LEACHATE CHARACTERISTICS OF WASTE ARISING FROM THE LAND REMEDIATION OF A FORMER STEELWORKS

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SUMMARY: The steelworks at Ravenscraig, Lanarkshire closed in 1992 after 35 years of steel making. Management of the environmental legacy of the 400-hectare site to enable future redevelopment posed a significant challenge to the owner. The Best Practical Environmental Option was to construct a complex engineered secure containment facility (SCF) to take the 1.2 million m^3 of contaminated materials identified on site. The land remediation and SCF was completed in 1998 and this paper describes the contaminants contained within the SCF, the quality of the subsequent leachate and its treatment in a purpose designed treatment plant.

1. INTRODUCTION

Ravenscraig was a fully integrated iron and steelworks, which included ore stockyards, sinter plant, lime plant, coke ovens, a power station and rolling mills as well as blast furnaces and BOS (Basic Oxygen Steelmaking) furnaces. Contamination was identified in ten principal areas contained within or on made ground comprising slag, clay or construction hardcore. These areas were of three main types, raw material stockyards, operational areas and waste or by-product stockpiles or lagoons. The raw material stockyards contaminants included arsenic and aromatic compounds; the operational areas contained oils, aromatic compounds, toxic metals and inorganic compounds; and the waste product areas comprised filter cakes, sludges and lagoon dredgings containing oils, aromatic compounds, toxic metals and inorganic compounds. Also included in the remediation works was the disposal within the SCF of asbestos from the plant demolition and significant quantities of complexed cyanide residues from the coke oven gas distribution network. These required special handling and disposal procedures within the SCF and influenced details of the SCF engineering design.

The quality of the leachate has been monitored since March 1997 with on-site testing during the operational phase of the SCF and the construction of a leachate treatment plant. The leachate treatment plant includes oil separators, pH controlled settlement, rotating biological contactors, a contingency facility for cyanide treatment (not required to date), and a reed bed. It also treats contaminated groundwater, which is mixed with the leachate. This plant treats the leachate prior to discharge to the South Calder Water and since commissioning of the plant in January 1998,

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laboratory testing of the leachate and the treated effluent has been conducted to demonstrate the efficacy of the treatment plant and compliance with the discharge consent.

2. WASTE COMPOSITION

A comprehensive desktop study and site investigation was carried out prior to the design and implementation of the remediation programme from which an understanding of the potential leachate quality from the waste was ascertained. These investigations identified the principal areas of contamination and characteristics as described below:

2.1 Identified Areas for Remediation

2.1.1 Area 1: South Calder Lagoon Dredgings

A lagoon existed on the South Calder Water that encouraged silts to form from the surface water run-offs around the site. This had been periodically dredged and the deposits were stockpiled in this area. The primary chemical hazards were lead, arsenic and cadmium.

2.1.2 Area 2: Former Oil Slurry Lagoons

Two lagoons had been constructed where oil slurries were deposited and the primary chemical hazards identified were polycyclic aromatic hydrocarbons, benzene, xylene, toluene and styrene as well as flammable gases and toxic organic vapours. During the remediation of the area, construction waste and barrels, etc were also found within the lagoons.

2.1.3 Areas 3 and 4: BOS Filter Cake and Blast Furnace Filter Cake

These two areas were used as stockpiles for the filter cakes formed from the steelmaking process and the primary chemical hazards were cadmium and lime for the BOS filter cake and cadmium, arsenic and lead for the blast furnace filter cake. Because of their high alkalinity, up to pH 12.5, their particle size distribution and their permeability, they were used as part of the engineered design of the SCF in the form of liner protection and drainage layer. Their alkalinity also provided a means of stabilising metals by precipitation, and any cyanide leaching from the waste mass.

2.1.4 Areas 5 and 6: Lanarkshire Lagoons and Dalzell Oil Catchment Ponds

This was a large, grossly contaminated area arising from waste management licensed lagoons formed to deposit sludges and slurries from the steelworks. Although much of the area had been capped there were still two open lagoons and both the capped and open areas presented a considerable obstacle to redevelopment. The primary chemical hazards identified were polycyclic aromatic hydrocarbons, metals, volatile organic contaminants as well as potential flammable gases and toxic organic vapours that included methane, benzene, hydrogen cyanide and hydrogen sulphide.

2.1.5 Area 7: By-products Plant

This area was primarily concerned with the production and cleaning of coke oven gas. The cleaning process recovered, and in some cases refined for commercial production, coal tars, benzene, toluene, xylene, naphthalene, and ammonia and ammonium sulphate. Also within the area was a primary water treatment plant for separation of oils from various effluents. This area was grossly contaminated to depth and it was agreed with the regulator that excavation would be limited to 6m in depth and backfilled with clean clay, the waste material comprised contaminated soils, perched waters and substructures. Other hazards included potential flammable and toxic gases including methane, benzene, toluene, hydrogen cyanide and hydrogen sulphide.

2.1.6 Areas 8 and 9: Southern Coal Stockyard and Ore Stockyard

These two areas were the stockpile areas for the raw materials used in the steelmaking process and some contamination of the ground had been identified caused by the leaching of the raw materials and supplementary fuels by rain. The worst affected area was the Southern Coal Stockyard where polycyclic aromatic hydrocarbons, benzene, xylene and toluene had been found whilst only arsenic was identified as a primary hazard in parts of the Ore Stockyard.

2.1.7 Area 10: Gas Seal Pots

A network of large diameter, overhead, pipes delivered coke oven gas around the plant for the steelmaking process. At frequent intervals, small pipes from the overhead lines allowed condensate from the gas to discharge into gas seal pots and then dispersed into the ground. The condensate from coke oven gas includes cyanides, metals and polycyclic aromatic hydrocarbons. There were in excess of 120 gas seal pots around the plant.

2.1.8 Demolition Waste

Running concurrently with the land remediation was the demolition of the steel works. Some parts of the plant were dismantled and sold to other facilities around the world but the majority was broken up and sold for recycling. However, there were some elements that were hazardous and were disposed within the SCF including some of the overhead gas lines containing cyanide residues, sheet asbestos and asbestos lined pipes and fittings.

2.2 Quantities of Waste Generated from the Remediation Areas

Table 1 provides a comparison of the anticipated volumes of waste for each of the areas at the design stage and the actual volumes excavated during the remediation phase. Whilst, there is an increase in the actual volume excavated it does show the effectiveness of the initial assessment of the extent of contamination in the made ground.

Table 1 – Waste Quantities from Remediation Areas

Remediation Areas	Design Estimates (m^3)	Actual Volumes (m^3)
Area 1: South Calder Lagoon Dredgings	40,000	31,448
Area 2: Former Oil Slurry Lagoons	60,000	84,247
Area 3: BOS Filter Cake	440,000	367,020
Area 4: Blast Furnace Filter Cake	180,000	249,908
Area 5: Lanarkshire Lagoons	200,000	338,172
Area 6: Dalzell Oil Catchment Ponds	2,000	5,992
Area 7: By-products Plant	310,000	261,880
Area 8: Southern Coal Stockyard	5,000	2,575
Area 9: Ore Stockyard	4,000	3,059
Area 10: Gas Seal Pots	7,000	9,535
Demolition Waste	50,000	51,990
Total Waste Generated	1,298,000	1,405,826

2.3 Contaminants Found in the Remediation Areas

2.2.1 *Contaminants found in soils and waste material*

As can be clearly seen in the preceding section, there were a wide range of contaminants and hazards found in the various areas including toxic and phytotoxic metals, inorganic non-metallic compounds, and major volatile and semi-volatile organic contaminants. Table 2 (below) sets out the chemical data from laboratory analyses for the three largest source areas of the site, Areas 3, 5 and 7. These provide a representative characterisation of the waste within the SCF.

Table 2 – Chemical Characteristics of Soils from Selected Remediation Areas

Determinand	Area 3: BOS Filter Cake ($mg\ kg^{-1}$)*	Area 5: Lanarkshire Lagoons ($mg\ kg^{-1}$)*	Area 7: By-products Plant ($mg\ kg^{-1}$)*
pH	12.6	-	10.0
Leached/Ammonia (NH_3-N) $mg\ l^{-1}$	-	30	72
Sulphur (S)	-	-	21120
Sulphide (S^{2-})	-	6	110
Total Sulphate (SO_4)	1.09%	0.2%	14% max.
Total Boron (B)	<1	19	18
Soluble Boron (B)	-	32	18
Solvent Extractable Material	125	400-120000	238-49300
Benzene	-	<10-990 ($\mu g\ l^{-1}$)	<1-1400 ($\mu g\ l^{-1}$)
Toluene	-	<10-710 ($\mu g\ l^{-1}$)	<1-650 ($\mu g\ l^{-1}$)
Xylene	-	<10-190 ($\mu g\ l^{-1}$)	<1-230 ($\mu g\ l^{-1}$)
Sodium (Na)	4450-10900	-	-
Potassium (K)	1350-14000	-	-
Calcium (Ca)	32000-63000	-	-
Iron (Fe)	600000	-	-
Manganese (Mn)	<1-17	-	-
Cadmium (Cd)	4-23	1	<1
Chromium (Cr)	<1-30	190	340
Copper (Cu)	31-94	120	68
Nickel (Ni)	37-65	93	38
Lead (Pb)	14-79	310	330
Zinc (Zn)	137-987	1520	360
Arsenic (As)	13-17	26	10
Mercury (Hg)	1.1-2.5	0.1	<1
Total Cyanide	-	370	142
Thiocyanide	-	50	26
Cyclohexane Extract		<10-60 ($\mu g\ l^{-1}$)	-

Note: * single figures indicate the average concentration of the contaminant unless otherwise shown

Table 3 – Chemical Characteristics of Waters from Selected Remediation Areas

Determinand	Area 5: Lanarkshire Lagoons ($mg\ l^{-1}$)*	Area 7: By-products Plant ($mg\ l^{-1}$)*
Ammonia (NH_3-N) $mg\ l^{-1}$	27 (231)	84 (554)
Sulphate (SO_4)	100 (750)	350 (1500)
Arsenic (As)	19 (190)	14 (200)
Cadmium (Cd)	<1.0 (<1.0)	9800 (127000)
Chromium (Cr)	<1.0 (<1.0)	980 (11000)
Lead (Pb)	28 (510)	110 (2550)
Mercury (Hg)	<1.0 (<1.0)	130 (1660)
Selenium (Se)	20 (190)	120 (1510)
Boron (B)	210 (550)	83 (330)
Copper (Cu)	5 (100)	22 (530)
Nickel (Ni)	60 (270)	43 (830)
Zinc (Zn)	570 (6200)	5500 (123000)
Free Cyanide	850 (10000)	52 (1170)
Thiocyanate	230 (26100)	39 (176)
Total Organic Carbon	150 (880)	68 (170)
Mineral Oil	6700 (62000)	98000 (864000 *free oil*)
Aromatic Hydrocarbons	1600 (11000)	9160 (84000)
NSO Resins	5700 (21000)	7150 (63000)
Total Phenols	5400 (25000)	5.6 (34)
Benzene	10-990 ($\mu\ l^{-1}$)	266-460000 ($\mu\ l^{-1}$)
Toluene	10-710 ($\mu\ l^{-1}$)	581-330000 ($\mu\ l^{-1}$)
Xylenes	10-190 ($\mu\ l^{-1}$)	227-250000 ($\mu\ l^{-1}$)

Note: * indicates the average concentration of the contaminant with the maximum concentration in brackets.

2.2.2 *Contaminants found in waters within the waste material*

Areas 5 and 7 also had a significant quantity of grossly contaminated water found either as perched water within the waste material, or underlying made ground, or as free product in ducts and service pipes. In Area 5 this was apparent as black aromatic oily water and in Area 7 as aromatic, green, luminescent wash oil both of which presented a significant hazard. Where possible and in most cases, these waters were collected and sent for onward disposal at a water treatment plant but where this was not practical they were mixed with the surrounding contaminated soils and sent to the SCF. Table 3 sets out the more significant contaminants found in these waters.

3. LEACHATE QUALITY

Having established the composition and nature of the wastes it is necessary to understand the engineering design of the disposal facility and how this affects the quality and quantity of the leachate produced at the site. Once this has been established, an understanding of the characteristics of the leachate can be formed.

3.1 Secure Containment Facility (SCF) Design (Ref 1)

The SCF was constructed on the site in an area previously used for cooling slag and recovering iron from the steelmaking process prior to being stockpiled. This area enabled the SCF to be constructed against an existing screening hill that had been required during ongoing steelmaking. The location was at least 15m above the maximum seasonal groundwater level.

The liner design was a tri-composite liner comprising, from top to bottom, a 2mm thick fully welded textured HDPE membrane, a 1m thick, engineered clay layer and, finally, a 1mm thick fully welded HDPE membrane. Similarly, the capping was a composite system comprising from top to bottom a 2mm thick textured HDPE membrane overlaying 1m thick, engineered clay layer. Both liner and capping were installed under construction quality assurance (CQA) thus providing a robust, engineered system that would ensure that leakage would be minimal, if at all. Subsequent groundwater monitoring over the past 6 years from perimeter boreholes and underlying pressure vacuum lysimeters (PVLs) indicate that no significant detectable leakage has occurred to date.

A key feature of the design was to utilise the alkaline BOS and blast furnace filter cakes as a 1m thick buffer layer between the liner, and capping, and the waste mass. During the disposal phase this layer acted as a liner protection layer and to act as a stable platform for the capping installation. However, the main purpose of the buffer layer was to act as a leachate drainage pathway and, critically, to ensure that the leachate retained a high pH, above 9.0, to precipitate toxic metals and ensure that any cyanide that was released from the waste mass remained in a stable form.

In Scotland, leachate generation at restored landfills with engineered caps can average between 5-10% of the adjusted rainfall figure, adjusted for evaporation and transpiration. On this basis the SCF, with an effective area of around 40 ha, would have a potential daily leachate production in the order of 50-100 m^3 day^{-1}. However, because of the robust design and the nature of the waste mass the actual leachate generation rate following restoration is only $14m^3$ day^{-1}. This suggests an infiltration rate of only 1-2% of the adjusted rainfall figure and on-site observations indicate that most of the infiltration is at the combined leachate and gas venting wells that penetrate the capping.

3.2 Leachate Quality

The leachate has been sampled and analysed at an independent laboratory regularly for the last 6 years and the results for the last 4 years have been summarised in Table 4, Ravenscraig SCF Leachate Quality. The determinands have been selected to reflect the composition of the waste with the key pollutant indicators being pH, chemical oxygen demand (COD), ammoniacal nitrogen and total cyanide. At the same time, the leachate is inspected for visible signs of oil but to date no sign has been recorded. On a less frequent basis, electrical conductivity, metals and organics are sampled and analysed to establish any new trends in the leaching of the waste mass particularly associated with free cyanide and metals.

In general, the quality of leachate does not reflect the extent of contamination in the waste mass and the main treatment requirements for the leachate are for pH control, and COD and ammonia removal prior to discharge. There are no significant signs of toxic metals leaching out of the waste with only sodium, potassium and calcium appearing at elevated levels. These contaminants are relatively benign and remain soluble in alkaline water, indeed they are probably largely derived from the BOS filter cake drainage layer.

This further suggests that ingress of water is limited to around the leachate wells and subsequent leaching of the buffer layer BOS filter cake material that is the only waste type with significant levels of these elements.

Table 4 - Ravenscraig SCF Leachate Quality

Determinand	Nº of Samples	Maxima	Minima	Mean	Median	Standard Deviation
pH	204	12.0	8.0	9.9	9.8	0.8
Suspended Solids mg l^{-1}	83	100.0	5.0	12.7	8.0	14.7
Electrical Conductivity (EC) µS	32	3060.0	1515.0	2255.2	2224.5	403.2
Ammonia (NH_3-N) mg l^{-1}	204	27.1	0.2	11.4	11.3	3.3
Biochemical Oxygen Demand (BOD) mg l^{-1}	11	7.5	<2.0	<2.0	5.2	3.3
Chemical Oxygen Demand (COD) mg l^{-1}	203	87.0	8.0	44.2	44.0	13.6
Total Sulphur as SO_4 mg l^{-1}	11	860.0	510.0	712.9	711.0	130.9
Sulphide	11	<2.0	<2.0	<2.0	<2.0	-
Alkalinity as $CaCO_3$ mg l^{-1}	11	94.0	47.0	66.7	58.0	15.7
Total Organic Nitrogen (TON) mg l^{-1}	11	32.2	3.0	18.7	20.0	8.3
Total Organic Carbon (TOC) mg l^{-1}	10	36.0	9.7	16.6	14.5	7.7
Sodium (Na) mg l^{-1}	11	152.0	83.6	120.7	120	22.4
Potassium (K) mg l^{-1}	11	366.0	176.0	264.1	266.0	61.8
Calcium (Ca) mg l^{-1}	11	207.0	130.0	163.6	157.0	29.2
Magnesium (Mg) mg l^{-1}	11	10.3	1.0	5.5	6.7	3.1
Iron (Fe)	5	0.3	0.2	0.2	0.2	0.1
Manganese (Mn) mg l^{-1}	6	<0.01	<0.01	<0.01	<0.01	-
Cadmium (Cd) mg l^{-1}	6	<0.01	<0.01	<0.01	<0.01	-
Chromium (Cr) mg l^{-1}	5	<0.02	<0.02	<0.02	<0.02	-
Copper (Cu) mg l^{-1}	6	<0.01	<0.01	<0.01	<0.01	-
Nickel (Ni) mg l^{-1}	6	<0.02	<0.02	<0.02	<0.02	-
Lead (Pb) mg l^{-1}	6	<0.03	<0.03	<0.03	<0.03	-
Zinc (Zn) mg l^{-1}	6	<0.01	<0.01	<0.01	<0.01	-
Total CN mg l^{-1}	200	5.4	0.2	1.2	1.2	0.6
Free Cyanide mg l^{-1}	93	0.8	0	0.2	0.2	0.2
Thiocyanite mg l^{-1}	11	2.2	<0.01	1.3	1.0	0.6
Free Oil mg l^{-1}	83	1.1	0.2	0.4	0.3	0.2
Total Oil mg l^{-1}	55	3.1	0.4	0.9	0.8	0.5
Phenol Index mg l^{-1}	11	<0.05	<0.05	<0.05	<0.05	-
Cyclohexane Extract mg l^{-1}	11	15.0	<1.0	5.0	3.0	5.6

Note: There is downward trend of all elevated determinands.

The quality of leachate also appears to be improving with time with a 10% reduction in levels each year for the elevated determinands and a reduction from pH 10.3 to pH 9.3 over a four-year period. It will be interesting to see if, with further reduction of the pH, the metals start to mobilise in the waste mass and start to appear in the leachate or, as is suggested, the leachate is generated from the ingress of rain at the leachate wells where leaching will be progressively exhausted.

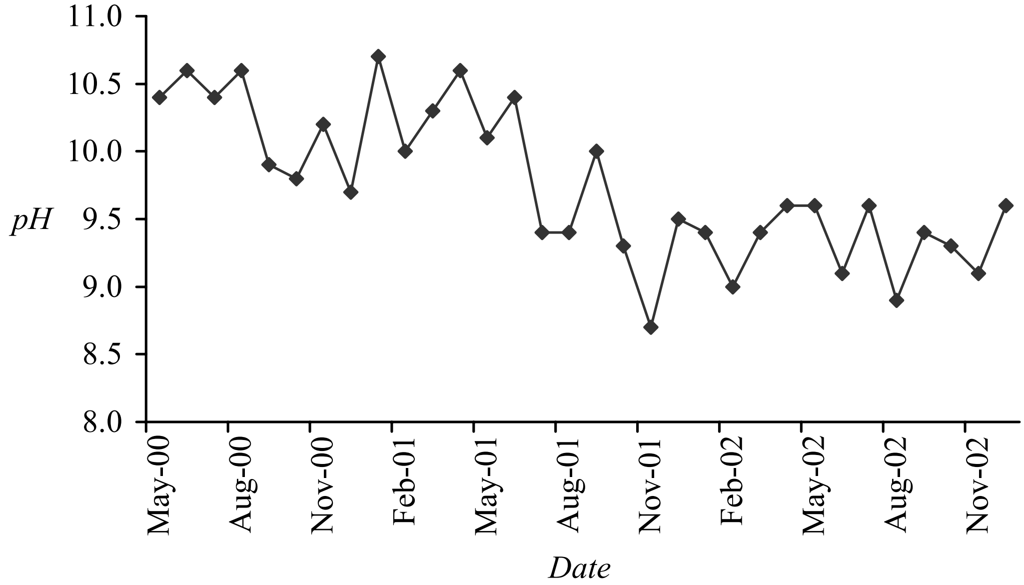

Figure 1. pH trends.

Table 5 - Ravenscraig Treated Leachate Discharge Quality

Determinand	Nº of Samples	Maxima	Minima	Mean	Consent Level
pH	116	7.8	6.6	7.1	6.0-9.0
Suspended Solids mg l^{-1}	116	<5	<5	<5	-
Ammoniacal-N mg l^{-1}	116	5.4	<0.1	0.2	10
Chemical Oxygen Demand (COD) mg l^{-1}	116	27	<5	0.9	30
Total Cyanide mg l^{-1}	116	3.2	0.6	0.06	-
Free Cyanide mg l^{-1}	116	0.1	<0.01	<0.01	-
Total Oil mg l^{-1}	116	1.6	<0.4	0.02	-
Free Oil mg l^{-1}	116	0.4	<0.2	0.003	-
Visible trace of Oil	116	0	0	0	0

Note: results include Regulators analyses.

3.3 Leachate Treatment

The leachate is treated at a combined leachate and groundwater treatment plant 1km distant on the Ravenscraig site with an effluent discharge into a river running through the site. In order to satisfy the Regulators and to assist future planning and development constraints, the plant was designed to treat the worst-case scenario of elevated levels for cyanide, ammonia and oils.

The treatment process comprises pH control, oil separation with flocculation, the ability to treat cyanide by liquid chlorine, de-nitrification using a rotating bio-chemical contactor (RBC) and final polishing prior to discharge through an engineered reed bed.

Currently, the treatment process is limited to simple oil separation, de-nitrification and final polishing through the reed bed. This is due to the high volume groundwater throughput, typically between 100 and 200 m^3 day^{-1}, comprising elevated iron and free phase oil, which effectively dilutes the leachate. The chemical dosing plant, for pH control and flocculation, and the chlorination plant have been left in a state of operational readiness bar the provision of the requisite chemicals. To date, the plant has achieved 100% compliance in meeting the requirements of its discharge consent into a controlled water as indicated by Table 5.

4. DISCUSSION

Steelworks sites present a considerable environmental threat with extensive areas of contaminated land including waste stockpiles that require an intelligent remediation strategy in order to restore the land. At Ravenscraig remediation was required to a standard suitable for facilitating future development and at the same time to dispose of the waste material in such a manner as to minimise the long-term liability.

At Ravenscraig these materials were classified as special wastes and with the variety of contaminants the best practicable environment option at that time was to dispose of the material in an on site landfill. This meant that there was a potentially significant long-term liability associated with leachate generation and quality.

The laboratory results for the assessment of the waste material clearly demonstrate the gross contamination of the material that could potentially lead to a difficult leachate in terms of handling and treatability. However, this paper has also shown through the frequent laboratory analyses on the leachate that it is relatively simple to manage and that the quality is improving with age.

This is largely due to the robust and innovative engineering design of the secure containment facility that has effectively minimised the ingress of water and, through the buffer layer, maintained the alkalinity of the waste mass thus stabilising the metals and preventing their subsequent leaching. Similarly, the nature of the waste is predominately soils which on engineered compaction would naturally inhibit the passage of water through the waste mass. It should also be noted that much of the contamination was within made ground which had a degree of permeability that comprised areas of reworked clay and granular material such as slag and colliery spoil. However, by controlled disposal methods, including proper compaction, the permeability of the waste can be minimised thus also contributing to the reduction of leachate generation.

The experience at Ravenscraig may prove to be a precursor of similar future landfills influenced by changing legislation driven by the EU Landfill Directive. With the withdrawal of co-disposal, future landfills are more likely to contain toxic contaminants without the range of biodegradable organic waste materials that has been the case historically. Ravenscraig's SCF is effectively inert in a biodegradable sense, in that the organic materials are dominated by mineral oils and derivates which are stable in the long term in soils. As such the long term trends now being discerned in the leachate quality from Ravenscraig are thought provoking for those charged with designing and managing future special waste facilities which will behave very differently from the mixed waste landfills in operation at the present.

5. CONCLUSIONS

In conclusion, the wastes arising from grossly contaminated land may not necessarily lead to the generation of difficult leachate when landfilled, providing that a clear understanding of the nature of the waste is obtained at the design stage, as well as the potential chemical interactions within a waste mass. With this information an optimal engineering design of the facility can be produced to minimise the environmental risk and the long-term liability.

This paper has provided the composition of the contamination found at the former Ravenscraig steelworks and following disposal within an engineered facility the resultant characterisation of the leachate produced. This demonstrates the reduction in risk from leachate by adhering to a competent remediation strategy that has allowed informal public access and aided the successful planning application for redeveloping the site for a mixed-use new community.

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