Ground Floor
Rose Wharf
78-80 East Street
Leeds
LS9 8EE

0113 274 8509
leeds@curtins.com
www.curtins.com

Curtins

Our Ref: 081801-CUR-XX-XX-T-GE-00003-P01

24 January 2024

David Marsh
BAM Construction
Ground Floor, Unit 2C
The Gateway East
Marsh Lane
Leeds
LS9 8AU

Dear David,

Kirklees Cultural Heart – Ground Gas Risk Review

1. Introduction and Background

The following report presents an updated ground gas risk assessment for the site at Queensway, Huddersfield. This risk assessment is intended to present a comprehensive appraisal of factual data pertaining to the subject site to derive a suitable ground gas risk assessment.

Previous ground gas risk assessment undertaken by a third party concluded that gas protection measures would be required. This previous assessment has been reviewed within this report to provide an updated and current detailed ground gas risk assessment for the site. In the process of undertaking this assessment, Curtins has supplemented the third-party ground gas monitoring data with additional gas monitoring.

The currently proposed development programme indicates that the derelict land in the south of the site will be re-developed as a multi-storey carpark and venue, the current piazza centre and Queensgate market building will be retained and redeveloped, as will the museum and garden area. Along the eastern edge of the site an art gallery will be constructed. Appendix A includes a site development plan (1).

2. Regulatory Framework

The following current British Standards have formed the basis of the approach to, and undertaking of, the ground gas risk assessment at the site:

1. BS8485:2015+A1:2019 - Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings
2. BS8576:2013 - Guidance on investigations for ground gas - Permanent gases and volatile organic compounds (VOCs).

Reference is made to the framework provided in the British Standard throughout this report and, where deemed appropriate, supplemented by current guidance listed below:

- CIRIA C665 *Assessing risks posed by hazardous ground* (2007).
- CL:AIRE RB17 A Pragmatic Approach to Ground Gas Risk Assessment, 2012
- CL:AIRE TB17 Ground Gas Monitoring and 'Worst-Case' Conditions, 2018
- Ambisense and EPG Ltd Using ternary plots for interpretation of ground gas monitoring results. Ground Gas Information Sheet No. 1, 2018
- Ground Engineering Technical paper: Risk and reliability in gas protection design – 20 years on: Part 1 and Part 2, 2019
- CL:AIRE, Continuous Ground-Gas Monitoring and the Lines of Evidence Approach to Risk Assessment, 2019
- CL:AIRE, Good practice for risk assessment for coal mine gas emissions, 2021

- EPG Ltd, Multiple lines of evidence approach using continuous monitoring data, 2022
- NHBC, NF94 Hazardous ground gas - an essential guide for housebuilders, 2023

3. Previous Reporting

Curtins have been provided with the following third-party geo-environmental reports that relate to the subject site:

- Aecom, (2020), *Kirklees Council Queensgate Quarter - Phase 1 Geo-environmental Report (Ref. 60613541).*
- Arup, (2023), *Kirklees Cultural Heart, Ground Investigation Report (Ref. CDT430201-ARP-XX-XX-RP-CG-0002).*
- Silkstone Environmental Ltd, (2023), *Factual Report on Ground Investigation (Ref. 22203/GI/1)*

In 2022, Silkstone undertook a ground investigation at the site on behalf of Arup. This ground investigation included the installation and monitoring of 11 ground gas wells at the site. Six gas/groundwater monitoring visits were undertaken over a period of five months between October 2022 and February 2023. Based upon the resultant monitoring data, Arup (2023) concluded that the site should be classified as Characteristic Situation 2 (CS2) and that appropriate gas protection measures would be required. However, it was noted by Arup that the majority of the monitoring data would suggest that the site is representative of a CS1 classification, and that additional monitoring may support a reduction from CS2 to CS1.

4. Site Setting

The following section highlights the site information considered relevant to the assessment of ground gas sources and potential risks at the development site.

4.1. General

The site is located in Huddersfield town centre off Queens Road, HD1 2RS. The wider site is occupied by a plot of derelict land in the south of the site, with the Piazza Centre located immediately north of this, Huddersfield Art Gallery is locate in the centre of the site and is surrounded by a garden area of soft landscaping. In the north and east of the site are retail units associated with Queensgate Market. The site is bounded by King Street to the north, Queen Street and Queensgate Road to the east, Queensgate Road to the south and the south of the site is demarcated by Alfred Street, Peel Street, and Victoria Lane. An approximate site location plan is given as *Figure 1.*

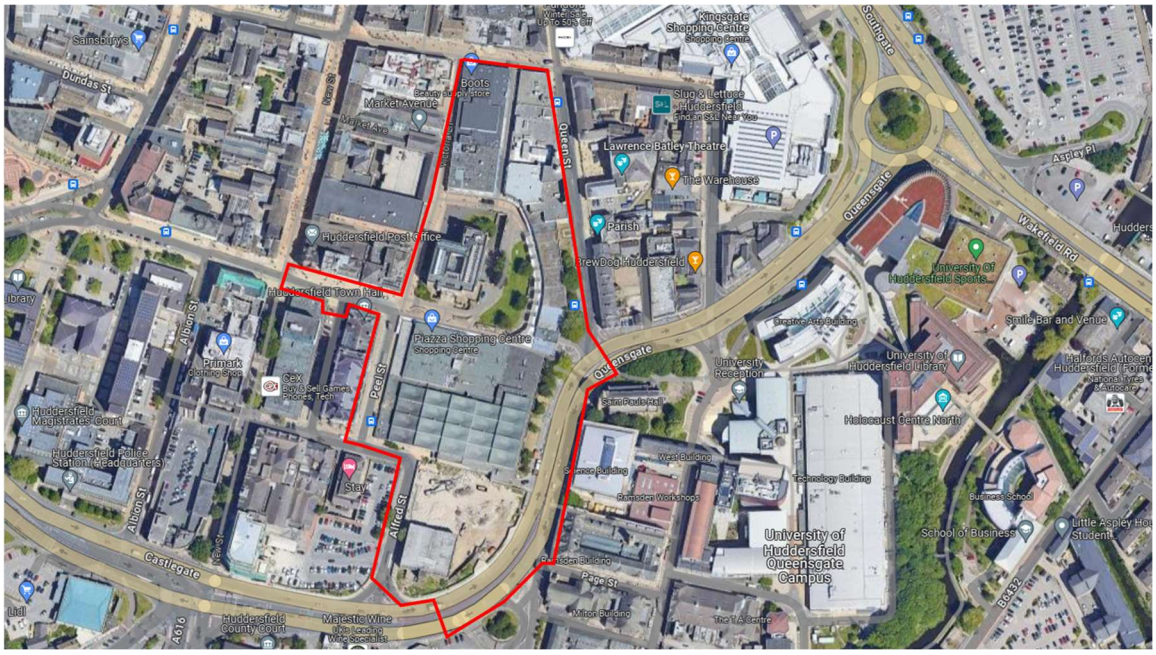


Figure 1 - Approximate Site Location Plan

4.2. Site History

Historical mapping (2) indicates that most of the site and the surrounding area had been developed prior to the first available historical mapping in the 1850s. 1850s mapping shows the site to be occupied by the New Market to the north, a chapel, and various public buildings in the centre of the site, with commercial buildings and fields in the south of the site.

Mapping from the 1900s shows the site to be further built up, with a police and fire station shown at the south-western boundary of the site. A works building is shown in the south of the site, this mapping shows the site to be further built up with new buildings shown in the south of the site, and a higher density of buildings shown across the site a s a whole. This mapping also shows an iron works to be present approximately 80 m south of the site.

Mapping from the 1970s does not highlight any significant changes to the site or surrounding area.

From the interpreted site history, it is anticipated that any made ground at the site will be limited in thickness and is likely comprised of inert demolition materials associated with the historical phases of development on the site. As no indication of landfilling, either through recorded sites or potential infilling has been identified at the site it is anticipated that made ground is primarily inert material with no putrescible material included and so is unlikely to be a source of ground gas.

The site history has been considered as part of an appraisal of potential ground gas sources, which is discussed in *Section 5*.

4.3. Geology and Encountered Ground Conditions

4.3.1. Published Data

Made Ground is not mapped to be present by the British Geological Survey (BGS) but is anticipated to be present due to the site's development history.

The 1:10,000 geological map sheet of the area (British Geological Survey, (2003), *Sheet SE11NW Huddersfield West*) (3) shows the site to be underlain by head superficial deposits, which is underlain by bedrock of the Middle Band Rock, a named sandstone unit of the Pennine Lower Coal Measures Formation (PLCMF). According to the BGS, head deposits typically comprise a poorly sorted and stratified deposits of gravel, sand and clay and the Middle Band Rock typically comprises a thin and relatively impersistent thinly bedded rubbly sandstone up to 10 m in thickness. The Middle Band Rock is subsequently underlain by undifferentiated PLCMF, comprised of interbedded mudstone, siltstone and sandstone.

The Soft Bed coal seam outcrops to the north west and south of the site and dips in a general easterly direction below the site. The Soft Bed coal seam is reported by the BGS to be between 0 to 0.8 m thick (being potentially workable) and lie stratigraphically below the Middle Band Rock, within the undifferentiated PLCMF strata. The Middle Band coal seam immediately overlies the Middle Band Rock, is reportedly 0 to 0.6 m thick but outcrops to the east of the site. Based upon the BGS mapping the Soft Band Coal should be present below the site but the Middle Band coal should be absent.

The Coal Authority online viewer (4) shows the site lies within a coal mining reporting area, and is within a surface coal resource area, development high risk area and an area with probable shallow coal mine workings. Whilst the site is within an area of probable shallow mine workings (associated with the Soft Bed coal), there are no recorded shallow coal mine workings within 500 m of the site. Furthermore, no mine shafts have been recorded within 250 m of the site, with the closest recorded mine entry to the site is approximately 450 m north-west of the site.

4.3.2.Ground Investigation Findings

Silkstone Environmental Ltd (2023) undertook a ground investigation at the site in 2022. The exploratory hole locations are presented in *Appendix A.*

Topsoil, typically comprising gravelly silt and sand with rootlets low cobble content, was encountered across much of the site from ground level, though it was absent from the Venue and MSCP areas in the south.

Made ground was encountered underlying topsoil across the site (and from ground level in the Venue and MSCP area), ranging in thickness between 0.2 and >5.0 m, though this varied by area. The greatest thickness of made ground was recorded in TP06B, located in the north-west of the site in the 'museums and gardens', and its thickness may be attributable to its location, adjacent to the service tunnels. However, except for TP06B, the thickness of made ground was typically less than 3 m and in most instances less than 1.0 - 1.5 m.

The made ground was up to 2.8 m thick at one location (BH10) but less than 1.55 m in all other exploratory holes in the Venue and MSCP area, and in the Gallery area the made thickness was between 1.7 m and 2.8 m at the two locations where the made ground base was proven.

Made ground generally comprised inert construction type materials and was typically described as sand and gravel with occasional cobbles and boulders of sandstone, brick and concrete. Occasional roots and some areas of gravelly silt and clay were recorded. There is no evidence within the soil descriptions of putrescible material or household waste at the site nor other such materials that may have a high degradable organic carbon content that could cause hazard gas emissions at ground surface.

The Silkstone Ground Investigation Report (5) indicated that 35 soil samples were tested for soil organic matter (SOM) content. Of the 35 samples, two were from the underlying natural deposits and 33 were from made ground samples. Of the 33 made ground samples tested, all were below 3% SOM except for those highlighted in *Table 1*.

Table 1 - Soil Organic Matter Results in Made Ground Samples Exceeding 3% and Reasoning

Exploratory Hole Location	Depth of Sample	Soil Organic Matter Result (%)	Reason for Result >3%
OP05	0.25 – 0.42	3.7	Occasional roots, cobbles of concrete, gravel of brick, concrete, ceramics and coal
OP11	0.02 – 0.32	6.0	Topsoil sampled, contained concrete, brick fragments and infrequent litter
OP06	0.13 – 0.28	6.2	Tree roots ceramic drain fragments, gravel of brick and occasional clinker
TP07 (ws)	0.01 – 0.05	7.9	Roots and rootlets, plastic turf reinforcement mesh
BH02	0.18 – 0.42	7.7	Made ground is of variable materials, gravels of brick, tile and coal
TP11	0.37 – 0.57	3.6	Ceramic drain fragments, gravel/cobbles of concrete, pottery and plastic
TP10	0.3 – 1.16	3.5	Ceramic drain and brick fragments
BH05	0.4 – 0.57	3.6	Fragments of timber, gravel of bitumen brick and polystyrene, solvent smell
BH08	1.6 – 1.8	4.3	Brick fragments, occasional roots

Disregarding the nine samples listed in *Table 1* the average SOM values for the made ground at the site was found to be 1.3%, which when converted to an average total organic content (TOC) is approximately 0.75%. The nice samples with SOM above 3% typically contained rootlets, clinker, coal fragments or plastic which are likely to be the cause of the more elevated SOM results. According to NHBC N94, whilst organic in nature, such materials do not represent a significant viable ground gas source.

Waste Acceptance Criteria (WAC) testing was undertaken on 14 of the made ground soil samples, inclusive of samples where SOM exceeded 3%, and gave results ranging between <50 mg/kg to 100 mg/kg of dissolved organic carbon in a 10:1 leachate preparation. These low results demonstrate that the TOC present within made ground soils at the site is not highly degradable and, as such, would meet the requirements for inert waste and is therefore unlikely to provide a significant ground gas source.

The superficial head deposits were typically encountered as soft to stiff clay with fine to coarse sandstone gravel, which is consistent with the BGS description. They were encountered between depths of 0.2 and 5.0 m bgl.

Middle Band Rock was found directly underlying the head deposits at the site and was encountered from 0.4 to 6.2 m bgl, proven to a maximum depth of 29.8 m bgl, it was generally recovered as a weathered moderately weak to strong sandstone interbedded with thin layers of mudstone and siltstone.

Shallow coal was identified in one borehole, BH05, at the site, at a depth of 3.6 m bgl and a seam thickness of 0.3 m, it is anticipated to be the Middle Band coal, which is mapped to outcrop to the east of the site. The Soft Bed coal seam was identified from depths of between 14.56 and 21.65 m bgl and a maximum seam thickness of 0.6 m. From the exploratory holes that encountered coal, five logs provide Ordnance Datum levels, which indicate that Soft Bed coal seam dips to the east with a maximum elevation change of four metres shown across the site (west to east).

No evidence of workings was identified during the ground investigation and the Arup ground investigation report concluded that the site is at a low risk from shallow underground mine workings.

5. Potential Ground Gas Source Assessment

The magnitude of the generation potential of each of the identified sources has been determined using the framework outlined in Clause 8.7 of BS8576:2013, Figure 6.

Tables 5.5a and 5.5b in C665 (2007) also refer to generational potential and use the terms ‘Very low’, ‘Low’, ‘Moderate’, ‘High’ and ‘Very High’; however, ‘Note 2’ to that table states:

> 2 There is no industry consent over “high”, “medium” or “low” generation potential of source.

This statement is superseded by Clause 8.7 in BS8576:2013 and, as such, the British Standard is the appropriate standard to confirm the gas generation of a source, not guidance.

Two potential sources of ground gas were identified by Arup (2023):

- *Source 1* – Made Ground across the site.
- *Source 2* – Potential mine workings below the site.

When considering the gas generation potential of the above sources, reference has been made to clause 8.7 in BS8576:2013 Figure 6, as extracted in *Figure 2*.

Figure 6 **Decision matrix for initial monitoring**

Very low	• Natural carbonate soil and strata, e.g. chalk and limestone. • Natural soil strata with a low degradable organic content, e.g. alluvium, peat. • In-filled pond less than 15 m diameter, in-filled before 1930s to 1940s. • Made ground with low degradable organic content (e.g. up to 5% organic material such as pieces of wood, pieces of paper, rags, etc. with a high proportion of ash and no food or other easily degradable waste). • Mine workings shallow or shaft (where there is clear evidence that they are flooded). (Gas in coal is historically generated and is trapped or adsorbed so the actual current generation rate is very low but it accumulates in workings and large volumes can be emitted very quickly.) • Inert landfill sites. (Lack of regulation in the past means that most sites are never entirely inert – they can include timber, plasterboard and even domestic refuse and consequently care is needed when assessing such sites. They might require a higher risk classification.)
Low	• Natural soil strata with a high degradable organic content (DOC). • Made ground with total organic carbon (TOC) up to 6% (e.g. dock silt. No food or other easily degradable waste). • Foundry sand (includes phenolic binders, rags and wood that decay, albeit at low rates). • Landfill 1945 to mid 1960s (see also "moderate"). Higher TOCs might not always indicate high degradability. For example, coke breeze can contain up to 51% TOC but only 4% DOC. In this case, the assessor should estimate what proportion of the TOC is degradable.
Moder-ate	• Sewage sludge. • Mine workings – unflooded, more than 50 years since last worked (gas is liberated from coal when mine workings are excavated; this continues for up to about 50 years). • Landfill 1945 to mid 1960s (this could also be "low" or, if disturbed, "high").
High	• Landfill mid 1960s to early 1990s. • Mine workings – unflooded – less than 50 years since last worked.
Very high	• Municipal landfill sites. • Landfill early 1990s onwards.

Figure 2 - Risk ratings from BS8576:2013 Figure 6

In accordance with NHBC NF94, the six key factors that should be considered when assessing the risks associated with ground gas emissions a potential source have been assessed for Source 1 below:

- *Organic content* – As outlined in Section 4.3.2, no substantial quantities of organic content or materials have been recorded. Made ground soils generally comprise inert materials.
- *Available degradable material* – WAC testing results show that the made ground soils have a low degradable carbon content. Furthermore, the key indicators of a high gas generation potential, fresh vegetable matter and food waste (NHBC N94), are absent from the soil descriptions.
- *Nature of the fill material* - Groundwater levels were recorded to range between circa 72 and 79 m above ordnance datum (AOD) from Arup, Silkstone and Curtins water monitoring data. Perched water has been encountered in the made ground, but typically made ground layers are unsaturated. Made ground deposits are largely less than 3 m thick and in many instances less than 1.0 – 1.5 m thick. Made ground is typically recorded as non-cohesive sand and gravel with occasional cobbles.
- *Age of materials* - From historical mapping the likely province of the made ground is from buildings that were demolished in the 1960s/70s to allow for the construction of the current Piazza shopping center.
- *Distance from receptor* - The proposed redevelopment is situated directly over the encountered made ground material.
- *Presence of preferential pathways* - Given the variable nature of the made ground, it is likely that any potential gasses present would migrate vertically and horizontally, primarily by diffusion and advection, through these soils. The drilled boreholes, whilst present, represent may preferential pathways too.

Given the inert soil description, low organic content, limited thickness and anticipated age of the made ground soils a gas generation potential for Source 1 is assessed to be Very Low in accordance with BS8576:2013 (Figure 2). According to NHBC N94, shallow made ground comprising predominantly construction and demolition waste, as identified during the ground investigation, is not a credible source. Based upon this, ground gas risks from the made ground soils on site are Low.

When considering the gas generation potential for Source 2 and the potential risks it poses, reference has been made to CL:AIRE (2021) to undertake a risk assessment using Decision Support Tool it provides. On this basis, the following is relevant prior to development:

- According to the Coal Authority, there are no recorded mine shafts within 50 m of the site.
- Though shallow coal deposits were encountered by the Silkstone (2023) ground investigation, no evidence of shallow coal workings was encountered. Furthermore, due to the depth and thickness of the seams it is unlikely that they would be worked in this area due to being economically unviable.
- The ground water level was found by Silkstone (2023) to lie between c. 72 and 79 m AOD, the borehole records for the site indicate the Soft Bed coal to lies at c. 61 to 65 m AOD, meaning that the coal seam likely lies below the water table. In the event that workings are present within this seam, they are likely to be flooded.
- No faults are mapped by the BGS within 700 m of the site. As such, faulting is unlikely to be a viable pathway.

Given the above information, the gas generation potential for Source 2 is assessed to be Negligible to Low, in accordance with CL:AIRE (2021). Under both risk classifications, mitigation (e.g. gas protection measures are not considered necessary by CL:AIRE (2021) and, furthermore, the assessment of mine gas risk should not use the BS8485 Gas Screening Value system.

6. Gas Monitoring

Though the review of the potential ground gas source assessment (Section 5indicates that neither of the two identified potential ground gas sources Arup (2023) necessitate gas protection measures to be implemented within the proposed development, a review of the gas monitoring collected by Silkstone (2023) and supplemented by Curtins has been undertaken.

The appropriate monitoring and frequency should be determined by the conceptual site model using the framework defined in BS8576:2013, where monitoring is considered appropriate. As detailed in Section 5, the overall gas generation potential for the made ground has been assessed to be Very Low. BS8576:2013 provides further guidance on monitoring frequencies as extracted in Figure 3. Figure 3 suggests that either no monitoring is required or that, at most, weekly monitoring over a period of 2 months would be appropriate given the gas generation potential at the site.

Figure 6 **Decision matrix for initial monitoring**

	Generation potential of source				
Gas monitoring requirements	Very low	Low	Moderate	High	Very high
Gas monitoring might not be necessary					
Gas monitoring over a period of 2 months with up to weekly measurements					
Gas monitoring over a period of 2 months up to 6 months with up to fortnightly readings					
Gas monitoring over a period of 6 months up to 12 months with up to fortnightly readings. Use high frequency monitoring where appropriate					

NOTE The darker the section on the matrix, the more likely it is that monitoring is needed.

Figure 3 - Guidance on ground gas monitoring frequencies

Between October 2022 and February 2023 Silkstone on behalf of Arup undertook six rounds of ground gas and water monitoring. Only peak flows were monitored for the duration of the monitoring period. The monitoring results of which are presented in *Figure 4.*

Arup (2023) derived maximum borehole gas screening values (GSVs) of 0.0108 l/hr for methane and 0.305 l/hr for carbon dioxide as in accordance with CIRIA C665. These GSVs would be representative of a characteristic situation 2 (CS2) scenario. However, in deriving these GSVs, Arup utilised peak flow rates, which BS8485 states

can result in a disproportionately high gas hazard prediction and assignment of an over-precautionary CS. Curtins considers this approach to be highly conservative given the significance of the potential risks posed by the identified sources.

Arup further interpreted the gas monitoring data, stating that much of the data recorded was representative of a CS1 scenario, however because of occasionally higher flow rates a CS2 classification must be given to the site. However, Arup noted that with further monitoring this classification may be possibly reduced to CS1.

To supplement the Silkstone (2023) gas monitoring data and collect steady state flow rates which are considered more appropriate for deriving GSVs, Curtins undertook four rounds of ground gas monitoring between 05 October 2023 and 31 October 2023. Six boreholes from the previous Silkstone (2023) rounds of monitoring were identified, accessible and in suitable condition to be monitored. The results from the Curtins 2023 ground gas monitoring rounds are presented in *Table 2.*

		Gas Readings													
Hole ID	Date	Oxygen (%)		Carbon Dioxide (%)		Methane (%)		Methane LEL (%)	Flow (l/hr)	Relative Pressure	Ambient Pressure (mBar)	Pressure Trend	Water Level (mBGL)	Base of Hole (mBGL)	Remarks
		Peak	Steady	Peak	Steady	Peak	Steady								
BH01A	10/10/22	8.5		6.0		0.1		2.0	0.5	-0.35	1009	Rising	Dry	11.19	5ppm CO & zero H_2S
	07/11/22	7.6		10.0		0.1		2.0	0.2	-0.30	990	Stable	11.00	11.15	2ppm CO & zero H_2S
	15/11/22	7.3		7.2		<0.1		0.0	0.2	0.20	984	Falling	Dry	11.20	3ppm CO & zero H_2S
	08/12/22	3.0	3.0	12.2	11.5	<0.1	<0.1	0.0	0.1	-0.23	1002	Falling	Dry	11.20	zero CO & H_2S
	19/01/23	4.0	4.0	9.3	9.0	0.1	<0.1	2.0	0.1	0.13	998	Rising	Dry	11.19	1ppm CO & zero H_2S
	16/02/23	0.2	0.2	11.8	11.8	<0.1	<0.1	0.0	2.5	-0.09	1007	Stable	Dry	11.20	2ppm CO & zero H_2S
BH02	10/10/22	1.8		1.6		<0.1		0.0	0.3	0.75	1009	Rising	4.34	7.14	4ppm CO & zero H_2S
	07/11/22	6.9		1.9		<0.1		0.0	0.3	-0.02	990	Stable	6.02	7.04	1ppm CO & zero H_2S
	15/11/22	2.7		1.5		0.1		2.0	0.2	-0.10	985	Falling	5.78	7.14	4ppm CO & zero H_2S
	08/12/22	10.0	12.1	1.7	1.5	<0.1	<0.1	0.0	0.1	-0.19	1003	Falling	6.13	7.08	zero CO & H_2S
	19/01/23	12.0	12.0	0.6	0.6	<0.1	<0.1	0.0	0.2	-0.49	998	Rising	5.89	7.10	zero CO & H_2S
	16/02/23	9.3	9.3	2.6	2.6	<0.1	<0.1	0.0	0.3	0.03	1007	Stable	5.85	7.00	zero CO & H_2S
BH03	10/10/22	17.0		3.6		0.1		2.0	0.2	0.33	1011	Rising	2.74	4.09	2ppm CO & zero H_2S
	07/11/22	17.2		3.6		<0.1		0.0	0.1	-0.02	990	Stable	2.41	4.06	1ppm CO & zero H_2S
	15/11/22	17.2		3.5		<0.1		0.0	0.1	0.02	983	Falling	2.70	4.10	zero CO & H_2S
	08/12/22	17.0	17.0	4.0	4.0	0.1	<0.1	2.0	0.2	-0.07	1004	Falling	2.50	4.05	zero CO & H_2S
	19/01/23	16.7	16.7	4.6	4.6	0.1	0.1	2.0	0.2	-0.10	998	Rising	2.53	4.05	zero CO & H_2S
	16/02/23	17.8	17.8	3.7	3.7	<0.1	<0.1	0.0	0.4	-0.02	1007	Stable	2.56	4.05	zero CO & H_2S
BH04	10/10/22	2.7		4.5		<0.1		0.0	0.3	0.51	1008	Rising	2.34	7.17	6ppm CO & zero H_2S
	07/11/22	6.2		5.1		<0.1		0.0	0.2	0.02	990	Stable	2.14	7.06	3ppm CO & zero H_2S
	15/11/22	7.4		5.7		0.1		2.0	0.2	0.00	984	Falling	2.05	7.13	zero CO & H_2S
	08/12/22	5.8	5.8	5.3	5.3	<0.1	<0.1	0.0	0.2	0.05	1004	Falling	6.92	7.13	zero CO & H_2S
	19/01/23	2.2	2.2	6.4	6.3	<0.1	<0.1	0.0	0.2	-0.63	998	Rising	6.90	7.10	zero CO & H_2S
	16/02/23	16.5	16.5	4.3	4.2	0.1	<0.1	2.0	3.2	-15.97	1008	Stable	6.81	7.10	1ppm CO & zero H_2S
BH05	10/10/22	15.9		1.4		0.1		2.0	0.5	0.82	1007	Rising	Dry	4.34	5ppm CO & zero H_2S
	07/11/22	21.2		0.1		0.1		2.0	0.1	0.05	990	Stable	Dry	4.15	1ppm CO & zero H_2S
	15/11/22	15.2		1.2		0.1		2.0	0.1	0.32	983	Falling	Dry	4.40	3ppm CO & zero H_2S
	08/12/22	5.2	6.8	10.1	8.8	0.1	<0.1	2.0	1.1	0.61	1004	Falling	Dry	4.40	zero CO & H_2S
	19/01/23	12.0	12.0	5.2	4.5	0.1	0.1	2.0	<0.1	-0.03	998	Rising	Dry	4.40	zero CO & H_2S
	16/02/23	7.2	7.5	1.0	1.0	0.1	<0.1	2.0	0.4	-0.32	1007	Stable	Dry	4.40	zero CO & H_2S
BH06 (Tunnel)															Borehole not completed
															Borehole not completed
	15/11/22	19.9		<0.1		<0.1		0.0	<0.1	-0.01	983	Falling	4.75	5.22	17ppm CO & zero H_2S
	08/12/22	12.9	12.9	0.1	<0.1	<0.1	<0.1	0.0	<0.1	60.44	1005	Falling	4.00	5.22	1ppm CO & zero H_2S
	19/01/23	6.0	6.0	1.0	1.0	0.1	0.1	2.0	0.8	7.89	998	Rising	3.85	5.10	zero CO & H_2S
	16/02/23	1.8	1.8	0.4	0.4	0.1	0.1	2.0	10.8	0.03	1007	Stable	3.40	5.10	1ppm CO & zero H_2S
BH07	10/10/22	17.6		3.1		0.1		2.0	0.2	0.61	1008	Rising	Dry	3.52	2ppm CO & zero H_2S
	07/11/22	12.4		3.9		<0.1		0.0	0.1	-0.05	991	Stable	Dry	3.46	2ppm CO & zero H_2S
	15/11/22	17.2		3.0		0.1		2.0	0.1	0.02	984	Falling	Dry	3.51	1ppm CO & zero H_2S
	08/12/22	10.7	10.7	5.1	5.1	<0.1	<0.1	0.0	0.2	-0.23	1004	Falling	Dry	3.49	zero CO & H_2S
	19/01/23	11.5	11.5	4.5	4.0	<0.1	<0.1	0.0	0.1	-1.23	998	Rising	Dry	3.51	1ppm CO & zero H_2S
	16/02/23	14.6	14.7	4.1	4.0	<0.1	<0.1	0.0	0.3	-0.68	1007	Stable	Dry	3.50	zero CO & H_2S
BH08	10/10/22	16.4		0.4		<0.1		0.0	2.6	-0.68	1011	Rising	9.72	22.14	653ppm CO & 1ppm H_2S
	07/11/22	10.3		5.8		0.1		2.0	0.8	0.12	991	Stable	12.16	22.13	5ppm CO & zero H_2S
	15/11/22	14.6		3.5		0.1		2.0	0.1	0.12	983	Falling	9.57	22.15	zero CO & H_2S
	08/12/22	18.8	20.1	2.3	2.3	<0.1	<0.1	0.0	0.1	0.02	1005	Falling	11.90	22.20	zero CO & H_2S
	19/01/23	17.4	18	3.3	3.3	0.1	<0.1	2.0	0.3	0.07	998	Rising	12.05	22.15	zero CO & H_2S
	16/02/23	16.5	16.5	4.0	4.0	0.1	0.1	2.0	0.3	0.14	1008	Stable	12.15	22.15	1ppm CO & zero H_2S
BH10	10/10/22	20.6		0.5		<0.1		0.0	0.2	1.03	1010	Rising	Dry	2.55	2ppm CO & zero H_2S
	07/11/22	20.1		0.4		<0.1		0.0	0.2	0.03	990	Stable	Dry	2.55	2ppm CO & zero H_2S
	15/11/22	20.6		0.3		<0.1		0.0	0.3	0.72	983	Falling	Dry	2.55	2ppm CO & zero H_2S
	08/12/22	20.1	21.5	0.2	0.2	<0.1	<0.1	0.0	0.1	0.17	1004	Falling	Dry	2.55	1ppm CO & zero H_2S
	19/01/23	21.0	21.2	0.4	0.3	<0.1	<0.1	0.0	0.1	0.03	998	Rising	Dry	2.55	zero CO & H_2S
	16/02/23	21.3	21.3	0.3	0.3	<0.1	<0.1	0.0	0.2	0.02	1007	Stable	Dry	2.55	zero CO & H_2S
PEMW01	10/10/22	20.0		1.3		<0.1		0.0	0.0	0.75	1010	Rising	0.91	1.09	1ppm CO & zero H_2S
	07/11/22	19.3		1.4		<0.1		0.0	0.2	0.23	990	Stable	0.89	1.10	1ppm CO & zero H_2S
	15/11/22	20.3		1.7		<0.1		0.0	0.1	0.37	983	Falling	0.95	1.10	3ppm CO & zero H_2S
	08/12/22	20.1	20.1	0.1	0.1	<0.1	<0.1	0.0	<0.1	-0.23	1004	Falling	0.95	1.10	zero CO & H_2S
	19/01/23	20.0	20.1	1	0.8	<0.1	<0.1	0.0	0.1	0.08	998	Rising	0.90	1.10	zero CO & H_2S
	16/02/23	20.1	20.1	0.9	0.9	<0.1	<0.1	0.0	0.2	-0.12	1007	Stable	1.00	1.10	zero CO & H_2S
PEMW02	10/10/22	19.4		1.8		<0.1		0.0	0.2	0.75	1011	Rising	Dry	1.70	2ppm CO & zero H_2S
	07/11/22	18.9		1.3		<0.1		0.0	0.1	-0.03	990	Stable	Dry	1.70	1ppm CO & zero H_2S
	15/11/22	20.9		1.7		<0.1		0.0	0.1	0.09	982	Falling	Dry	1.70	4ppm CO & zero H_2S
	08/12/22	20.7	20.7	0.2	0.2	<0.1	<0.1	0.0	<0.1	-0.63	1004	Falling	Dry	1.70	zero CO & H_2S
	19/01/23	22.0	22.0	0.7	0.7	<0.1	<0.1	0.0	0.1	-1.78	998	Rising	Dry	1.70	zero CO & H_2S
	16/02/23	22.3	22.3	0.6	0.6	<0.1	<0.1	0.0	0.1	0.20	1007	Stable	Dry	1.70	zero CO & H_2S

Figure 4 - Ground gas monitoring results (Silkstone Environmental Ltd (2023))

Ground Floor
Rose Wharf
78-80 East Street
Leeds
LS9 8EE

0113 274 8509
leeds@curtins.com
www.curtins.com

Curtins

Table 2 - Curtins 2023 gas monitoring results

Borehole Reference	Date	Barometric Pressure	Pressure Trend	Flow (l/hr)		Methane %		Carbon Dioxide %		Oxygen %	Hydrogen Sulphide (ppm)	Carbon Monoxide (ppm)	Water Level (m bgl)	Base (m bgl)
				Max	SS	Max	SS	Max	SS					
BH01A	5/10/203	1008	Falling	<0.1	<0.1	<0.1	<0.1	7.9	7.7	0.0	<1	<1	10.99	11.17
	13/10/23													
	24/10/23	985	Falling	<0.1	<0.1	<0.1	<0.1	7.9	7.9	0.2	<1	<1	10.97	11.10
	31/10/23	990	Rising	<0.1	<0.1	<0.1	<0.1	3.4	1.6	7.4	<1	<1	10.98	11.14
BH03	5/10/203	1008	Falling	<0.1	<0.1	<0.1	<0.1	3.9	3.9	17.7	<1	<1	2.40	4.10
	13/10/23													
	24/10/23	985	Falling	<0.1	<0.1	<0.1	<0.1	3.1	3.1	16.5	<1	<1	2.41	4.08
	31/10/23	988	Rising	<0.1	<0.1	<0.1	<0.1	3.1	3.1	17.1	<1	<1	2.26	4.08
BH04	5/10/203	1007	Falling	<0.1	<0.1	<0.1	<0.1	4.8	4.8	5.9	<1	<1	1.86	7.06
	13/10/23	989	Rising	8.4	<0.1	<0.1	<0.1	2.3	0.6	19.20	<1	<1	1.90	7.08
	24/10/23	985	Falling	<0.1	<0.1	<0.1	<0.1	4.7	4.7	11.3	<1	<1	1.81	7.09
	31/10/23	989	Rising	<0.1	<0.1	<0.1	<0.1	3.1	3.1	14.6	<1	<1	1.76	7.10
BH07	5/10/203	1006	Falling	<0.1	<0.1	<0.1	<0.1	5.3	5.3	12.5	<1	<1	3.44	3.54
	13/10/23	988	Rising	<0.1	<0.1	<0.1	<0.1	2.9	2.9	16,4	<1	<1	dry	3.50
	24/10/23	985	Falling	<0.1	<0.1	<0.1	<0.1	6.2	6.2	11.1	<1	<1	dry	3.32
	31/10/23	989	Rising	<0.1	<0.1	<0.1	<0.1	3.1	3.1	10.3	<1	<1	3.35	3.45
BH08	5/10/203	1009	Falling	<0.1	<0.1	<0.1	<0.1	0.8	0.8	12.5	<1	<1	6.00	21.92
	13/10/23	988	Rising	<0.1	<0.1	<0.1	<0.1	0.5	0.5	16.2	<1	<1	11.60	21.83
	24/10/23	985	Falling	<0.1	<0.1	<0.1	<0.1	1.4	1.1	15.2	<1	<1	11.70	21.80
	31/10/23	989	Rising	<0.1	<0.1	<0.1	<0.1	0.9	0.5	14.7	<1	<1	11.10	21.90
BH10	5/10/203	1006	Falling	<0.1	<0.1	<0.1	<0.1	0.8	0.7	19.8	<1	<1	dry	2.45
	13/10/23													
	24/10/23	985	Falling	<0.1	<0.1	<0.1	<0.1	0.6	0.5	19.9	<1	<1	dry	2.52
	31/10/23	989	Rising	<0.1	<0.1	<0.1	<0.1	0.5	0.5	19.8	<1	<1	2.50	2.52

On the second visit Curtins engineers were unable to access three of the boreholes (greyed out in *Table 2*) as the area they were located within was secured with locked hoarding.

Three of the monitoring rounds completed by Curtins engineers were undertaken during lower atmospheric pressures (<1000 mb), and two of the monitoring visits took place during a period of falling atmospheric pressure.

BH07 and BH10 were two of the six boreholes monitored by Curtins and both are screened within the made ground. NHBC N94 states that monitoring well response zones should be targeted to source materials, or potential permeable reservoirs for gas, or the zone should be within a permeable pathway for gas to migrate. The remaining four borehole response zones (B01A, BH03, BH04 and BH08) were installed in either the PLCMF, Middle Band Rock or Soft Bed coal seam (no workings/voiding). Consequently, the response zones of these monitoring wells are considered to meet the requirements NHBC N94 as they are installed in neither a source nor a pathway and, therefore, the resultant monitoring data is largely irrelevant for the purposes of source gas risk assessment. Furthermore, the response zones of BH04 and BH08, and potentially BH03, were flooded during all the monitoring rounds and so the data is unsuitable for use in the derivation of GSVs.

6.1. Gas Screening Value

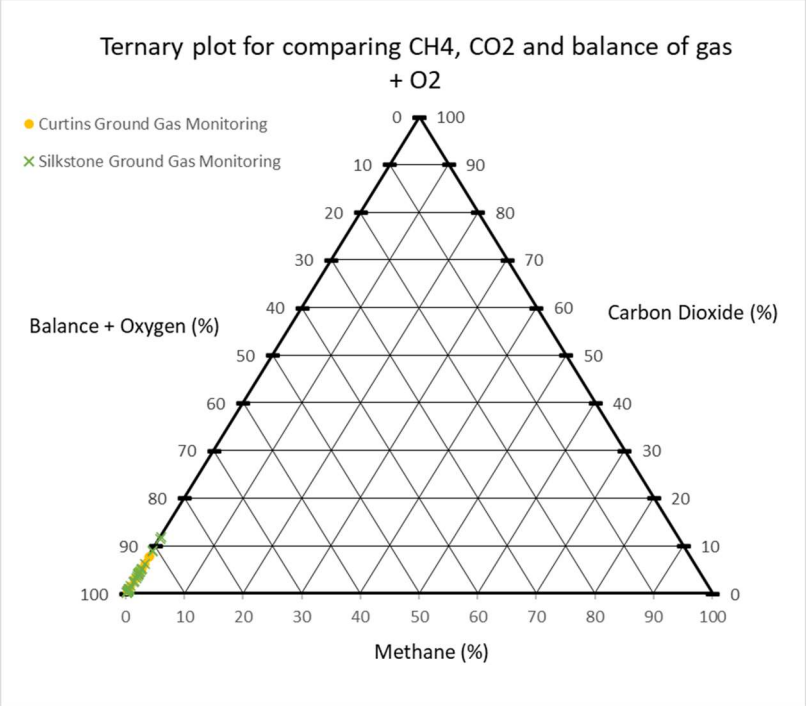
Based on the Curtins 2023 monitoring data, GSVs have been calculated for all boreholes where the response zones provide meaningful monitoring data when considered in the context of the conceptual site model. The derived GSVs are given in *Table 3*.

Table 3 - Calculated GSV by borehole for Curtins monitoring rounds

Borehole Reference	Response Zone Strata	Maximum Steady Flow (l/hr)	Maximum Peak CH_4 Concentration (%)	Maximum Peak CO_2 Concentration (%)	Calculated CH_4 GSV (l/hr)	Calculated CO_2 GSV (l/hr)
BH07	Made Ground	<0.1	<0.1	6.2	0.0001	0.0062
BH10	Made Ground	<0.1	<0.1	0.8	0.0001	0.0008

Based upon borehole GSVs and a worst-case scenario, CS1 classification is derived. The GSVs have been derived using the maximum steady flow rather than the maximum peak flow utilised by Arup (2023) (1), since that approach is considered overly conservative.

Clause 6.4 of BS8485 (6) states that an assessor should consider increasing (in full cognisance of the conceptual site model) CS1 to CS2 where methane is recorded >1% v/v or where carbon dioxide is recorded >5%v/v. Elevated carbon dioxide (6.2%) was recorded in boreholes BH07 and, as such, further consideration is warranted in this assessment.



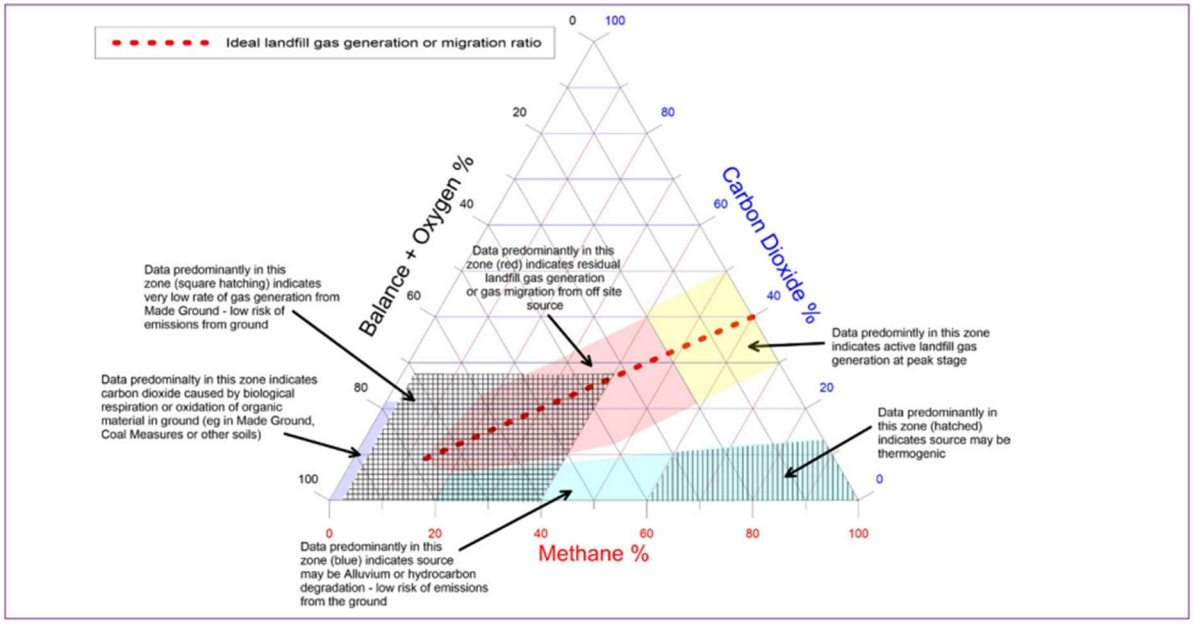


Figure 3.2 Ternary plot with zones indicating the potential gas source - Note this plot uses balance gas + oxygen on the z axis

Figure 5 - Ternary plot showing gas monitoring data from the site (top). Ternary plot with zones indicating the potential gas sources (NHBC, NF94) (bottom)

Figure 5 indicates that carbon dioxide is likely caused by biological respiration or oxidation of organic material in the made ground, as the site data would lie within the purple shaded area of the NHBC NF94 ternary plot. The NHBC NF94 guidance states that there may be no need to increase a sites classification from CS1 to CS2 if there are concentrations that occur in the purple, light blue or hatched areas and occur only occasionally. Based upon this, it is not considered appropriate to upgrade the CS1 classification to CS2 based on the maximum carbon dioxide concentration.

In addition to the above, Curtins has reviewed the validity of the Silkstone (2023) (5) monitoring data and, therefore, the resultant CS2 classification conservatively derived by Arup (2023) (1).

The CS2 classification was driven by GSVs derived from BH01A, BH04 and BH06 with monitoring data from all other boreholes providing a CS1 classification. As previously discussed, response zones should be installed within either a source or pathway, which none of these three boreholes were. Therefore, the resultant data is

not considered relevant in relation to the conceptual site model of the two sources as all three were installed in the PLCMF or Middle Band Rock, which are neither a source nor pathway. Whilst potential mine workings were identified as one of the two sources, no evidence of workings was identified and, therefore, these borehole response zones are not considered to be a pathway. Furthermore, mine gas presents a risk primarily when a rapid migration/preferential pathway is available, such as a fault or mine shaft, rather than migration through variably permeable bedrock. Given no known shafts or faults are present within 250 m of the site then such a pathway is likely absent.

7. Conclusions

In reconsidering the conceptual site model, significance of the potential gas sources and gas monitoring data, Curtins considers that the gas risk classification for the site should be CS1 rather than the overly conservative CS2 that derived by Arup (2023) (1). Consequently, no gas protection measures should be incorporated within the development.

It is recommended that gas monitoring wells are decommissioned prior to the commencement of construction activities.

Jon Shaw
Associate
For and on behalf of
Curtins Consulting Ltd

References

1. **Arup.** *Kirklees Cultural Heart, Ground Investigation Report (Ref. CDT430201-ARP-XX-XX-RP-CG-0002).* 2023.
2. **National Libary of Scotland.** Georeferenced Maps. [Online] 2024. https://maps.nls.uk/.
3. **British Geological Survey.** *Sheet SE11NW Huddersfield West, 1:10 000.* 2003.
4. **The Coal Authority.** Interactive Map. [Online] 2024. https://mapapps2.bgs.ac.uk/coalauthority/home.html.
5. **Silkstone Environmental Ltd.** *Factual Report on Ground Investigation (Ref. 22203/GI/1).* 2023.
6. **British Standards Institution.** *BS 8485:2015+A1:2019 Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings.* 2019.

Curtins

Appendix A

Curtins Consulting Ltd
Ground Floor, Rose Wharf, 78-80 East Street, Leeds, LS9 8EE
0113 274 8509 leeds@curtins.com www.curtins.com

Legend

Site boundary

Site Section

- Food hall and library
- Gallery
- Museum and gardens
- Park and terraces (no GI)
- Venue and MSCP
- Public realm

Hole Type

- Observation Pit
- Borehole
- Trial Pit
- Window Sample
- Pre-existing Monitoring Well
- Existing Service Tunnels

Coordinate System: British National Grid

Metres

0 15 30 60

Rev	Date	By	Chkd	Appd
P01	2023-03-23	CT	PST	GH

ARUP

Client
Kirklees Council

Project Title
Kirklees Cultural Heart

Drawing Title
Exploratory hole location plan

Scale at A3
1:1,250
Role

Suitability
For information

Arup Job No
284642

Rev
P01

Name
Figure 2