ₃	71,000	76,000	6,000	25,000	29,000	2,600
SO ₄	kg	130,000	88,000	17,000	40,000	67,000	9,000
Cl	kg	76,000	28,000	10,000	17,000	32,000	5,400
Dissolved Metals							
Ag	kg	3	1.3	0.39	0.71	1.3	0.21
Al	kg	1,600	2,100	340	990	1700	99
As	kg	76	23	10	13	23	5
Ba	kg	23	9.9	3.3	5.6	11	1.5
B	kg	760	130	110	120	240	52
Ca	kg	32,000	17,000	4,100	8,500	16,000	2,000
Cd	kg	8.6	1.4	1.3	1.1	1.9	0.53
Co	kg	94	42	11	22	55	5.1
Cr	kg	6.8	2.3	1.3	1.9	4.7	0.49
Cu	kg	95	100	10	41	67	4.9
Fe	kg	5200	1,100	990	1400	3700	420
Hg	kg	0.56	0.26	0.07	0.13	0.24	0.039
K	kg	20,000	16,000	2,300	6,400	10,000	1,200
Li	kg	27	16	4.2	8.1	14	1.9
Mg	kg	8,800	6,400	1,400	3,200	5,500	660
Mn	kg	110	110	14	44	60	6.6
Mo	kg	23,000	3,300	3,300	2,700	4,600	1,400
Na	kg	4,000	1,300	780	1,000	2,300	270
Ni	kg	64	49	8.5	22	39	3.7
Pb	kg	3.7	2.3	0.72	1.4	2.8	0.26
Sb	kg	66	26	8.7	14	26	4.5
Se	kg	27	4.4	4.1	4.1	9.7	1.7
Sr	kg	420	110	67	89	200	32
Sn	kg	7.4	1.7	1.1	1.5	3.6	0.6
V	kg	53	10	7.8	7.8	15	3.4
Zn	kg	130	83	17	39	66	8.9

Source: \\VAN-SVR0\Projects\01_SITES\Rook 1\1CN034.002_Geochem Characterization\04_Task400_SourceTerms\Final Source Terms\Underground Source Terms\Compiled_UG_Source_Terms-Issue_to_NexGen_1NC034.002_JAC_REV01.xlsx\Sheet

Table 4-6: Source Term Concentrations for Uranium and Radionuclides

Parameter	Unit	Source Term
Uranium	mg/L	4.67
Radium-226	Bq/L	70
Polonium-210	Bq/L	0.43
Lead-210	Bq/L	0.4
Thorium-230	Bq/L	2.8

5 Discussion

The following subsections discuss the results for waste rock source terms by comparing predictions for each of the proposed placement methods. A comparison of loadings for parameters of interest for the operations scenarios is provided in Figure 5-1 to Figure 5-7 and for closure scenarios is provided in Figure 5-8 to Figure 5-14. As there is only one scenario for the underground wall rock source terms, no discussion on the results is included. The influence of the underground wall rock source term on mine pool water quality is evaluated in the solute transport model.

5.1 Operations

5.1.1 Base Case versus Upper Case

A comparison of the predicted concentrations between the base and upper cases for the co-placement of PAG and NPAG material (Source Term 1) show the upper-case predictions are higher for most parameters (Table 4-1). As described in Section 3.2.3, the uranium and radionuclide source terms were derived from the measured concentrations in HCTs or SFEs and were not scaled. The base and upper cases are representative of changes to the grain size scaling factor. Therefore, the same source term is used for both the base and upper cases for uranium and radionuclides.

5.1.2 Toe versus Basal Seepage

Source term predictions were developed for leachate released as toe seepage and leachate released to shallow groundwater as basal seepage from leakage through the liner. In general, the concentrations for toe and basal seepage most parameters were the same for placement options that use a liner. Iron and copper both had lower concentrations for toe seepage in comparison to basal seepage as liner leakage for the co-placed PAG and NPAG material (Source Term 1 and 2) as well as the segregated PAG placement options (Source Term 3, 5). This is expected as ferrihydrite ($\text{Fe}(\text{OH})_3$) and malachite ($\text{Cu}_2(\text{CO}_3)(\text{OH})_2$) are modelled to precipitate at the more oxic conditions at toe seepage creating a solubility control for these constituents.

The segregated NPAG placement option (Source Term 4) is planned without use of a liner, therefore all leachate is modelled to be released as basal seepage.

5.1.3 Engineered Layer Design

To assess the effectiveness of the engineered layer design, the predicted concentrations from the WRSA with co-placement of PAG and NPAG material using engineered layering (Source Term 2) was compared with the WRSA with co-placed PAG and NPAG material without engineered layers (Source Term 1). As the engineered layer design (Source Term 2) is not expected to limit oxidation ingress during operations during active waste rock placement, the characteristics of leachate from waste rock are expected to be similar to Source Term 1. In general, the predicted concentrations for the co-placed PAG and NAG using an engineered layer design (Source Term 2) are higher than the co-placed option without engineer design (Source Term 1). This is attributed to the lower predicted flow from the water

balance model of the engineer design which results in a lower water to rock ratio, resulting in higher concentrations (Table 4-1).

5.1.4 Segregated versus Co-Placed Placement Methods

The predicted concentrations for placement methods with and without segregation of PAG material were compared to assess the effect on concentrations from segregation of materials. For this, the predicted source term concentrations from the segregated placement methods (Source Terms 3, 4 and 5) were compared with the co-mingled placement methods (Source Terms 1 and 2). The predicted concentrations for the segregated PAG WRSA (Source Term 3) were generally higher than the source term representing the co-placed PAG and NPAG WRSA (Source Term 1) (Table 4-1). This occurs because PAG rock containing higher sulfide content is segregated in Source Term 3, resulting in a higher sulfate production and release of trace metals associated with sulfides.

The pattern of higher concentration was also observed in the segregated PAG placement method using engineered layering (Source Term 5) compared with the predictions for the WRSA with co-placed PAG and NPAG material using engineered layering (Source Term 2) (Table 4-1).

Exceptions are arsenic and molybdenum which have lower concentrations in the segregated PAG placement methods in comparison to the co-placed PAG and NPAG WRSA. The geochemical testing show molybdenum and arsenic to be elevated in low-sulfide and NPAG HCTs resulting in higher concentrations in the co-placed scenario which has a higher proportion of NPAG material than the segregated PAG scenario.

Some parameters including aluminum, silver, antimony barium, boron, chromium, tin and mercury are trace constituents that also had lower concentration or equivalent in the segregated PAG placement method in comparison to the co-placed WRSA. However, the values were only slightly lower for these parameters.

Predicted seepage concentrations in the segregated NPAG placement method (Source Term 4) are generally lower in comparison to the co-placed methods (Source Term 1 and 2) (Table 4-1).

This is expected as the NPAG WRSA will only contain low sulfur-bearing material, resulting in lower sulfate production rates and lower release of trace metals contained within sulfide minerals. The exceptions are arsenic, molybdenum and antimony which have higher predicted concentrations in the segregated NPAG placement method. Geochemical testing indicates that arsenic and molybdenum are more mobile from NPAG samples. Therefore, concentrating low sulfur waste rock in the NPAG WRSA may result in an increase of seepage arsenic and molybdenum concentrations.

The predicted iron concentrations are higher in the segregated NPAG placement methods (Source Term 4) in comparison to the predicted concentrations for all other placement methods. The segregated NPAG placement method is the only source term modelled without a liner where all seepage reports directly to shallow groundwater at more reducing conditions. The lower iron concentrations in the scenarios modelled with a liner are attributed to the precipitation of ferrihydrite. As the saturation index for ferrihydrite is a function of redox conditions, the more oxidized conditions at the toe seepage will result in precipitation of ferrihydrite creating a solubility limit.

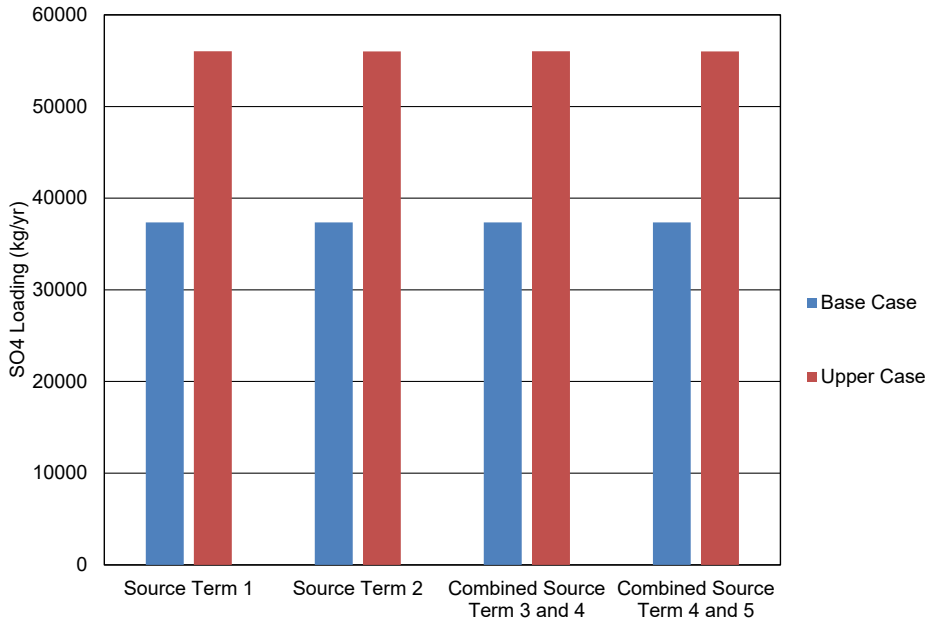
5.1.5 WRSA(s) Loadings

The source term water quality model is designed to predict seepage concentrations. In the segregated PAG and NPAG placement methods, PAG rock is segregated into a separate WRSA and therefore, direct comparison of the concentrations between options may be misleading without considering flow and loading for each WRSA (i.e., concentrations would be expected to be higher in the PAG WRSA in comparison to the co-placed PAG and NPAG drainage concentrations). Comparison of the loadings from the co-placed methods with the combined loadings from the segregated PAG and NPAG placement method for both the scenarios with and without engineered layering provides a direct basis for comparing the source terms for all the waste rock placement options.

Figure 5-1 to Figure 5-7 provide a comparison of loadings from select parameters for the co-placed (Source Term 1), co-placed with engineered layering (Source Term 2), combined loadings from the PAG and NPAG WRSAs (sum of Source Term 3 and 4) and combined loadings from the NPAG WRSA and PAG WRSA with engineered layering (sum of Source Term 4 and 5). Select parameters are those that were elevated in SFE or HCT testing (e.g., sulfate, copper, molybdenum) and those that are often screened as potential constituents of concern at uranium projects (e.g. arsenic, cobalt, uranium and radium-226).

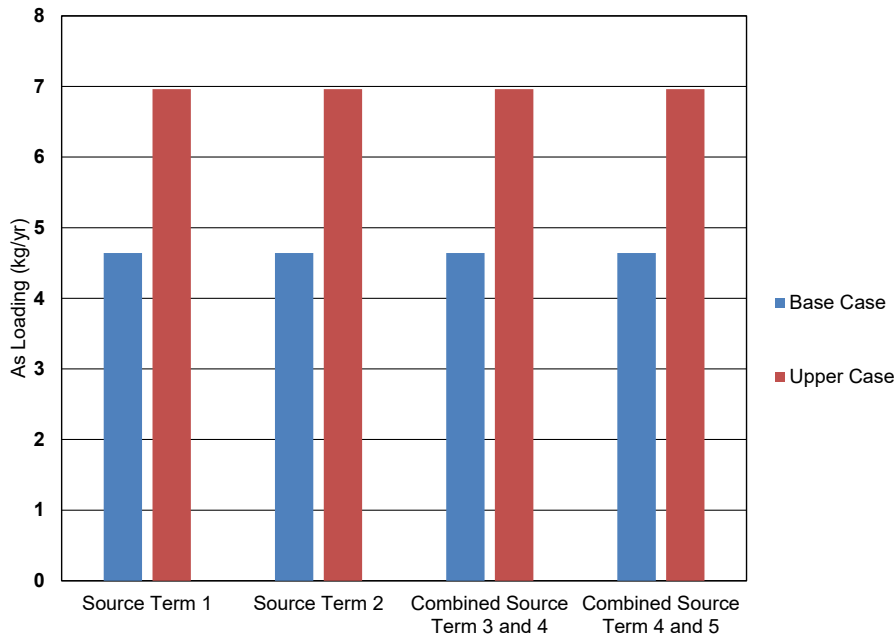
The following is a summary of the comparison of loadings from all options:

- Sulfate loadings are comparable for all placement methods (Figure 5-1)
- Most trace element parameters (arsenic, molybdenum, cobalt) are comparable for all placement methods (Figure 5-2 to Figure 5-4)
- Copper loadings are lower in the segregated PAG and NPAG placement methods (sum of Source Term 3 and 4, and sum of Source Term 4 and 5) in comparison to the co-mingled placement options (Source Term 1 and 2). The copper concentrations are sensitive to redox conditions, and the component of leachate released as toe seepage under oxic conditions is at solubility limit with malachite ($\text{Cu}_2(\text{CO}_3)(\text{OH})_2$) which is limiting copper concentrations. The component of leachate released as basal seepage under the more reduced environment in shallow groundwater is undersaturated for malachite ($\text{Cu}_2(\text{CO}_3)(\text{OH})_2$) resulting in higher concentrations for the component of seepage released as liner leakage (Figure 5-5) The differences between the PAG and NPAG co-mingled scenario (Source Term 1) and co-mingled placement scenario with engineer design (Source Term 2) are attributed to the same principles although as a result of differences in water balance, with a greater proportion of seepage reporting as toe seepage in Source Term 2.
- As the source term for uranium and radium-226 were derived on a concentration basis, their loadings are sensitive to the differences in the amount of infiltration for each of the placement options. The co-placed PAG and NPAG with engineer design (Source Term 2) has the lowest amount of annual infiltration in comparison to the other scenarios, and therefore has the lowest loadings (Figure 5-6 and Figure 5-7)



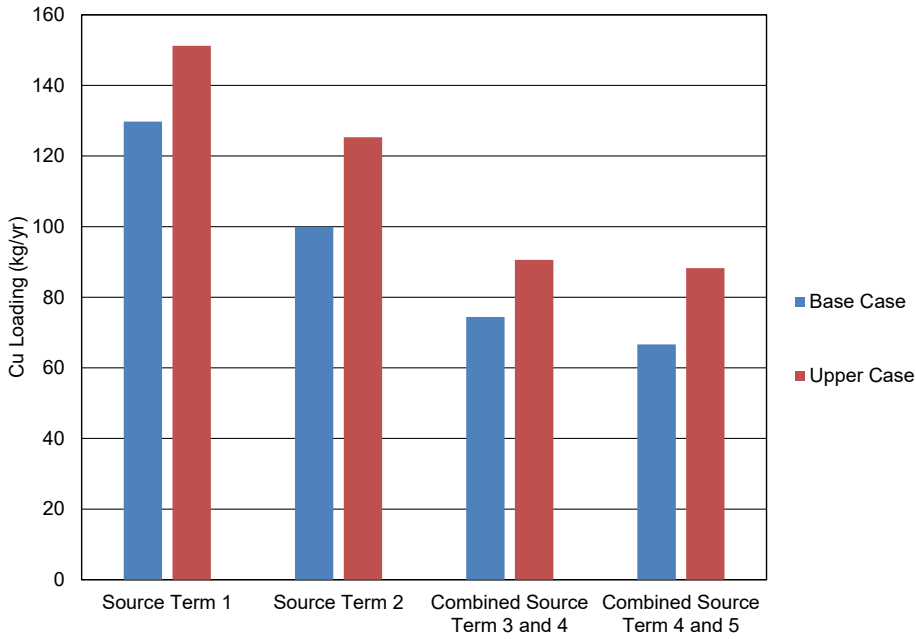
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Figure 5-1: Predicted WRSA(s) Sulfate Loadings – Operations



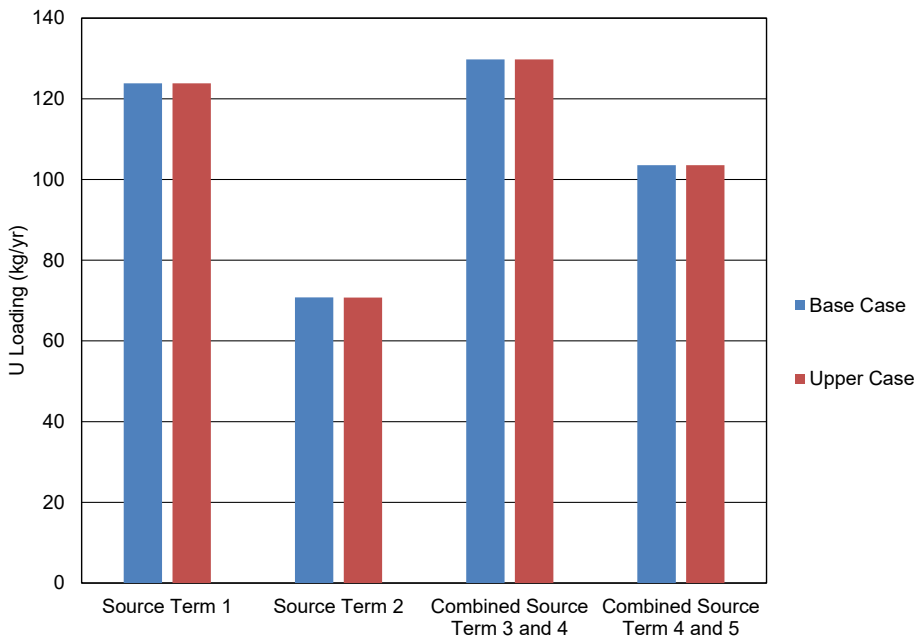
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Figure 5-2: Predicted WRSA(s) Arsenic Loadings – Operations



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Figure 5-5: Predicted WRSA(s) Copper Loadings – Operations



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Figure 5-6: Predicted WRSA(s) Uranium Loadings – Operations

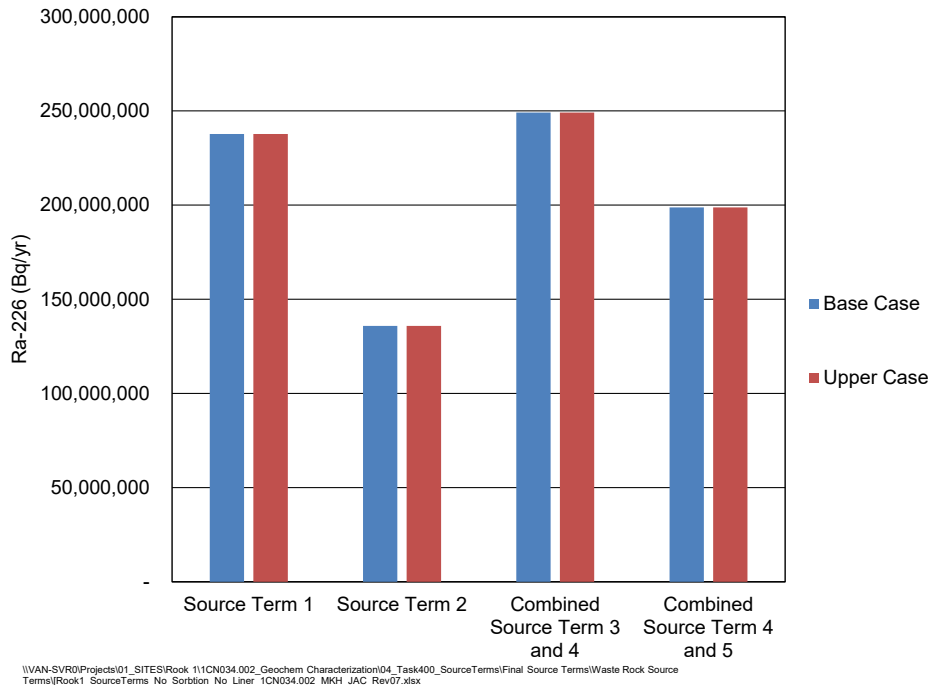


Figure 5-7: Predicted WRSA(s) radium-226 Loadings – Operations

5.2 Closure

5.2.1 Engineered Layer Design

At closure, the engineered layer design is predicted to restrict oxygen ingress to the upper portions of the waste rock piles, resulting in a reduction of reactive mass in the WRSA compared to options that do not include the engineered design. These conditions in the WRSA are modelled in Source Term 2 (co-placed PAG and NPAG material) and Source Term 5 (segregated PAG materials). The source terms for these WRSAs have lower concentrations for nearly all parameters in comparison to the placement methods representing the WRSAs without the engineered layering (Source Term 1 and 3). The lower concentrations in the placement methods that use an engineered layer design are attributed to the reduced reactive mass which results in a higher ratio of water to reactive mass. The exception is barium which has slightly higher concentrations in the placement methods with engineered layering.

5.2.2 Segregated versus Co-Placed Placement Methods

The predicted concentrations from segregating PAG and NPAG material at closure were compared to the predicted concentrations from the WRSAs with co-placement of PAG and NPAG material. The predicted concentrations for the placement method with segregated PAG material (Source Term 3) were generally higher than the co-placed PAG and NPAG material (Source Term 1) (Table 4-3). This occurs as segregated PAG rock containing higher sulfur has higher sulfate production rate and release of trace metals associated with sulfur as well as higher dissolution in acidic conditions for PAG

material. Exceptions are arsenic, molybdenum, tin, and vanadium, which have lower concentrations in Source Term 3 in comparison to Source Term 1. The geochemical testing with HCTs show these constituents to be elevated in low-sulfide and NPAG present in the co-placed PAG and NPAG placement option. Barium has only slightly lower values in Source Term 3 in comparison to Source Term 1.

Predicted concentrations in the placement method representing segregated NPAG material (Source Term 4) are lower in comparison to the co-placed PAG and NPAG material (Source Term 1) (Table 4-3). This is expected as the segregated NPAG WRSA will contain low sulfide material resulting in lower sulfate production rates and lower release of trace metals contained within sulfide minerals. The neutral pH conditions of the NPAG WRSA will also result in lower concentrations for constituents that typically have higher mobility at acidic conditions in comparison to the co-placed PAG and NPAG WRSA (Source Term 1) which is assumed to have acidic pH conditions at closure.

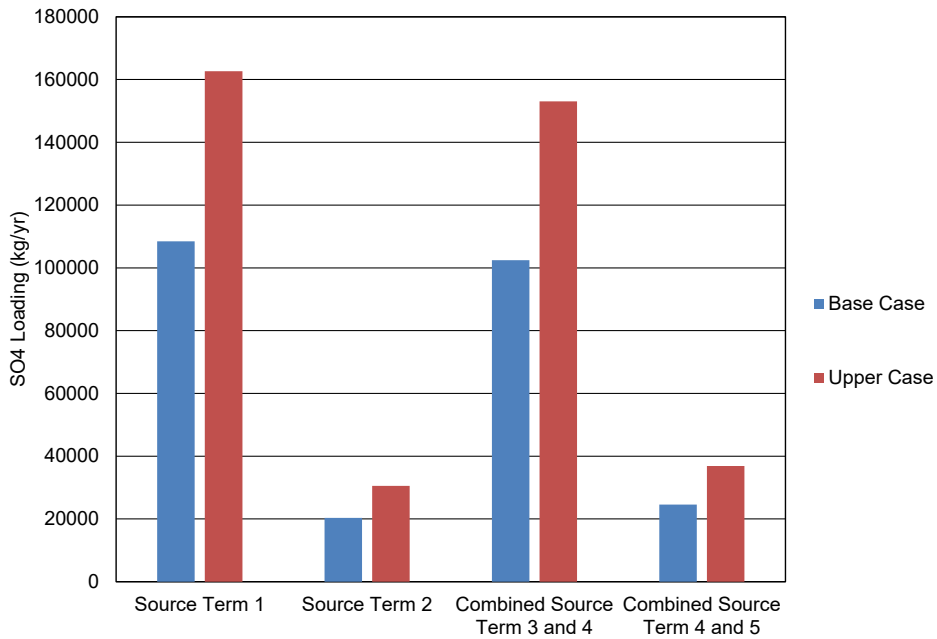
5.2.3 WRSA(s) Loadings

Like the operations scenario, a comparison of loadings provides a basis to compare the source terms for all the waste rock placement options at closure. Figure 5-8 to Figure 5-14 provide a comparison of the loadings for the waste rock placement methods from select parameters at closure.

The predicted loadings for the closure scenarios were most sensitive to the placement methods which use the engineered layer design. The following is a summary of the comparison of loadings for the placement options with and without engineered design:

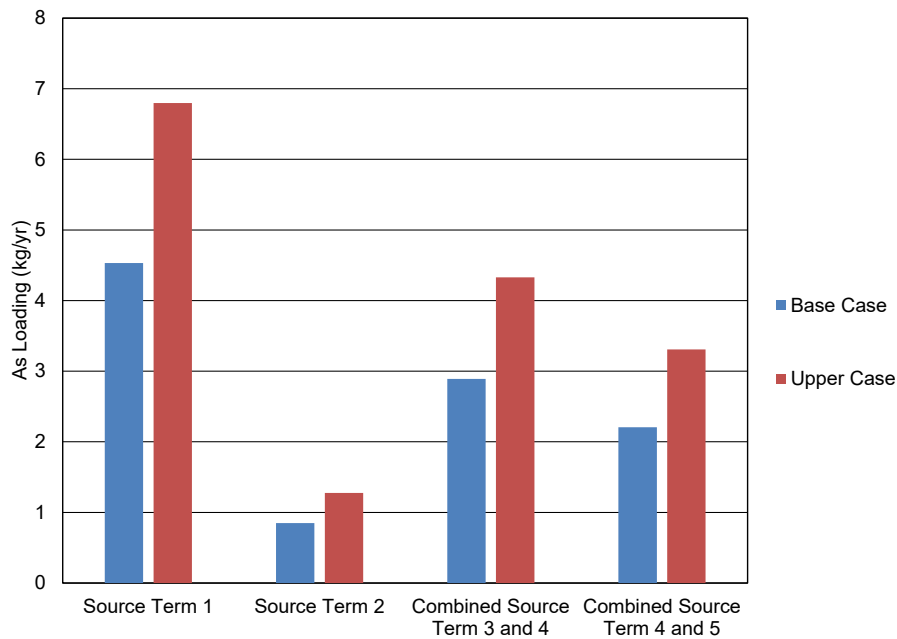
- Parameters that are associated with sulfide oxidation (e.g., SO_4 , Cu, Co) have lower loadings in the scenarios that use engineered layering to limit oxidation (e.g. Source Term 2 and Source Term 5) in comparison to the placement methods without engineered layering (Source Term 1, 3 and 4).
- Sulfate, copper and cobalt are comparable in the co-placed PAG and NPAG without engineered layering (Source Term 1) and the sum of the segregated PAG without engineered layering (Source Term 3) and segregated NPAG (Source Term 4); (
- Sulfate, copper and cobalt are comparable in the co-placed PAG and NPAG with engineered layering (Source Term 2) and the sum of the segregated PAG with engineered layering (Source Term 5) and segregated NPAG (Source Term 4); and
- Arsenic and molybdenum loadings are higher in the co-placed PAG and NPAG without engineered layering (Source Term 1) in comparison to the sum of segregated PAG without engineered layering (Source Term 3) and segregated NPAG (Source Term 4).

As the source terms for uranium and radium-226 were derived on a concentration basis, their loadings are sensitive to changes in water balance, resulting in the variations in calculated loadings observed in each of the different placement strategies. Additionally, as uranium mobility is pH dependent, a higher source term concentration was applied to all WRSAs which host PAG material. The calculated uranium loadings for the segregated PAG and NPAG WRSAs are lower in comparison to the WRSA options with conventional placement of combined PAG and NPAG material as the co-placed WRSA is conservatively assumed to be entirely PAG.



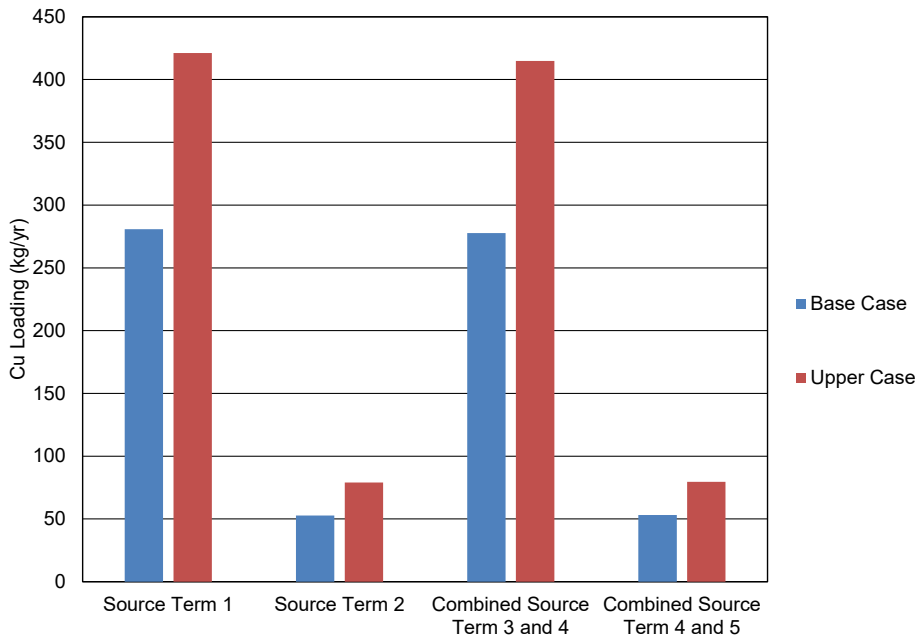
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Figure 5-8. Predicted WRSA(s) Sulfate Loadings – Closure



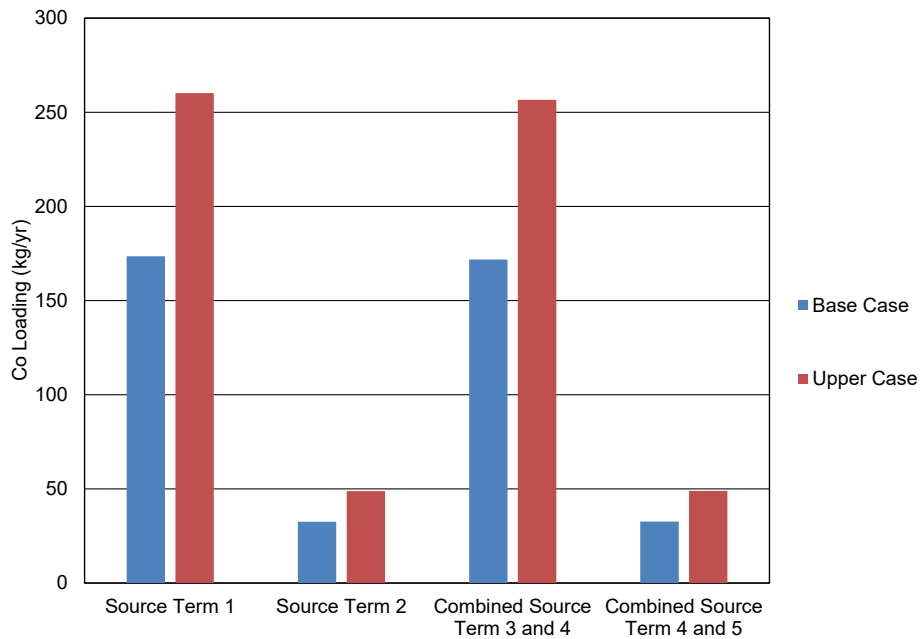
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Figure 5-9: Predicted WRSA(s) Arsenic Loadings – Closure



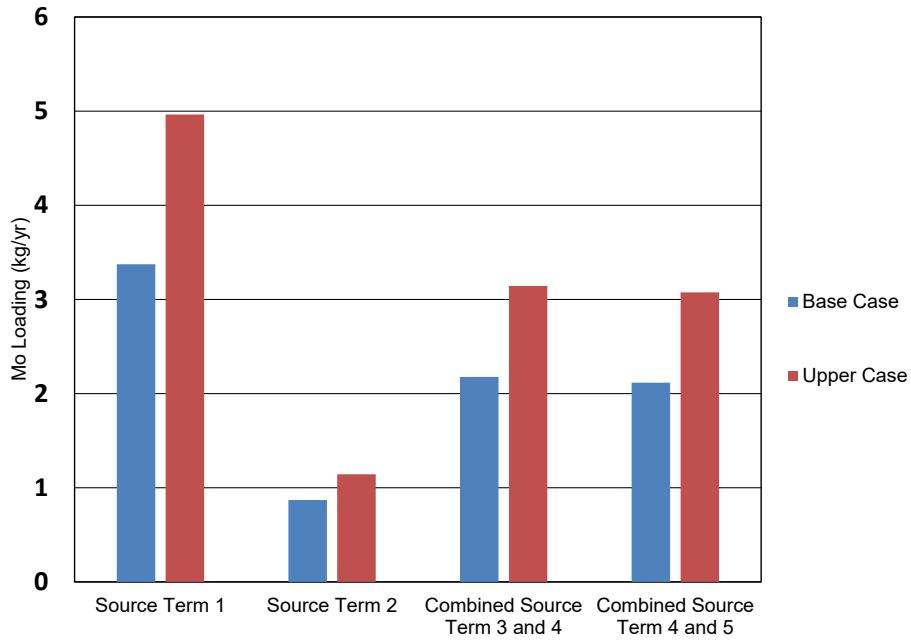
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Figure 5-10: Predicted WRSA(s) Copper Loadings – Closure



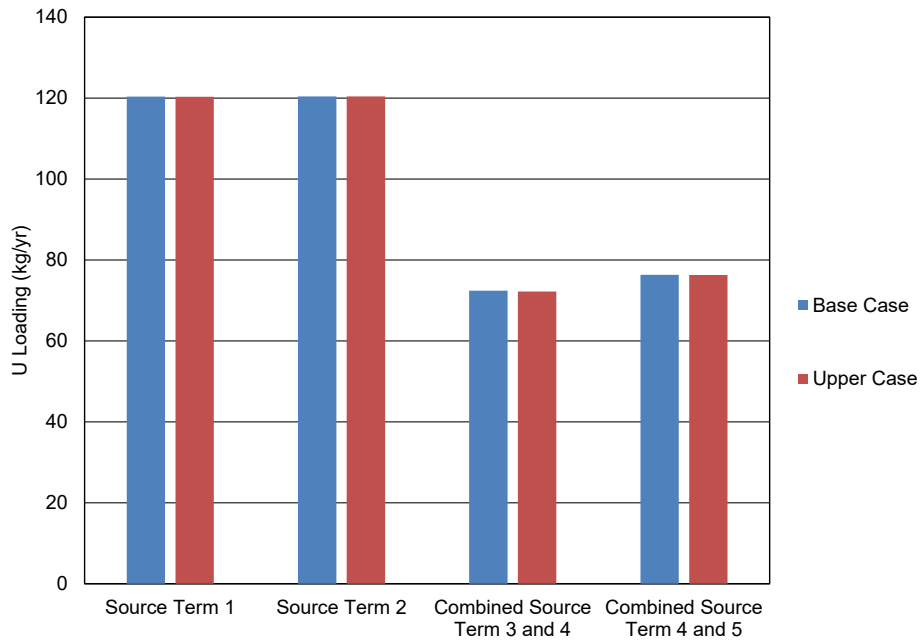
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Figure 5-11: Predicted WRSA(s) Cobalt Loadings – Closure



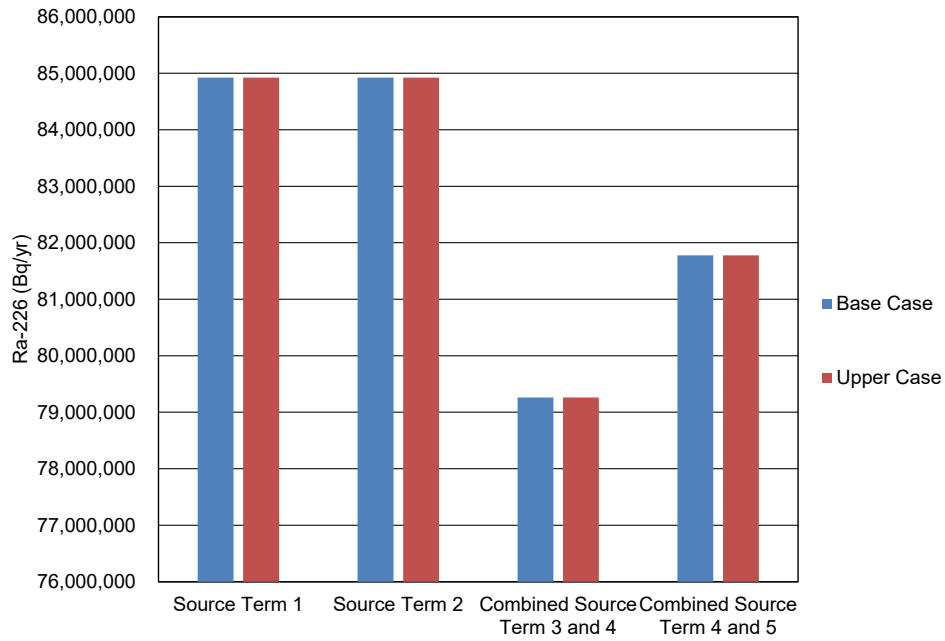
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Figure 5-12. Predicted WRSA(s) Molybdenum Loadings – Closure



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Figure 5-13: Predicted WRSA(s) Uranium Loadings – Closure



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Figure 5-14: Predicted WRSA(s) radium-226 Loadings – Closure

6 Key Findings

6.1 Waste Rock

A comparison of the source terms developed for five different placement options and scenarios representing co-placed versus segregated materials and conventional versus engineered layers indicated the following:

- As a result of a higher proportion of material with elevated sulfide content, concentrations for sulfate and chalcophile elements were higher in the WRSA with segregated PAG material in comparison to the WRSA representing co-placed material at closure. Exceptions included some oxyanion species which are not necessarily hosted in sulfides and are mobile under near neutral pH conditions including arsenic and molybdenum.
- Leachate characteristics from the WRSA with segregated NPAG material had overall lower concentrations and loadings for most constituents in comparison to the leachate characteristics for the WRSA representing co-placed material and WRSA representing segregated PAG material for both operations and closure. The lower values resulted from a lower concentration of sulfide material and associated metal constituents.
- For WRSAs that include PAG material, concentrations for most constituents increase in the closure scenario in comparison to the operations scenario. These constituents increased in concentration due to modelled acidic conditions, as well as higher proportion of high sulfide samples used as input to represent the acidic waste rock material at closure.
- Loadings between the co-placed WRSA (Source Term 1) and combined loadings from the segregated PAG and NPAG WRSAs (sum loadings for Source Term 3 and 4) were similar for the operations scenario for most constituents. For the closure scenario, several parameters have comparable loadings for these two placement options, with lower loadings in the segregated PAG and NPAG WRSAs for some parameters including arsenic, molybdenum and uranium.
- For the closure scenarios, the loadings calculated from placement methods using engineered layering (Source Term 2 and 5) resulted in the lowest loadings in comparison to the same material placed without engineered layering. This is a result of the engineered design reducing oxygen ingress resulting in a reduction in reactive waste rock modelled for these placement options.

The source terms are considered preliminary with the expectation that further refinement and modifications to the inputs will be conducted as more HCT data becomes available or if there are modifications to the placement designs, mine plan or water balance. In the meantime, conservative assumptions have been used at several stages of source term development to minimize the likelihood of underestimating concentrations and loadings.

6.2 Underground Wall Rock

This report also presents the methods, assumptions and data input used to develop the source term loading predictions from exposed wall rock in the underground workings at the Project. The source terms were developed for use in the solute transport modelling.

Closure

This revised draft report, Waste Rock and Underground Wall Rock Source Term Predictions – Rook 1 Project, was prepared by

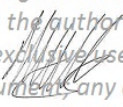


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and reviewed by

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Michael Herrell, PGeo (BC)
Principal Consultant

All data used as source material plus the text, tables, figures, and attachments of this document have been reviewed and prepared in accordance with generally accepted professional engineering and environmental practices.

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