4.0 IDENTIFICATION AND SCREENING OF REMEDIATION TECHNOLOGIES

This section identifies and screens technologies that may be included in remediation alternatives for the Site. A comprehensive list of technologies and process options that are potentially applicable to this Site is developed to cover all the applicable general response actions. The list of technologies is then screened to refine a list of potentially feasible technologies that can then be used to develop remediation alternatives for the Site. The remediation technologies are screened using the following criteria:

- **Effectiveness** – the potential effectiveness of the technology to (a) address the Site-specific conditions, including applicability to the specific media and Site COCs, (b) meet RAOs; (c) minimize human health and environmental impacts during implementation; and (d) provide proven and reliable remediation under Site conditions.
- **Implementability** – the technical and administrative feasibility of implementing a technology. Technical considerations cover Site-specific factors that could potentially prevent successful technology use such as physical interferences or constraints, practical limitations of a technology, or various material properties. Administrative implementability considers the ability to acquire permits needed for technology use and the availability of qualified contractors, equipment, and disposal services.
- **Cost** – the capital and operational and maintenance costs associated with the technology. Costs that are excessive compared to the overall effectiveness of the technology may be considered as one of several factors used to eliminate technologies. Technologies providing effectiveness and implementability similar to that of another technology by using a similar method of treatment or engineering control, but at greater cost, may be eliminated. At the screening level, the cost evaluation is engineering judgment of relative costs.

The technologies and process options are screened against the criteria in the priority order listed above using the "fatal flaw" approach. The approach ranks the criteria in order of importance, as listed above. When a technology is rejected based on effectiveness, it is not further evaluated based on implementability or cost. Similarly, if a technology is effective but not implementable, the technology is rejected, and a cost evaluation is not performed. This approach streamlines the evaluation of technologies while maintaining the EPA screening process.

Evaluation and screening of technologies are performed in a single step. The key selection criterion for the screening level (technology type, individual technology, or process option) is whether there is a significant difference between the technologies or process options when evaluated against the screening criteria (effectiveness, implementability, and cost). Technologies and process options judged to have significant differences are screened separately, and the retained technologies or process options will be developed into separate remediation alternatives to allow for full evaluation and comparison.

The potentially applicable technologies considered for the Site are presented and screened in Table 4-1. The technology screening is also summarized in the table. Brief descriptions of the technologies and discussions of the screening evaluations are provided in sub-sections below. Technologies retained through this screening process are then incorporated into the remediation alternatives in Section 5.

4.1 General Response Actions

General response actions are broad categories of remedial actions that can be combined to meet remediation goals for the Site. The following general response actions are applicable to this Site:

- No action
- Institutional controls
- Monitoring
- Monitored Natural Attenuation
- Containment
- Removal
- Treatment (ex situ and in situ)
- Disposal

Except for “no action,” each of these general response actions represents a category of technologies. Applicable technologies vary depending on the media and COCs.

4.2 Institutional Controls

Institutional controls are legal and physical restrictions that are typically used to prevent exposure to COCs or to prevent activities that might interfere with the remedy at a site. Risk is managed by institutional controls to the extent that they prevent exposure to affected media. However, institutional controls do not prevent off-site migration of COCs. Institutional controls can be effective for their intended purpose, are easily implemented, and are usually low in cost.

4.2.1 Use Restrictions

Land use restrictions are often implemented through “land use covenants” or “real property covenants.” Land use covenants are enforceable rights to restrict the use of property by the property owner. Land use covenants are contained in deeds, which transfer ownership of the property, or in a separate document filed in the real property records. The use restrictions in land use covenants are binding on subsequent owners of the property.

Governmental controls are implemented and enforced by a governmental entity to restrict land or resource use at a site. Most of the land adjacent to the Site is rural forest land, with a few residences and small businesses located to the east, along County Road 74. Governmental controls such as land use restrictions (i.e., zoning) could be implemented to prevent uses that would interfere with the remedy or that could result in human health or environmental risks. The State could similarly restrict uses of surface water or groundwater at the Site to prevent uses that are not compatible with the selected remedy.

Use restrictions are retained for further consideration.

4.2.2 Site Access Restrictions

Site access restrictions involve measures to prevent access by unauthorized persons. Access could be prevented, for instance, for areas containing materials that exceed Site cleanup levels. Fencing, combined with warning signs, is the most common means of restricting access. Security patrols are sometimes included for high-risk areas but would not be warranted for this site. Fencing provides a physical barrier to site access. Warning signs discourage trespass by warning potential intruders of the hazards of entering the area.

Site access restrictions are retained for further consideration.

4.2.3 Alternate Water Supply

In cases where existing or future supply is impacted by site COCs, an alternative source of water can be provided. This could be bottled water or a piped source. For the Site, groundwater impacts are localized in shallow aquifers and buried slag has shown low leachability of chromium. No groundwater supply is affected, and there are no off-site groundwater impacts. Therefore, an alternate water supply is not retained as a remediation technology.

4.3 Monitoring

Site monitoring is usually a required component of a site remedy (including "no action") where COCs remain on site above cleanup levels. Short-term monitoring is conducted to ensure that potential risks to human health and the environment are controlled while a site remedy is being implemented. Long-term monitoring is conducted to measure the effectiveness of the remedy and thereby ensure that the remedy continues to be protective of human health and the environment. Long-term monitoring would include periodic inspection as necessary, to determine maintenance needs (e.g., for armoring, fencing, or surface water controls). A monitoring plan will be developed for the selected remedial action. The type of monitoring performed will depend on the nature of the remedy. Monitoring could include periodic sampling and analysis of soils, sediments, surface water, and groundwater, as appropriate.

4.4 Monitored Natural Attenuation

Monitored natural attenuation (MNA) involves natural processes (physical, chemical, and biological) that act without human intervention, and can include precipitation, sorption, and dispersion. Natural attenuation processes result in reduction of toxicity, mobility, and/or volume of COCs.

Natural attenuation processes typically occur at all sites. The degree of effectiveness varies depending on the types and concentrations of COCs present, the physical, chemical, and biological characteristics of the soil and groundwater, and the proximity of potential receptors. Where conditions are favorable, natural attenuation processes can reduce COC concentrations at sufficiently rapid rates to be integrated into a site's remedy. In some cases, natural attenuation can be sufficiently effective without the aid of other (active) remediation measures.

Natural attenuation is not a "walk-away" or "no action" alternative. It is an appropriate remediation approach where it is capable of achieving cleanup within a timeframe that is reasonable compared to that offered by other methods. It is often appropriate as a follow-up remedy to source control measures. It may be appropriate to monitor natural attenuation of COCs in groundwater and surface water when the source material has been removed or capped.

For the Site, Cr(VI) that leaches into the groundwater from the slag interacts chemically with the underlying geological and biogeochemical environment. As Cr(VI) migrates downward via infiltration from aerobic (vadose zone) to anaerobic conditions (groundwater), Cr(VI) undergoes attenuation (i.e., chemical reduction to Cr(III), precipitation of insoluble Cr(III) (hydr)oxide, and adsorption). The reduction of Cr(VI) is enhanced by the presence of methanogenic coal seams, which further promote the precipitation of solid-phase Cr(III) species or adsorption to mineral surfaces, including metal sulfide minerals commonly present in coal (Buerge and Hug 1997; Eary and Rai 1988; Thornton and Amonette 1999; Palmer and Puls 1994).

As a consequence of the various attenuation processes, Cr(VI) and total chromium concentrations decline prior to any vertical transport downward to the regional bedrock aquifer. Cr(VI) was not detected in the bedrock aquifer.

Groundwater discharges from the perched bedrock zones at seeps along the slopes of the uplands. Some of these seeps have elevated concentrations of Cr(VI) and total chromium. Water discharging at these seeps is supersaturated with respect to several minerals, principally hydroxyapatite [Ca5(PO4)3(OH)], calcite, and dolomite. These minerals precipitate following daylighting of the groundwater, forming accretions around seep locations and in the downstream drainage channel. Published literature indicates hydroxyapatite (and other calcium phosphates in the apatite minerals) have a significant capacity for removing metals (including chromium) from solution. Thus, attenuation of COCs continues after the groundwater discharges at seeps, which further limits the concentrations of metals migrating to Cross Creek.

The Valley Fill Aquifer is largely unimpacted with respect to chromium, with the exception of in the vicinity of MW-05 and MW-16. Sediments accumulated in abandoned stream channels likely caused holes in the clay layer in the vicinity of MW-05 and MW-16, allowing local downward transport of chromium-impacted water to the Valley Fill Aquifer. The Valley Fill Aquifer is characterized by mildly reducing geochemical conditions, promoting reduction of Cr(VI) and subsequent attenuation of contaminant mass, which limits chromium migration to Cross Creek. Surface water and groundwater from both the Interflow Zone and the Valley Fill Aquifer eventually discharge to Cross Creek. Extensive chemical and biological investigations have been performed to assess the effect of these discharges on Cross Creek, clearly showing that:

- Cr(VI) discharging into Cross Creek rapidly attenuates, and is not found outside the mixing zones
- A comparison of results for samples collected upstream and downstream of the Site show no measurable impact from Site discharges
- Biological habitat and creek ecological receptors have not been adversely affected by either surface water or groundwater discharges from the Site

MNA is retained for further consideration in conjunction with containment.

4.5 Containment

Containment is a general response action used to prevent exposure to material affected by COCs that are left in place, and to control migration of COCs. Containment will effectively mitigate COC migration by reducing the amount of stormwater contacting the slag. This will reduce the availability for leaching to occur and reduce the volume of leachate that may discharge (either by runoff or shallow perched groundwater) to Cross Creek. Containment technologies are identified and screened in this section.

4.5.1 Capping

In general, capping is a proven and effective technology for providing reliable long-term containment and preventing or minimizing off-site migration of COCs. Capping will prevent contamination of surface water by capped material. Capping will decrease infiltration through waste or affected soil, and thereby reducing the potential for COC migration into groundwater.

Caps may be constructed of a variety of natural materials and synthetic materials. Caps may consist of a single layer or be a composite of several layers including a synthetic flexible geomembrane layer as well as clay and other soil layers. Capping provides containment in three primary ways:

- As a physical barrier to prevent humans, other animals, and vegetation from coming in contact with materials affected by COCs.
- Preventing erosion of soil by surface water and wind, thereby preventing off-site transport of COCs.
- A vegetated soil cap or low-permeability cap reduces infiltration through waste, thereby decreasing the potential for migration of COCs from waste into groundwater.

Capping may be an appropriate technology for the final cap on slag. The capped area would be graded for stormwater drainage. The cap would incorporate surface water control features to minimize surface water ponding and erosion of the cap.

4.5.1.1 Vegetated Soil Cap

A vegetated soil cap consisting of 1.5 feet of clean fill and 0.5 feet of vegetated topsoil would increase evapotranspiration of precipitation, thereby reducing infiltration. Grading and other surface water controls installed to promote stormwater runoff would further reduce infiltration. Reduced infiltration would result in reduced leaching of slag, thereby reducing COC migration into underlying aquifers. Reduced migration of contaminants into groundwater would then result in reduced COC migration to eventual discharges to Cross Creek.

A vegetated soil cap is a proven and effective technology. It is readily implemented using standard design and construction techniques. It has lower cost than other cap options. A vegetated soil cap is retained for further consideration.

4.5.1.2 Low-Permeability Cap

Per OEPA guidance (OEPA 2000), a low-permeability cap would consist of two feet of low-permeability soil, a geomembrane liner, a one-foot granular fill drainage layer, and 2.5 feet of vegetated topsoil. It would reduce infiltration somewhat more than a vegetated soil cap, but because of a variety of factors (e.g., natural attenuation of Cr(VI) in leachate) would not be significantly more effective at decreasing risk to human health or the environment, especially considering that Cross Creek has not been adversely affected by the Site. It is readily implemented using standard design and construction techniques.

At the Site, a low-permeability cap is not needed. A vegetated soil cap would achieve the objective of reducing stormwater infiltration at much less cost. A vegetative soil cap would also be easier to construct and maintain. This technology is not retained.

4.5.1.3 Paving

Asphalt or concrete paving would prevent direct contact with slag and affected soil. It would have effectiveness (and minimize leaching) between a low-permeability cap and a vegetated soil cap.

A vegetated soil cap would achieve the objective of reducing stormwater infiltration at less cost. A vegetative soil cap would also be easier to construct and maintain. Paving is also subject to cracking (breaks in the paving, primarily due to freeze-thaw cycles), and thereby may be less effective than a vegetated soil cap. Therefore, paving is not retained for further consideration.

4.5.2 Surface Water Controls

Surface water management involves controlling surface water run-on and run-off at the site. The purpose of these controls is to minimize erosion that can entrain exposed soil affected by COCs and expose underlying affected materials. These controls may be used as short-term measures (e.g., during excavation), or as long-term measures (e.g., in conjunction with capping). Surface water controls can include:

- Grading
- Swales and ditches for surface water diversion
- Surface water deflector structures
- Dams to create sedimentation ponds
- Dams for surface water flow control (flood control).

Surface water controls are a proven technology and are effective. Many surface water controls are easily implemented and relatively inexpensive, although large dams can be difficult and expensive to construct. Surface water controls are retained for further consideration in conjunction with capping.

4.5.3 Vertical Barriers

Vertical barriers are intended to minimize lateral flow of groundwater or direct or contain groundwater flow to locations for collection and treatment, thereby preventing or minimizing migration and discharge of COCs to surface water. For reliable containment, vertical barriers should be keyed into a continuous low-permeability stratum or an artificial horizontal barrier to prevent migration underneath the vertical barrier. Slurry walls, sheet pile walls, and grout walls are established technologies for constructing vertical barriers under appropriate site conditions.

Groundwater contamination at the Site is localized and there are no off-site groundwater impacts. There are no measurable impacts to Cross Creek or other off-site receptors. Implementing a technology such as capping will reduce the amount of infiltration into slag that could potentially leach out contaminants, thereby reducing groundwater contamination and further reducing contaminant seepage into Cross Creek. Therefore, no vertical barrier technologies are retained.

4.5.4 Hydraulic Containment

Hydraulic containment involves pumping groundwater at a rate that limits its ability to flow laterally, which restricts the physical ability of contaminants to migrate. However, as explained in detail in Section 4.5.3, groundwater contamination at the Site is localized and there are no measurable impacts to Cross Creek or other off-site receptors. COC migration would be reduced sufficiently by capping. Hydraulic containment would be difficult to implement because of the hydrologic connection to the creek. Therefore, hydraulic containment is not retained.

4.6 Removal

Removal is a general response action for media affected by COCs prior to discharge, ex situ treatment, or disposal. Removal can be complete (i.e., all portions of soil or groundwater with constituents above remediation goals), or partial (i.e., the highest concentrations of COCs). Removal by itself is not a complete remedial action but must be combined with subsequent disposal or discharge of the removed media.

4.6.1 Excavation

Removal of slag or affected soil would involve excavation using standard earthmoving equipment. Excavation is feasible and implementable, generally at reasonable unit cost. Excavation of slag and affected soil is retained for further consideration in conjunction with capping or off-site disposal.

4.6.2 Removal of Groundwater

Groundwater removal would consist of extracting groundwater (pumping), and/or by intercepting groundwater surfacing in seeps. Groundwater extraction could be performed with extraction wells and/or extraction trenches. The affected groundwater would then be treated and discharged.

Groundwater contamination at the Site is localized and there are no measurable impacts to Cross Creek on a human health or ecological risk basis, even without the application of a remediation technology. Groundwater extraction would be difficult to implement because of the hydrologic connection to the creek. Therefore, groundwater extraction is not retained.

4.7 Treatment (Ex Situ and In Situ)

Treatment is intended to reduce the toxicity, mobility, or volume of material affected by COCs. Where metals are the COCs, the options for treatment are greatly reduced compared to organic COCs. Unlike organic compounds, metals are elements and cannot be destroyed. The best that can be done is to transform the metals into less mobile or less toxic compounds. Metal toxicity can be reduced via chemical conversion to a less toxic compound of the metal, and metals can be immobilized by fixation (stabilization). Treatment of groundwater can remove metals from the water, resulting in a solid waste for disposal.

Treatment (soil or groundwater) involving biological processes typically use bacteria or plants to reduce contaminant levels. Bioremediation does not destroy metals and often does not reduce the toxicity, mobility, or volume of metals in affected media. Biological treatment processes are unproven at scale for chromium. Non-biological processes would be more effective. Therefore, biological treatment technologies are not retained for soil or groundwater.

The same classes of treatment are generally available for both ex situ and in situ treatment. Ex situ processes are generally more reliable and easier to control but will generally require more operation and maintenance effort than in situ treatment.

4.7.1 Treatment of Slag and Affected Soil

4.7.1.1 Ex Situ Soil Washing

Slag and affected soil can be removed by excavation into a designated area where the material can be washed by acid to leach Cr(VI) from the slag and affected soil. Chemical additives such as sodium phosphate can then be added to reduce Cr(VI) to Cr(III) and immobilize Cr(III) to precipitates. It is likely that some of the treated material would still require capping.

Capping would reduce leaching from slag sufficiently without the additional waste streams created by soil washing. Some solid waste from the process would still require capping. The decrease in leaching would not significantly decrease risk to the environment at much higher cost than capping. Therefore, ex situ soil washing is not retained.

4.7.1.2 Ex Situ Metal Recovery Using Jig Separation

A Treatability Study by Cronimet dated July 15, 2017 was performed to test ex situ metal recovery. The concept is to reduce the volume of material requiring disposal and decrease the leachability of disposed material.

In this process, slag is excavated, crushed to a suitable maximum size, and run through a wet jig to separate metal based on specific gravity. The metal chromium is heavier than the slag and will fall to the bottom of the jig. Slag will discharge from the jig in a water slurry separately from the metal.

Recovered metal is recycled off-site. Contaminated water from the jig is treated and discharged. Treated slag is disposed on- or off-site.

Metal recovery decreased the volume of contaminated material less than 5%. As discussed in Appendix A, treated slag was tested for leachability and compared to leaching from RI samples. It was found that treated slag had an increase in leachability compared to untreated slag, and therefore would increase potential risk to human health and the environment. This technology is therefore rejected as ineffective.

4.7.1.3 In Situ Soil Flushing

Similar to ex situ soil washing, in situ soil flushing involves using chemical additives to leach Cr(VI) from slag and affected soils in situ, then injecting chemicals to reduce Cr(VI) to Cr(III) and immobilize Cr(III) to precipitates. This treatment is risky especially considering that groundwater is currently only slightly affected, and in situ acid washing and chemical injections could potentially increase the levels of groundwater contamination. Previous studies have also shown chromium does not readily leach from the slag. Therefore, in situ soil flushing is not retained.

4.7.1.4 Thermal Treatment (ex situ or in situ)

Most thermal treatment technologies are designed for destruction of organic compounds and are not applicable to metals. One thermal treatment technology, vitrification, was developed for encapsulation/stabilization of radionuclide wastes. However, both ex situ and in situ thermal treatment technologies are extremely expensive and have many operational difficulties. It has not been proven for use with mine wastes. Therefore, thermal treatment technologies are not retained.

4.7.2 Treatment of Groundwater

4.7.2.1 Pump and Treat

Pump and treat is a commonly used method for remediating groundwater contamination. Impacted groundwater is pumped via a series of wells or interception trenches. The collected water could be treated using one of a number of different processes. For Cr(VI) affected groundwater, typical treatment is reduction of Cr(VI) to Cr(III) followed by filtration to remove precipitated Cr(III). Ion exchange could also be used. Treated water is then discharged.

Dissolved contaminants in groundwater are not measurable in Cross Creek. On-site groundwater contamination is sufficiently managed by institutional controls. Groundwater contamination at the Site is localized and there are no measurable impacts to Cross Creek or other off-site receptors. Therefore, this technology is not retained.

4.7.2.2 In Situ Permeable Reactive Barrier (PRB)

A proven in situ technology for the treatment of Cr(VI) is the use of PRBs. PRBs are porous barriers installed within the impacted aquifer, perpendicular to the direction of groundwater flow. The PRB treats the groundwater as it flows away from the source past the PRB. Commonly, Cr(VI) is reduced by a reactive medium and subsequently precipitates as a Cr(III) hydroxide. PRBs are also passive systems that have low operation and maintenance costs. While PRBs present a viable, economical technology for groundwater remediation, groundwater contamination at the Site is localized and there are no measurable impacts to Cross Creek or other off-site receptors. Therefore, PRBs are not retained.

4.8 Disposal

Disposal is a general response action for the final disposition of excavated waste and affected soil or waste generated by treatment processes.

4.8.1 On-Site Disposal

On-site disposal would be protective of human health and the environment, and thus effective. It is implementable at a much lower cost than on-site treatment or off-site disposal. Therefore, on-site disposal in existing slag locations, including consolidation of these areas, is retained for further consideration.

4.8.2 Off-Site Disposal

It would be difficult and expensive to haul wastes off-site. In addition, hauling waste off-site would create the potential for off-site exposure via accidents during transportation. On-site disposal would be protective of human health and the environment. Therefore, off-site disposal is not retained for large quantities of slag. However, off-site disposal could be appropriate for some materials in small quantities.

TABLE 4-1
Identification and Screening of Remediation Technologies
Former Satralloy Site

General Response Actions	Options	Affected Media	Process Description	Effectiveness	Implementability	Relative Cost	Retain for Further Consideration	Reasons for Screening Decision
Institutional Controls	Use restrictions	Slag/Soil Groundwater Surface Water	Legal controls, including deed restrictions and governmental use restrictions, to limit or prevent activity that would lead to exposure, or damage to remedy, e.g., restrictions on use of site groundwater for drinking water or activities that would damage a cap.	Effective at eliminating risk due to exposure to constituents of concern.	Implementable	Low	Yes	Effective at limiting exposures and easily implementable at low cost.
	Site access restrictions	Slag/Soil Groundwater Surface Water	Prevention of access to affected area by fencing and warning signs.	Effective at limiting exposure by warning potential intruders of hazards.	Implementable	Low	Yes	Effective at limiting exposures and easily implementable at low cost.
	Alternate water supply	Groundwater	Supply of an alternate source of drinking water in cases where existing or future supply is impacted by Site COCs.	Effective at eliminating risk from exposure to COCs in drinking water.	Providing drinking water via bottled water or alternate piped source has poor implementability as a permanent remedy.	Moderate to High	No	Groundwater impacts are localized in shallow aquifers and buried slag has shown low leachability of chromium. No groundwater supply affected. No offsite impacts.
Monitoring	Monitoring	Groundwater Surface Water	Sampling and analysis of groundwater and surface water.	Effective at ensuring that the remedy continues to be protective.	Implementable	Low to Moderate	Yes	Required component of any remedy where COCs remain above cleanup levels after completion of remedy.
Monitored Natural Attenuation (MNA)	MNA	Groundwater Surface Water	Allow natural processes to gradually remove site contamination.	Groundwater impacts are localized in shallow aquifers and chromium that does leach from the buried slag rapidly attenuates in the subsurface or is sequestered in mineral precipitates.	Implementable	Low	Yes, as part of slag containment	Will occur naturally as part of slag containment. Cap installation will reduce the quantity of stormwater able to infiltrate to the slag deposits and leach chromium to groundwater.
Containment	Capping	Slag/Soil	Vegetated soil cap. Minimum of 1.5 feet of clean fill and 0.5 feet of vegetated topsoil.	Effective at preventing direct contact with slag and affected soil.	Readily implemented using standard design and construction techniques. Periodic maintenance required.	Low	Yes	Proven and effective technology.
		Slag/Soil	Low-permeability cap: Ohio EPA Recommended Final Cover (July 2000 Guidance Document). Minimum 2 feet low-permeability soil, a geomembrane liner, a 1 foot granular fill drainage layer, and 2.5 feet vegetated topsoil.	Effective at preventing direct contact with slag and affected soil.	Readily implemented using standard design and construction techniques. Periodic maintenance required.	High	No	Vegetated soil cap achieves objective of reducing stormwater infiltration at much less cost. A vegetative soil cap is easier to construct and maintain.
		Slag/Soil	Paving (asphalt or concrete)	Effective at preventing direct contact with slag and affected soil.	Readily implemented using standard design and construction techniques. High maintenance requirements under site conditions.	Moderate	No	A soil cover will be effective, more implementable, and easier to maintain at less cost.
	Surface water controls	Surface Water	Stormwater drainage controls	Effective at minimizing erosion of soil cover.	Readily implemented using standard design and construction techniques. Periodic maintenance required.	Low	Yes, as part of soil cover	Proven and effective technology.
	Vertical barriers	Groundwater	Slurry wall or similar impermeable wall around slag and/or affected soil.	Effective	Implementable, but difficult excavation in site soils.	High	No	COC migration reduced sufficiently by capping. Contaminated groundwater not measurably affecting Cross Creek or other off-site receptors.
	Hydraulic containment	Groundwater	Groundwater pumping	Potentially effective	Difficult to implement because of hydrologic connection to river.	High	No	COC migration reduced sufficiently by capping. Contaminated groundwater not measurably affecting Cross Creek or other off-site receptors.
Removal	Excavation	Slag/Soil	Standard excavating equipment such as backhoes, trenchers, bulldozers, and scrapers could be used.	Effective	Implementable	Low	Yes	Used in conjunction with capping or off-site disposal.

TABLE 4-1
Identification and Screening of Remediation Technologies
Former Satralloy Site

General Response Actions	Options	Affected Media	Process Description	Effectiveness	Implementability	Relative Cost	Retain for Further Consideration	Reasons for Screening Decision
	Groundwater removal	Groundwater	Pumping or intercepting seeps	Effective	Difficult to implement because of hydrologic connection to creek.	High (because treatment required after removal)	No	Groundwater contamination at the site is localized and there are no measurable impacts to Cross Creek on a human health or ecological risk basis, even without the application of a remediation technology.
Soil Treatment	Biological processes	Slag/Soil	Typically uses plants or bacteria products to accelerate biological degradation.	Not effective. Biodegradation does not destroy metals, and often does not reduce the toxicity, mobility, or volume of metals in affected media.	N/A	N/A	No	Does not destroy metals. Biological treatment processes are unproven at scale for chromium. Non-biological processes would be more effective.
	Ex situ soil washing	Slag/Soil	Excavate affected soils and use chemicals to leach chromium out from the soils and treat the leached material. Separate the soils and solution and treat the solution to precipitate chromium in trivalent form.	Potentially effective	Potentially implementable	Very high	No	Capping would reduce leaching from slag sufficiently without the additional waste streams created by soil washing. It is likely that some of the treated material would still require capping. Decrease in leaching would not significantly decrease risk to the environment at much higher cost than capping.
	Ex situ metal recovery using jig separation	Slag/Soil	Excavate slag, crush to suitable maximum size, run material through a wet jig to separate metal based on specific gravity. Recovered metal is recycled off-site. Contaminated water is treated and discharged. Treated slag is disposed on- or off-site.	Not effective because the Treatability Study (July 15, 2017) showed this treatment increased chromium leachability of slag.	N/A	N/A	No	Comparison of leach testing results in RI (untreated) samples vs. Treatability Study samples indicate a statistically significant increase in chromium leaching from Treatability Study samples compared to the RI samples.
	In situ soil washing		Flush water containing chemicals through slag and/or affected soils. Collect flushed water and treat.	Uncertain effectiveness (pilot study would be required). Likely ineffective due to low permeability of in situ slag. Depending on chemicals used, it could also present additional environmental risks.	Difficult	Very high	No	Unproven (most likely ineffective), poor implementability, and very high cost.
	Thermal treatment	Slag/Soil	Vitrification	Not proven for mine wastes	Difficult	Extremely high	No	Unproven, poor implementability, and very costly.
Groundwater Treatment	Biological processes	Groundwater	Typically uses plants or bacteria products to accelerate biological degradation.	Not effective. Biodegradation does not destroy metals, and often does not reduce the toxicity, mobility, or volume of metals in affected media.	N/A	N/A	No	Biodegradation does not effectively reduce metals contamination. Non-biological processes would be more effective.
	Pump and treat	Groundwater	Varies. Typically uses pump and treat with chemical reduction and filtration. Treated groundwater is then discharged.	Technologies that would be effective for this site (e.g., filtration through iron media) are available.	Implementable	High	No	Dissolved contaminants in groundwater not measurably affecting Cross Creek or other off-site receptors. On-site groundwater contamination sufficiently managed by institutional controls.
	In-situ Permeable Reactive Barrier (PRB)	Groundwater Surface Water	Intercept affected groundwater with a reactive barrier to reduce or remove groundwater contamination prior to leaving off-site.	Potentially effective	Implementable, but difficult installation in site soils.	High	No	Contaminated groundwater not measurably affecting Cross Creek or other off-site receptors. On-site groundwater contamination sufficiently managed by institutional controls.
Disposal	On-site	Slag/Soil	Placement under soil cover	See vegetated soil cap	Implementable	Low	Yes	See vegetated soil cap
	Off-site	Slag/Soil	Permitted landfill	Effective containment; possible exposure to COCs from accidents during transportation.	Implementable for small quantities; transportation difficulties for large quantities.	High	Not for large quantities of slag. Retained for small quantities.	On-site disposal effective and easier to implement at much lower cost. Could be appropriate for some materials in small quantities.

APPENDIX A – EVALUATION OF SLAG LEACH TEST RESULTS

TECHNICAL MEMORANDUM

DATE March 5, 2025

TO Lee Holder
WSP USA Inc.

CC

FROM Rens Verburg, Paul La Pointe **EMAIL rverburg@wsp.com**

RE: EVALUATION OF SLAG LEACH TEST RESULTS – FORMER SATRALLOY SITE

Introduction

This Technical Memorandum presents an evaluation of two sets of slag leach test results:

- Twelve slag samples collected and tested as part of the Satralloy Remedial Investigation ("RI samples") (Golder 2023)
- Ten processed slag samples tested as part of the Cronimet Treatability Study ("Cronimet samples") (Cronimet 2017)

The slag processing by Cronimet consisted of screening and crushing, followed by density separation using an air pulsed jig to recover chromium. The resulting waste product (i.e., the Cronimet samples consisting of processed slag) was subjected to a testing program that included chemical analysis (including total chromium), determination of the hexavalent chromium content, and leach testing using the Synthetic Precipitation Leaching Procedure (SPLP - EPA Method 1312). The RI samples underwent the same suite of tests as part of the geochemical characterization program conducted during the RI program.

The principal objective of this assessment was to determine whether the leachability of the two sample sets differed in any way.

Approach

Two populations are similar if they have statistically similar means, standard deviations, and distributional forms. There are many statistical tests (EPA 2009) to compare populations, though some of the tests assume particular distributional forms, such as Normal or Lognormal, and equality of variances, while others do not have as stringent requirements. The first step in the analysis, Exploratory Data Analysis (EDA), was to examine the distributional form of the data, identify possible outliers, and assess the equality of variances. This was followed by a second stage, Data Set Comparisons, in which statistical tests appropriate with the findings in the first set of analyses were carried out to assess whether the populations were statistically similar or not. All statistical tests were carried out with probability values of $\alpha = 0.05$ to test the statistical Null Hypotheses. If the probability of a statistical test result was 0.05 or less, the Null Hypothesis was rejected ("Reject"); otherwise, the Null Hypothesis was not rejected ("Failure to Reject"). All statistical tests were carried out using EPA or commercial statistical software.

Table 1 presents the analytical results for the RI and Cronimet samples (from Table 5.1-1C in Golder 2023 and Appendix G in Cronimet 2017, respectively). Figures 1 through 3 show the general relationships between solid-phase chromium content, solid-phase hexavalent chromium content, and chromium leachability as determined from the SPLP.

Table 1. Chromium Results

RI Slag					Cronimet Processed Slag			
Sample	**total Cr (mg/kg)**	**hex Cr (mg/kg)**	**SPLP Cr (mg/L)**		**Sample**	**total Cr (mg/kg)**	**hex Cr (mg/kg)**	**SPLP Cr (mg/L)**
SLGBH-01	1,300	104	0.29		S1	1,800	280	0.62
SLGBH-01	1,600	193	0.055		S2	2,400	44	0.56
SLGBH-02	2,700	181	0.34		S3	2,200	2.6	0.73
SLGBH-02	690	55.3	0.38		S4	1,200	220	0.33
SLGBH-03	2,300	134	0.54		S5	550	62	0.31
SLGBH-03	310	19.2	0.14		S6	1,300	3.3	0.32
SLGBH-04	690	68.7	0.096		S7	3,100	300	0.55
SLGBH-04	1,700	66.3	0.19		S8	1,700	18	0.32
SLGBH-04	11,000	270	0.14		S9	420	24	0.11
SLGBH-04	540	20	0.023		S10	530	9.2	0.07
SLGBH-05	69		0.038					
SLGBH-06	41	0.307	0.036					

Figure 1. SPLP Leachability vs Total Chromium

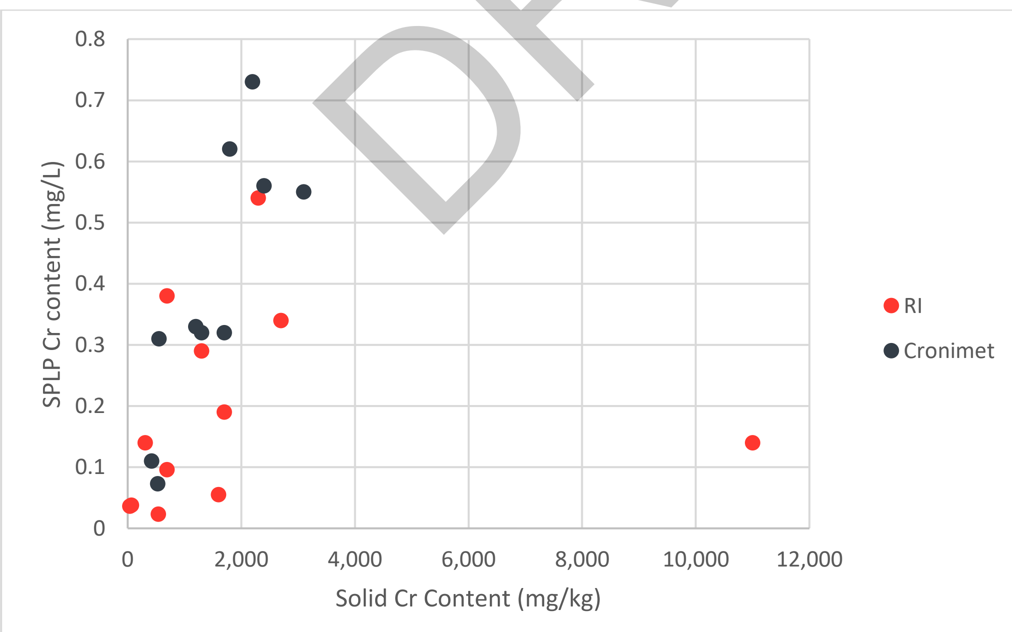


Figure 2. SPLP Leachability vs Hexavalent Chromium

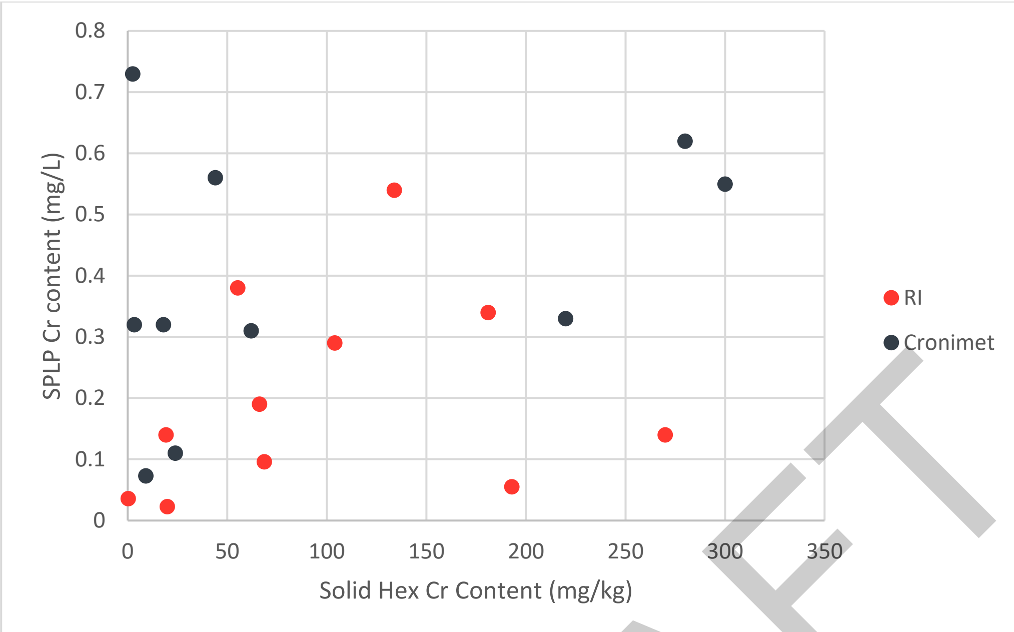
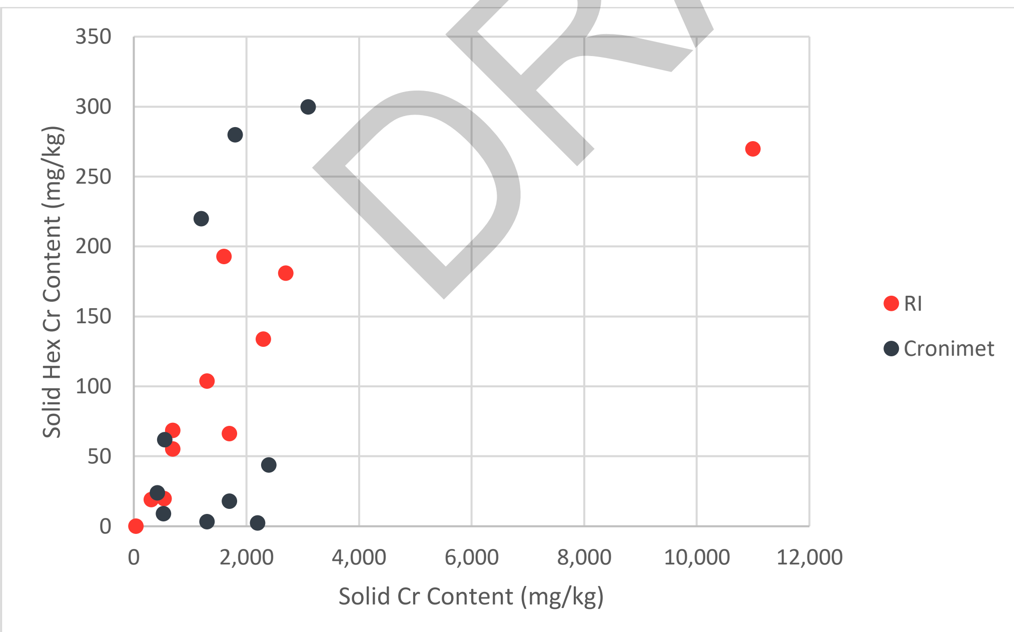


Figure 3. Hexavalent Chromium vs Total Chromium in Solid Samples



Results

Exploratory Data Analyses

Table 2 presents the analytical results for testing different common probability distributions (Normal, Lognormal and Gamma) using EPA's ProUCL V 5 software. The RI and Cronimet sample values were taken from Table 5.1-1C in Golder 2023 and Appendix G in Cronimet 2017, respectively). Shapiro Wilk and Lilliefors tests were used to assess the Normal and Gamma distributions, while Anderson-Darling and Kolmogorov-Smirnoff tests were used to assess Lognormality.

Table 2. Goodness-of-Fit Testing Results

Data Set	Parameter	Normal	Lognormal	Gaussian
Cronimet	Cr Total	FR	FR	FR
RI Slag	Cr Total	R*	FR	FR
Cronimet	Cr Hex	R	FR	FR
RI Slag	Cr Hex	FR	R	FR
Cronimet	Cr SPLP	FR	FR	FR
RI Slag	Cr SPLP	FR	FR	FR

*Data is Normal if outlier removed
FR = Failure to Reject the Null Hypothesis
R = Reject Null Hypothesis

The results shown in the table are a mix of rejection (R) and failure to reject (FR). A failure to reject indicates that the data can be represented by the assumed distribution. As the number of samples varies from 10 to 12, depending upon the data set and parameter, the statistical power may be a potential reason for failure to reject in some cases. The statistical power was not further investigated because non-parametric tests were eventually selected, so the distributional form became moot.

As can be seen in Figures 1 and 3, the RI data set contains an anomalous sample (SLGBH-04). This data set was subjected to the EPA-recommended Dixon's Test for outlier detection (EPA 2009), and the sample value of 11,000 was found to be an outlier at both 0.05 and 0.01 probability values.

Equality of variances were tested using the F-test. The results of these tests are shown in Table 3.

Table 3. F-Test Results

Parameter	Test Probability	Decision
Cr Total	0.001	R
Cr Total (minus outlier)	0.981	FR
Cr Hex	0.098	FR
Cr SPLP	0.482	FR

FR = Failure to Reject the Null Hypothesis
R = Reject Null Hypothesis

A T-test could be used to test the similarity of the means for the Cr SPLP data and for the Cr Total data if the outlier can be justifiably removed, as these two data sets would satisfy the equality of variances and Normality assumptions underlying the test. However, it is not known if the anomalously high RI Slag value represents a laboratory error or other data issue, or just a high value. Moreover, the Cr Hex data is not uniformly Normal or Lognormal, and there are no statistically detected or visually obvious outliers, so the T-test would be inappropriate. For these reasons, non-parametric tests were used to assess the statistical similarity of the Cronimet and RI data sets for all parameters.

Data Set Comparisons

The data sets were compared using the Wilcoxon-Mann-Whitney test (EPA 2009). The Null Hypothesis in this test is that the medians of the two data sets are the same. The results are shown in Table 4. The full data sets were used; no outliers were removed from the data.

Table 4. Wilcoxon-Mann-Whitney Test Results

Parameter	Test Probability	Decision
Cr Total	0.539	FR
Cr Hex	0.557	FR
Cr SPLP	0.030	R

FR = Failure to Reject the Null Hypothesis
R = Reject Null Hypothesis

The results show that the Cr Total and Cr Hex data sets are statistically similar at the 0.05 level, while the Cr SPLP data sets are not. Figure 4 shows that the leachability (SPLP Cr) in the Cronimet data set is distinctly higher than in the RI Slag data set.

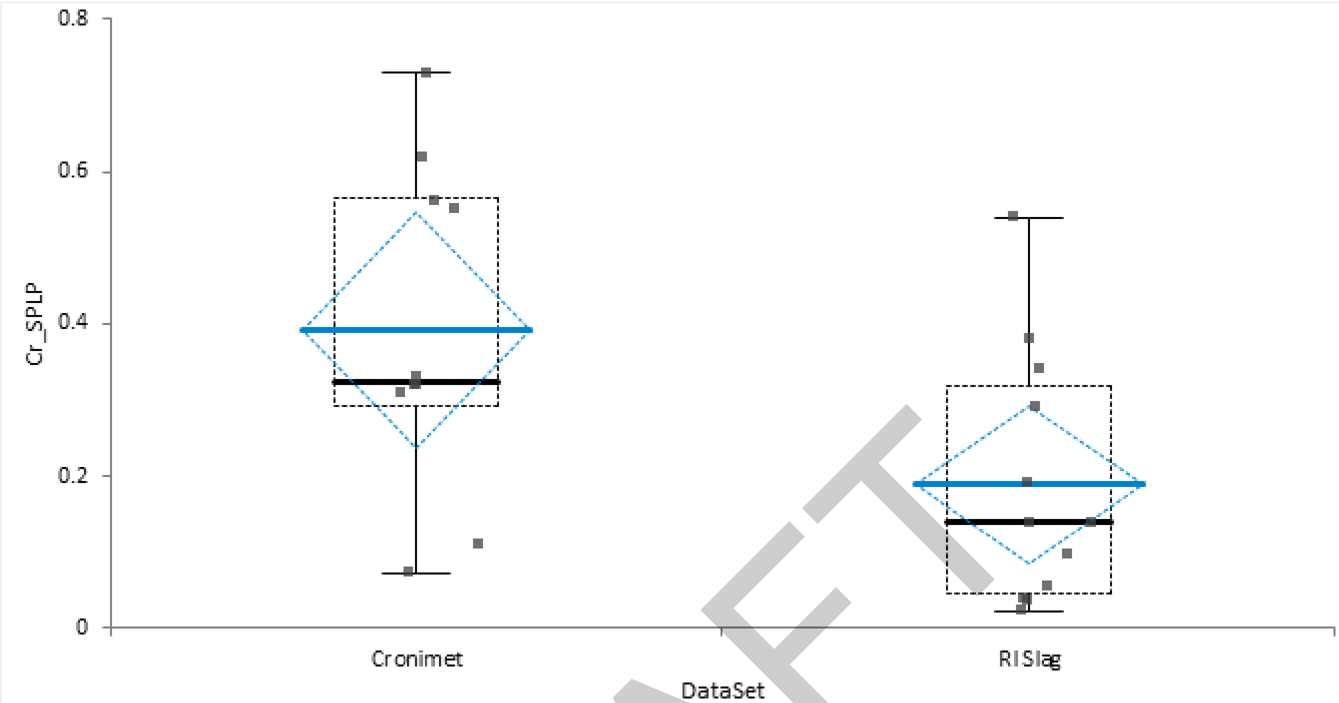


Figure 4. Box-and-Whisker Plots of Cronimet and RI Slag Cr SPLP Data

As shown in Figure 5, chromium leachability is correlated with solid-phase chromium content for both sample sets, while correlation between leachability and solid-phase hexavalent chromium content is less pronounced (Figure 6). Correlation between solid-phase chromium and hexavalent chromium content is good for the RI samples and less so for the Cronimet samples (Figure 7).

Figure 5. Correlation of SPLP Leachability to Total Chromium

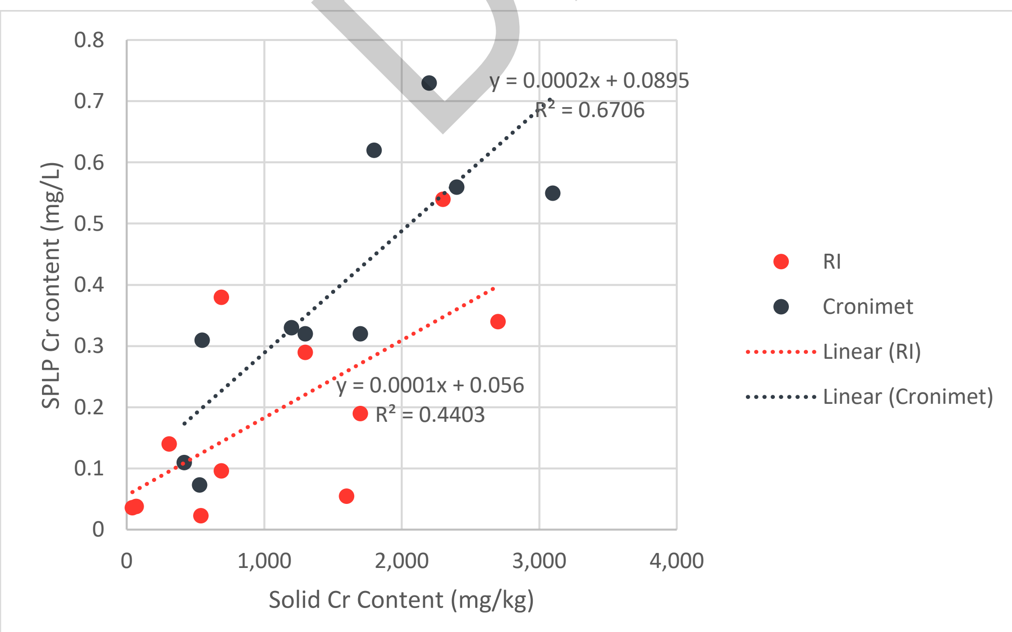


Figure 6. Correlation of SPLP Leachability to Hexavalent Chromium

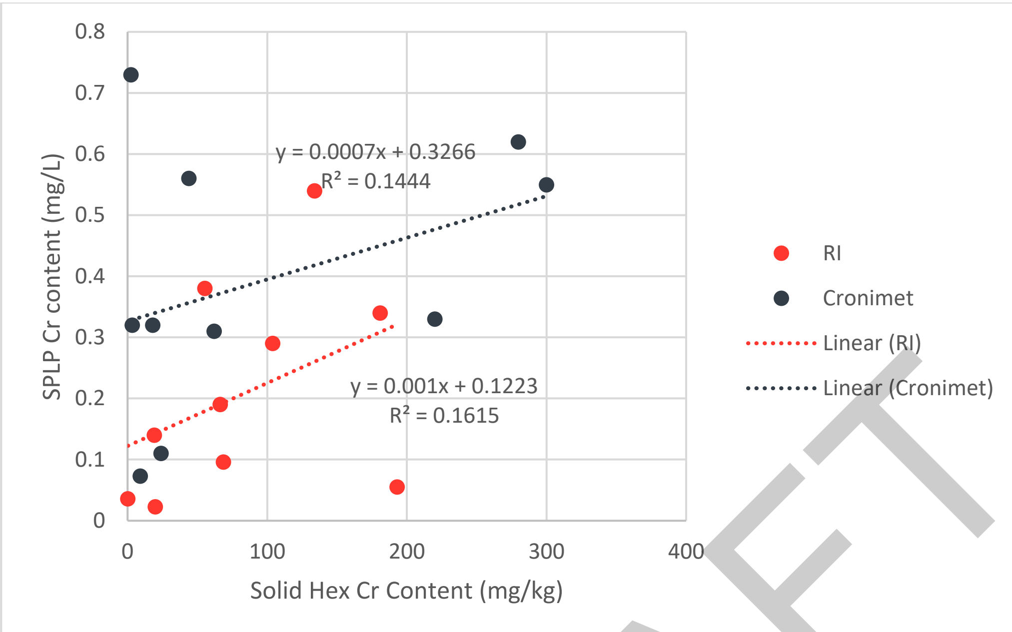
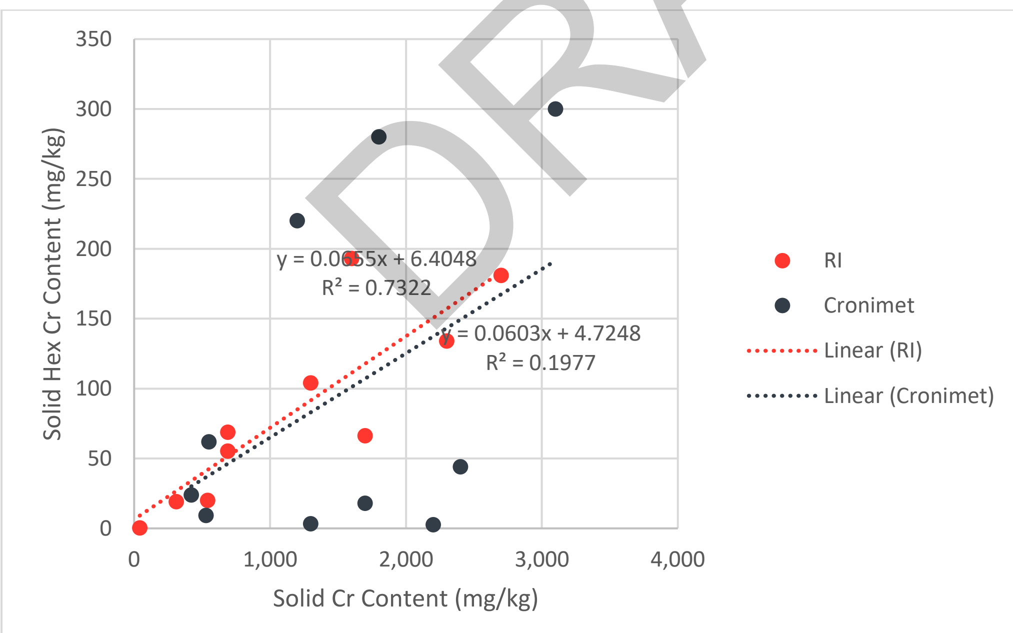


Figure 7. Correlation of Hexavalent Chromium to Total Chromium in Solid Samples



The test results indicate that there is no statistically significant difference between the RI and Cronimet data sets for solid-phase total chromium and solid-phase hexavalent chromium content, regardless of whether the anomalous RI sample is included. For the SPLP chromium results, a statistically significant difference is observed, with the Cronimet samples leaching more chromium than the RI samples.

Discussion

The results from the Wilcoxon-Mann-Whitney tests indicate that the RI slag sample set and Cronimet processed slag sample set are statistically similar in terms of their solid-phase total chromium and hexavalent chromium contents. However, the chromium leachability of the Cronimet sample set is higher than that of the RI sample set.

The increased leachability of the Cronimet processed slag may be attributed to the sieving, crushing, and jigging undergone by the Cronimet samples. These activities resulted in processed slag samples with a grain size between 8 and 25 mm, thereby likely enhancing the reactivity of the material by increasing its surface area. It should be noted that the SPLP procedure also requires screening and/or crushing, to a grain size < 9.5 mm. Although this would seem to nullify the grain size effect caused by the slag processing, the Cronimet samples were subject to more disturbance than the RI samples, in the form of additional active crushing and jigging during the processing.

Alternatively, or in addition, the processing of the Cronimet samples resulted in removal of the “metal” (i.e., FeCr) from the slag (Cronimet 2017). Although no leach test information is available for just the metal fraction of the slag, it can be assumed that this component is much less leachable than the non-metal portion. As such, for an equivalent content of solid-phase chromium, processed slag is likely to consist of a higher proportion of leachable material than non-processed slag.

Conclusions

Statistical comparison of two sample sets consisting of untreated (RI) slag and Cronimet processed slag has demonstrated that the latter is more leachable. Although a detailed investigation as to the cause(s) was not conducted, the enhanced disturbance during the metal recovery process and/or the removal of the most insoluble fraction from the processed slag may provide an explanation.

References

Cronimet. 2017. Results – Treatability Study of Ferrochrome Slag, Former Satralloy Mine Site, Mingo Junction, OH. July 15, 2017.

United States Environmental Protection Agency (EPA). 2009. Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities Unified Guidance. EPA 530/R-09-007.

Golder Associates USA Inc. (Golder). 2023. Remedial Investigation Report for the Former Satralloy Site, Jefferson County, Ohio. May 17, 2023.

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