

RESTRICTED - COMMERCIAL

Radiological Survey Report of Maelor Gas Works Site, Wrexham for I&H Brown

February 2014

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Report Title: Radiological Survey Report of Maelor Gas Works
Site, Wrexham for I&H Brown

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1. INTRODUCTION

Aurora Health Physics Services Ltd (Aurora) were requested by I&H Brown to carry out a surface and intrusive radiological survey of the Maelor Gas Works Site at Wrexham. The survey was carried out from 18th November to 13th December 2013. The site has previously used catalyst pellets containing depleted uranium in a gas recovery process. The depleted uranium pellets and associated contamination were remediated by WasteChem in the late 1990's (ref. 1). Confirmation was obtained from Natural Resources Wales that the Permits for Accumulation and Disposal of Radioactive Waste (AW9498 and AY8590) issued to British Gas, Wales were revoked, in March 1997 and July 1998 respectively. The purpose of this survey was to carry out a complete survey of the site to current standards and legislation and to establish if the extent of any existing radiological contamination of the site at levels of regulatory concern.

2. RADIOLOGICAL SURVEY

2.1 External Areas Survey

The external ground survey was undertaken using Aurora's 'RadSurvey' System (RadSurvey). The RadSurvey instrument consists of a sensitive gamma radiation detection system linked to a Global Positioning System (GPS) enabling accurate gamma radiation contour mapping of the site. The data collected during the survey is used to accurately demonstrate and validate the radiological status of the site.

The survey system is configured using real time differentially corrected GPS to provide continual spatial reference information allowing the survey unit to be operated at sub-metre accuracy. Radiation and positional information is displayed and collected autonomously in the data logger.

2.1.1 RadSurvey Detector and Ratemeter

The survey unit is configured with a 75mm by 75mm high-sensitivity sodium iodide detector mounted in a protective case carried at a height of approximately 0.2m above ground level.

The detector is connected to a multi-channel analyser (MCA) which is configured to provide gross gamma counts per second, every second, to the data logger. However if areas of interest (or areas with above background radiation readings) are identified then the system can be used in gamma spectrometry mode, a spectrum taken, and the likely radionuclides identified. The RadSurvey system is capable of detecting material of regulatory interest to a depth of approximately 0.3m in soil. Therefore at soil depths significantly greater than 0.3m it

is possible that radioactive contamination may not be identified. The RadSurvey detector responds to gamma rays only. The key radionuclide in depleted uranium ^{238}U does not emit a gamma ray however its daughter product ^{234}Th does emit a low energy gamma ray (at 5% abundance) and therefore the system does respond to depleted uranium.

2.1.2 RadSurvey Methodology

The survey methodology involved traversing the site in nominal 1m wide lanes using the survey equipment. Data was accumulated at the rate of one reading per second and recorded in the data logger, resulting in one radiation reading per 1m^2 of the accessible areas of the site. Global Position System (GPS) information is automatically linked to the radiological data for ease of interpretation.

In areas of the site where the ground is populated with trees or shrubs, GPS coverage is not always 100 percent and gaps in the displayed data are possible. Where this occurs, detector data is still collected and reviewed to check if any high count rates are observed in any areas that aren't covered by the GPS.

2.2 RadSurvey Results

Using a Geographical Information System (GIS) the gathered data is displayed in map form. Interpolation was carried out on the data to provide a display of the radiation contours of the site as a surface picture.

During the survey over 236,000 survey points were recorded. Count rates ranged from a minimum of 73 cps to a maximum of 1124 cps with an average of 231 cps. There were 9,532 readings above the mean plus 2 standard deviations (401 cps) representing 4% of results (i.e typical of a normal distribution). Areas of inconsistent elevated count rate were investigated further and are discussed in the following sections.

2.2.1 RadSurvey Results Main Site

The map of radiation count rate for the main site can be seen below in Figures 1 and 2.

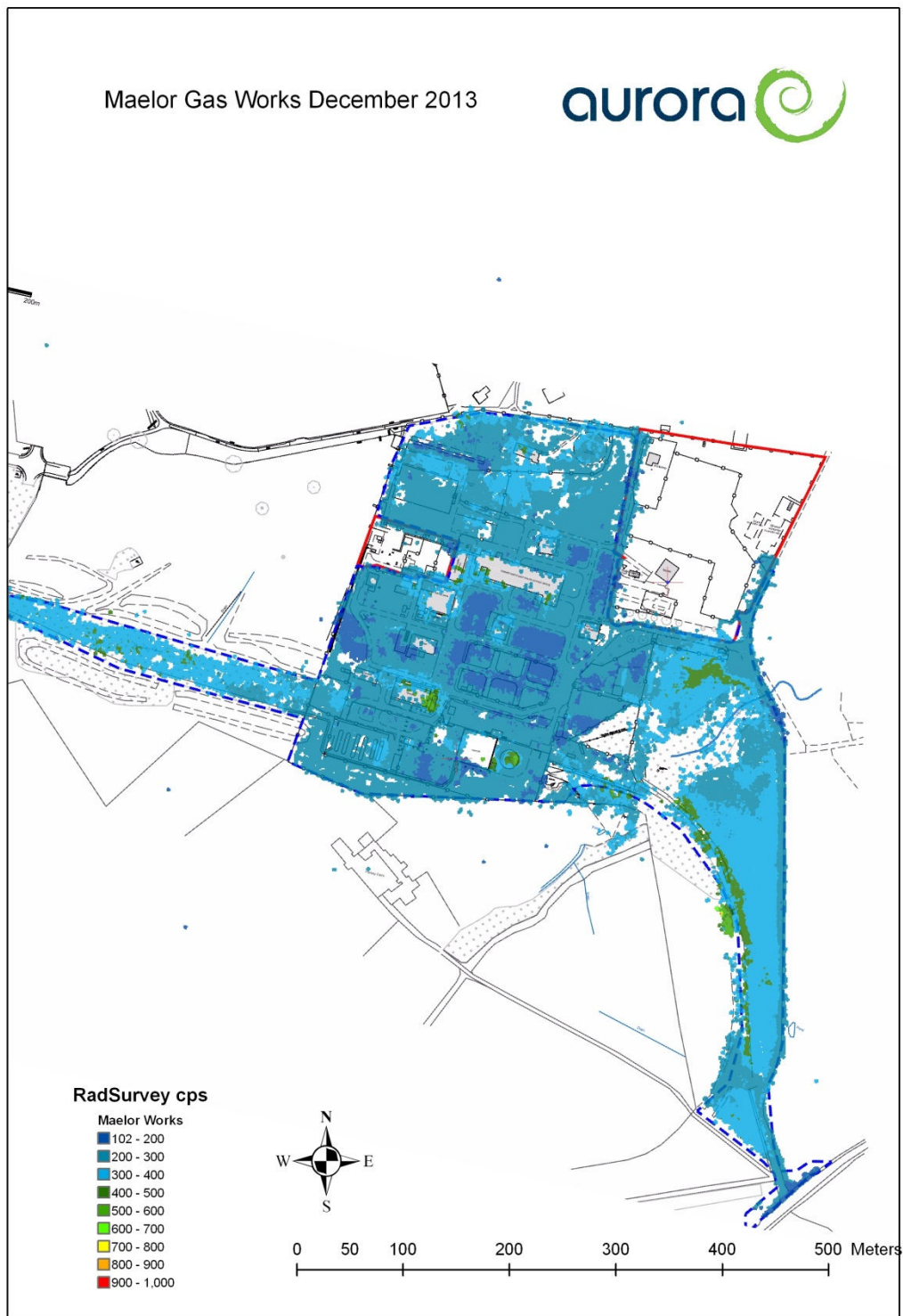


Figure 1 RadSurvey Map of Maelor Gas Works Site.

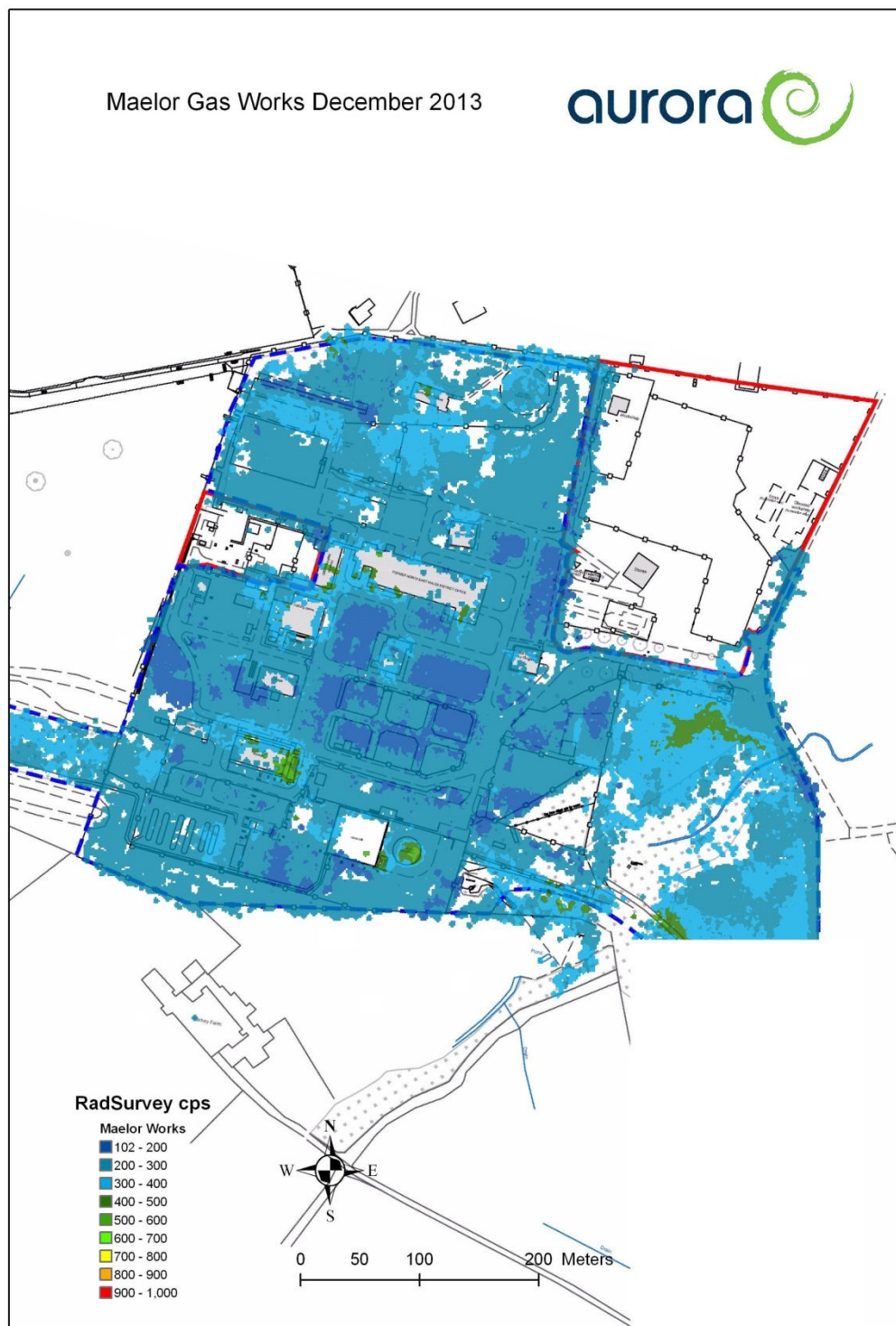


Figure 2 RadSurvey Map of Maelor Gas Works Main Site.

Typical background count rates vary from 150 to 250 cps which are indicated in blue on the above figure. There were some areas of elevated count rate on the main site in the range 400 to 600 cps as indicated in green on the above figure. Most of these areas were associated with brick buildings and brick walls where the naturally occurring radioactive

materials in the brick provide an enhanced count rate, especially where the detector has brick walls on both sides (see Figure A12 in Appendix 1). Other areas of slightly enhanced readings were created by naturally occurring radioactive materials in soil which again gave higher count rates where the detector was placed next to soil below and to the side such as near banks, dips and trenches. The other area of enhanced count rate was the circular pad at the south of the site, here the granite chippings provided an enhanced count rate again due to naturally occurring radioactivity. There were no elevated count rates in the area where previous remediation works had been carried out and no areas of elevated count rate on the main site which would suggest contamination with industrial radioactive materials.

There were some areas of the main site where it was not possible to access because of dense vegetation. In these areas a gardening contractor was employed to cut access paths so that good coverage could still be obtained (see Figure A3 in Appendix 1) even though a reading in every square metre could not be achieved. Some areas of the site had heavy tree coverage and in these areas it is not possible to obtain GPS satellite data, however they were still surveyed using the detector. No elevated radiation readings were found in these areas without GPS data.

2.2.2 RadSurvey Results Area B West

The map of radiation count rate for Area B West can be seen below in Figure 3.



Figure 3 RadSurvey Map of Maelor Gas Works Site Area B West.

Typical background count rates vary from 150 to 250 cps which are indicated in blue on the above figure. There were some areas of elevated count rate on the Area B West site in the range 400 to 600 cps as indicated in green on the above figure. Most of these areas were associated with naturally occurring radioactive materials in soil which again gave higher count rates where the detector was placed next to soil below and to the side such as near banks, dips and trenches.

One area of elevated significant count rate (up to 1,100 cps) which was inconsistent with surrounding soil was investigated further (see Figure 3 below). Excavation of this area revealed some pieces of glazed brick (see Figures A10 and A11 in Appendix 1). Decorative glazed bricks containing naturally occurring uranium are often found in municipal structures such as railways and hospitals. These bricks are not considered radioactive material for the purposes of legislation.

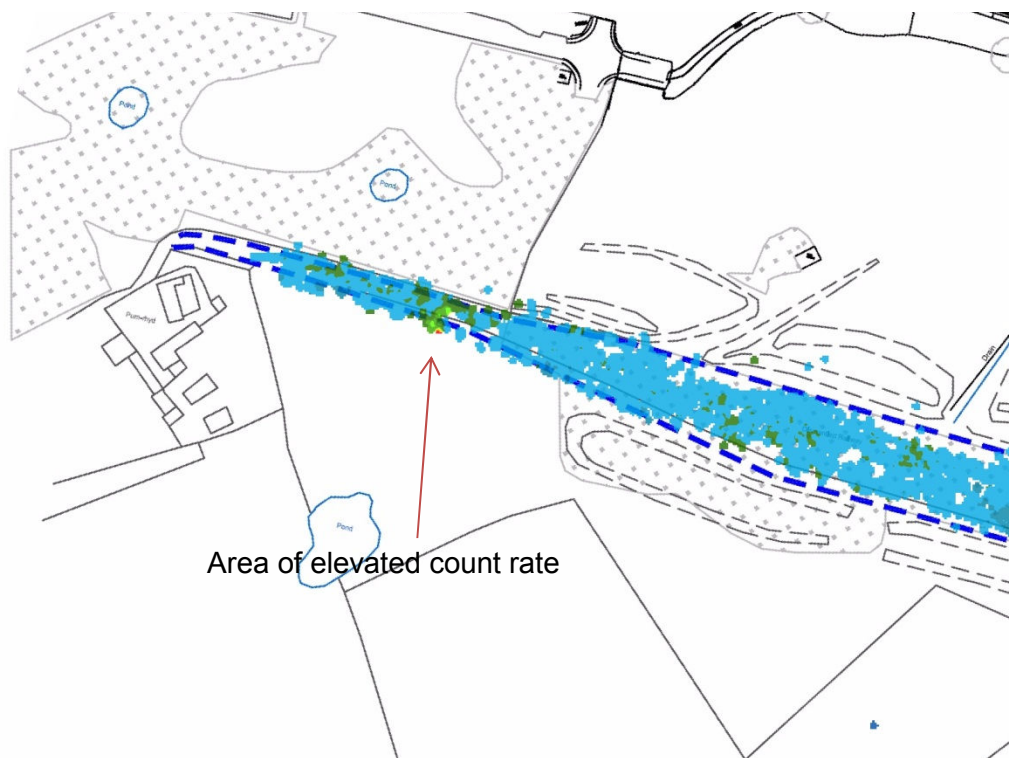


Figure 4 Area of Elevated Count Rate at Area B West.

Some areas of the site had heavy tree coverage and in these areas it is not possible to obtain GPS satellite data, however they were still surveyed using the detector. No elevated radiation readings were found in these areas without satellite GPS data.

2.2.3 RadSurvey Results Area B East

The map of radiation count rate for Area B East can be seen below in Figure 4.

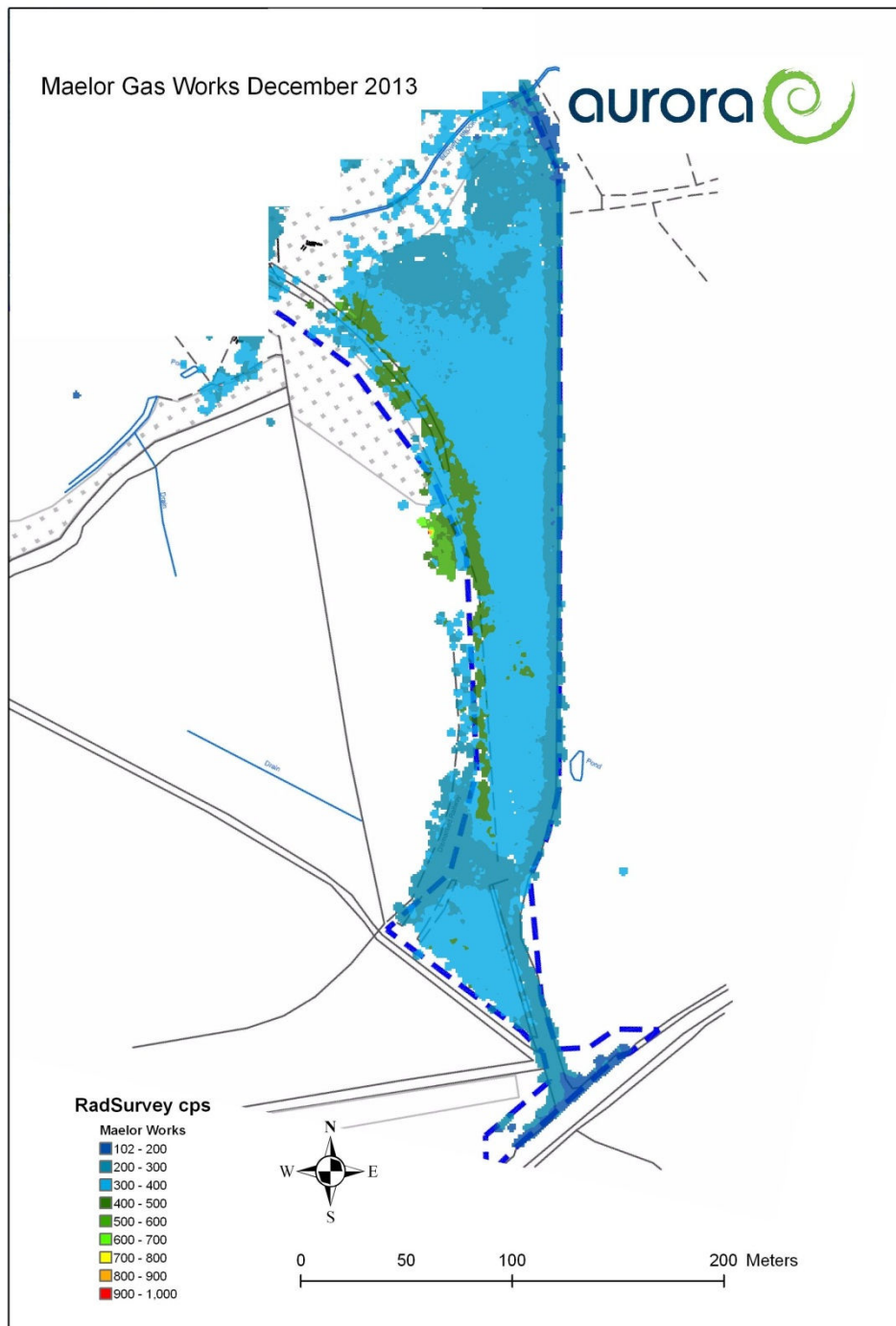


Figure 5 RadSurvey Map of Maelor Gas Works Site Area B East.

Typical background count rates vary from 150 to 250 cps which are indicated in blue on the above figure. There were some areas of elevated count rate on the Area B East site in the

range 400 to 600 cps as indicated in green on the above figure. Most of these areas were associated with naturally occurring radioactive materials in soil which again gave higher count rates where the detector was placed next to soil below and to the side such as near banks, dips and trenches.

One area of elevated significant count rate (up to 900 cps) which was inconsistent with surrounding soil was investigated further (see Figure 6 below). Excavation of this area revealed buried ash. Coal and oil contain naturally occurring radioactive materials such as uranium and radium, when burnt the heavier radioactive minerals are concentrated in the ash. This ash can be seen in Figure A9 in Appendix 1 and gave rise to elevated count rates approximately double the normal count rate and very consistent across all the ash material. The ash is not radioactive material for the purposes of legislation.

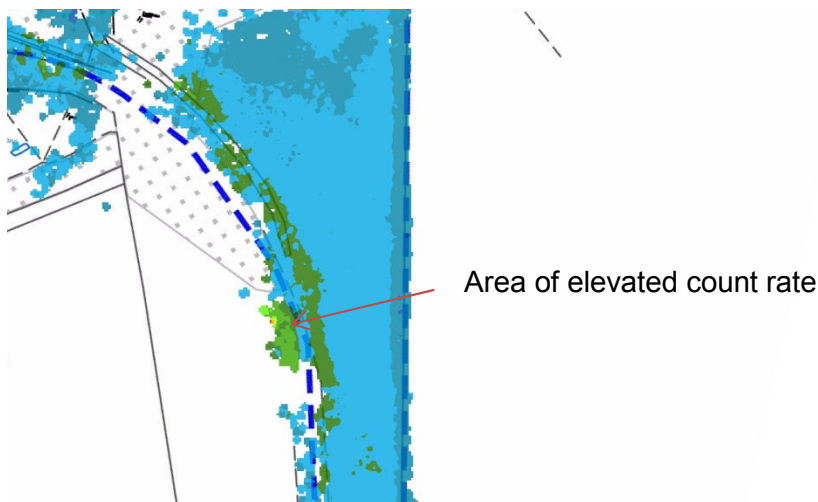


Figure 6 Area of Elevated Count Rate at Area B East.

2.3 Building Surveys

2.3.1 Floor probe

The Ludlum 239-1F floor probe consists of a gas proportional counter linked to a rate meter and is displayed in Figure 7. The height adjustable detector head has a proportional counter with a large active area of 582cm^2 . The counter contains thin anode wires inside a constant flow proportional gas detector using an argon methane gas mix, the gas provides a constant electrical charge gain while excluding air. The counter is sensitive to alpha and beta radiation (although it does not discriminate between them) through the aluminised boPET (biaxially-oriented polyethylene terephthalate) window covered by a protecting mesh. The probe is operated at a low walking speed (approximately 0.2 ms^{-1}).

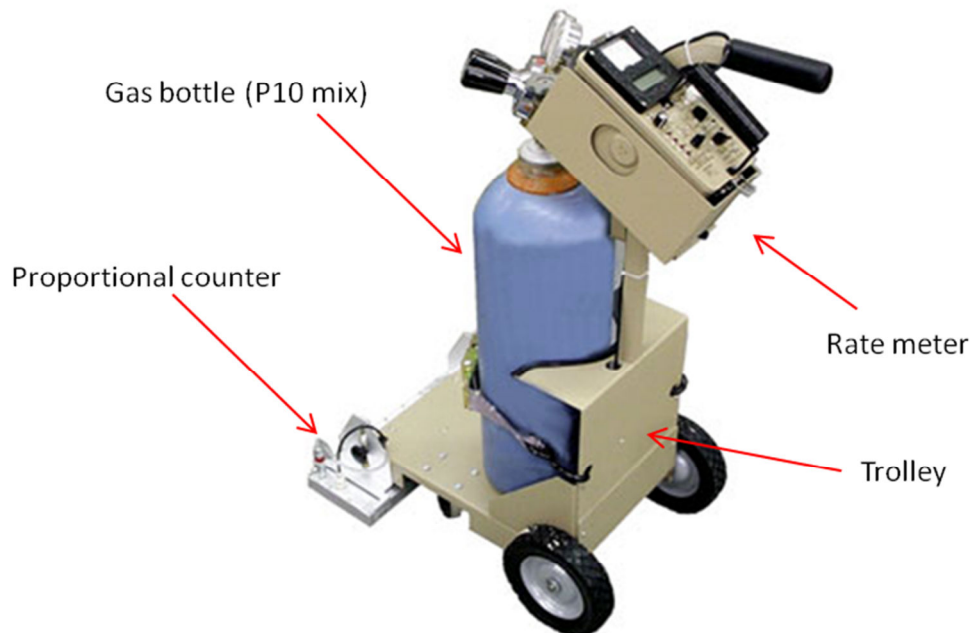


Figure 7: Ludlum 239-1F Floor Monitor

2.3.2 Other instruments

While the floor probe was used to cover some floor areas, hand held probes were also used to survey uneven floors, walls, benches, sinks and ventilation extracts. Details of all the instruments used are provided below in Table 1.

Table 1 Instruments Used

Instrument	Serial number	Calibration Due Date	Background Reading	Function Test Pre Work	Function Test Post Work
Floor Probe	146345 RN 015629	14/01/2014	$\alpha + \beta$ 800 – 1000 cpm	OK	OK
RM6 1667 Beta probe	AHP0236	08/02/2014	β 10 – 15 cps	OK	OK
Electra BP19 Beta probe	AHP0229	15/03/2014	β 10 -15 cps	OK	OK
Electra DP6 Alpha & Beta probe	AHP0098	06/02/2014	α 0.1 cps β 8-12 cps	OK	OK
Electra DP6 Alpha & Beta probe	AHP0273	11/10/2014	α 0.1 cps β 8-12 cps	OK	OK
Mini 900 44A Gamma probe	AHP0129	02/08/2014	γ 5 – 10 cps	OK	OK
Mini 900 44A Gamma probe	AHP0271	21/06/2014	γ 5 – 10 cps	OK	OK
Identifinder Gamma spectrometer	2506	07/02/2014	γ 50 – 80 cps	OK	OK

The background radiation readings measured on site are provided in Table 1 above. All organic materials contain some level of radioactivity. Naturally occurring radionuclides include the uranium (^{238}U and ^{235}U) and thorium (^{232}Th) decay chains commonly found in soils and rock and radioactive potassium (^{40}K) commonly found in wood, clay and brick. These background levels vary between different materials (e.g. rock and soil) and in different areas of the UK. The background readings for different instruments are detailed in this report as measured on the site however they are also typical of average background levels found throughout the UK.

2.4 Building Survey Results

All the buildings on site were surveyed including:

- Main reception
- Workshops
- Western Gas Alliances Building
- Wales and West Stores
- Former paint store
- Former North East Wales District Offices

Floors and walls of all buildings were surveyed (see Figure A4 in Appendix 1). No areas of elevated count rate and no evidence of contamination with radioactive materials were discovered during the building surveys.

2.5 Drain Surveys and Water Samples

Accessible drains were surveyed and swabbed, each drain cover was lifted and the drain was monitored using surface contamination probes (Electra DP6) and a gamma sensitive detector (Mini 900 44A). Swabs were analysed on the Aurora Tricab Liquid Scintillation Counter, the counter can identify the presence of soft beta emitting radioisotopes such as ^3H (tritium) as well as other radioisotopes. The drain survey results in are given in Table 2.

Table 2 Smear samples & liquid scintillation counter results

Sample	Sample Description	Liquid scintillation counting result counts per minute (cpm)			Surface contamination
		Channel 1 0 - 19 keV	Channel 2 19 - 156 keV	Channel 3 156-2000 keV	
S1	Background standard	14	7	11	
S2	Tritium standard	126,339	604	13	
S3	C14 standard	26,252	100,449	548	
1	Water sample from drain at SJ 38187 48274	10	13	14	<0.1 Bq/ml
2	Water sample from drain at SJ 38173 48272	8	15	13	<0.1 Bq/ml
3	Water sample from drain at SJ 38012 48268	26	13	15	<0.1 Bq/ml
4	Water sample from drain at SJ 38052 48287	28	16	16	<0.1 Bq/ml
5	Swab sample from drain at SJ 38042 48032	16	24	19	<0.1 Bq/cm ²

Sample	Sample Description	Liquid scintillation counting result counts per minute (cpm)			Surface contamination
		Channel 1 0 - 19 keV	Channel 2 19 - 156 keV	Channel 3 156-2000 keV	
6	Swab sample from drain at SJ 38042 48032	28	21	17	<0.1 Bq/cm ²

Note: Count rates exceeding approximately 120 cpm indicate that radioactivity is present

The location of water samples can be seen below in Figure 8

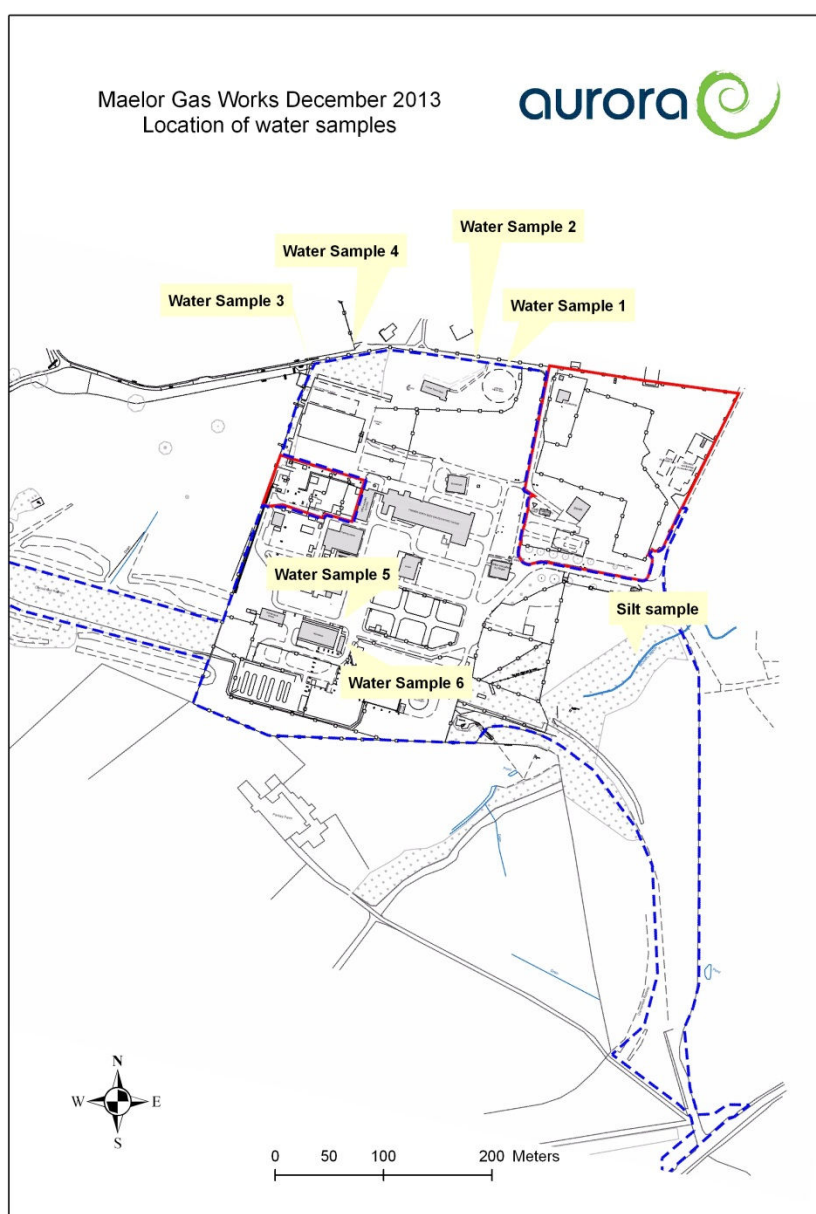


Figure 8 Location of water samples

3. BOREHOLES & TRIAL PITS

Boreholes and trial pits were excavated around the site under supervision by an Aurora Radiation Protection Supervisor (RPS). A cordoned off 'Supervised Area' was designated at each excavation site and a pre-works radiological survey was carried out at the surface.

For trial pits the top soil was removed and placed to one side and monitored for radioactive contamination. All arisings were then placed on a polythene sheet and each load monitored for radioactive contamination. A sample was taken from material with higher count rates if applicable. The trial pit was then back filled and top soil replaced. The bucket and tyres of the excavator were monitored for radioactive contamination before the 'Supervised Area' was removed prior to moving to the next location. Excavators and drilling rigs were regularly monitored during excavation work and again before going off site.

3.1 Trial Pits and Boreholes on the Main Site

The following trial pits were supervised on the main site:

TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP8A, TP9, TP10, TP11, TP12, TP13, TP15, TP16, TP17, TP18, TP19, TP20, TP21, TP22, TP23, TP24, TP25, TP26, TP27, TP28, TP29, TP30, TP31, TP32, TP33, TP34, TP35, TP36, TP37, TP40, TP41, TP49, TP50, TP51.

No regions of elevated count rate were found during surveys of all the trial pits. Some pellets were observed in Trial Pit 4 although these were not radioactive and matched the previous description of non-radioactive spacers (ref. 1). TP4 was in the location of the previous remediation work in the late 1990s.

The following boreholes were supervised on the main site:

BH1, BH2, BH3, BH4, BH5, BH6, BH7, BH23, BH24

For boreholes, arisings were placed on a large polythene sheet and monitored as earth was removed and readings taken at successive depths. Samples were taken from the region of highest count rate if there were variations. On some of the boreholes it was possible to lower a gamma probe on an extended cable to obtain gamma count rate at various depths. The results of those measurements can be found in the tables below. It should be noted it is common for the probe reading to increase with depth as the probe is increasingly surrounded by naturally occurring radioactivity in soil. Count rates in excess of 50 cps by Mini 900 44A would typically indicate artificial radioactivity. No regions of elevated count rate were found during surveys of the boreholes.

Table 3 Excavation ID: **Borehole 6 IHB B/H6 021213**

Depth mm	Gamma Count Rate Mini 900 44A cps
0	10
100	10
200	15-20
300	15-20
500	15-20
1000	15-20
2000	15-20
3000	15-20
4000	15-20
5000	15-20

Table 4 Excavation ID: **Borehole 5 IHB B/H5 041213**

Depth mm	Gamma Count Rate Mini 900 44A cps
0	10
100	10
500	10
1000	10
2000	10
3000	10
4000	10
4500	20
5000	20-25
5500	20-25
6000	20-25
6500	25-30

Water at 6500mm

Table 5 Excavation ID: **Borehole 23 IHB B/H23 091213**

Depth mm	Gamma Count Rate Mini 900 44A cps
0	10
100	10
200	10
300	10
400	10
500	10
600	15-20
700	15-20
800	15-20
900	15-20
1000	15-20
1200	15-20

Water at 1.2m

Table 6 Excavation ID: **Borehole 24 IHB B/H24 091213**

Depth mm	Gamma Count Rate Mini 900 44A cps
0	10
100	10
200	10
300	10
400	10
500	10
600	15-20
700	15-20
800	15-20
900	15-20
1000	15-20
1200	15-20

Water at 1.2m



Figure 9 Location of trial pits and boreholes

4. SAMPLE ANALYSIS

Samples from boreholes and trial pits were taken by Aurora for analysis by Environmental Scientifics Group (ESG) a summary of the results is provided in Table 18 below with the full report in Appendix 3.

Some of the samples showed levels of the man-made radionuclide ^{137}Cs above the limit of detection however they were typical of levels of ^{137}Cs that can be present in the environment from fallout (e.g. Chernobyl) and historic discharges from nuclear facilities.

The soil sample from TP4 (where the previous remediation work had been carried out in the late 1990's) showed some elevated levels of depleted uranium. Depleted uranium is characterised in a gamma spectroscopy sample by the ^{238}U daughter product ^{234}Th which is a gamma emitter. The absence of daughter products from lower down the decay chain (such as ^{214}Pb and ^{214}Bi) indicate processed rather than natural uranium. The maximum measured depleted uranium level at TP4 was 590 Bq/kg. This is significantly lower than the 'out of scope' threshold in Environmental Permitting (Amendment) (England and Wales) Regulations 2011 of 1,000 Bq/kg and therefore this material is not considered radioactive for the purposes of the legislation.

The results of the sample analysis show there is no contamination with industrial radioactive materials.

Table 18 Sampling results Main Site

Sample Ref	Description	¹³⁷Cs Bq/kg	²¹⁰Pb Bq/kg	²¹⁴Bi Bq/kg	²²⁶Ra Bq/kg	²³⁴Th Bq/kg	²³⁵U Bq/kg
BH4	Soil from BH4	<0.7	<20	14	31	<30	<4
BH7	Soil from BH7	<2	<20	21	45	<20	<4
TP3	Soil from TP3	<2	<30	20	50	<30	<5
TP2	Soil from TP2	<1	<30	19	<20	<30	<2
TP7	Soil from TP7	<2	<30	16	-	81	<4
TP4	Soil from TP4	<2	<30	37	-	590	15
TP5	Soil from TP5	<2	<30	46	90	<30	<6
TP32	Soil from TP32	<2	<20	22	<20	<30	<2
BH24	Soil from BH24	<2	<30	30	59	<40	<6
TP51	Soil from TP51	<2	<30	13	<20	<30	<2
BH11	Soil from BH11	5	<30	27	57	<30	<6
BH1	Soil from BH1	<2	<30	14	<20	<30	<2
TP8	Soil from TP8	<2	<30	31	54	<30	<4
BH6	Soil from BH6	<2	50	28	48	<30	<5
TP15	Soil from TP15	3.7	<30	12	<40	<30	<2
TP28	Soil from TP28	<2	<30	20	<30	<30	<2
W13	Sludge from drain at SJ 38034 48098	12	170	12	<30	<30	<2
W3A	Silt from site stream	3.3	58	13	<20	<30	<1
W4	Sludge from drain at SJ 38002 48047	<2	<20	16	<20	<20	<2
W5	Sludge from drain at SJ 38042 48032	<2	<30	14	<20	<30	<2
W8	Sludge from drain at SJ 38081 48060	31	140	8	<20	<30	<2
W3	Sludge from drain at SJ 37967 48102	23	210	11	<20	<20	<2

Appendix 1 Photos



Figure A1 Non-radioactive pellets found on main site



Figure A2 Using the RadSurvey system on the Maelor site.



Figure A3 Pathways cut through heavy vegetation to facilitate survey



Figure A4 Carrying out internal building surveys



Figure A5 Supervised Radiation Area signs at dig locations.

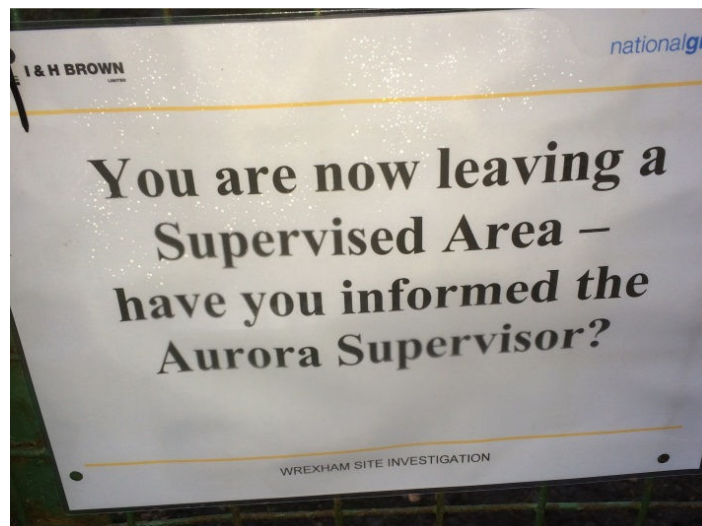


Figure A6 Signs on exit



Figure A7 The health physics surveyor supervises drilling works and monitors excavated material.



Figure A8 Supervising and monitoring drilling works.



Figure A9 Slightly elevated count rates due to naturally occurring radioactivity in ash.



Figure A10 Elevated beta and alpha count rates from naturally occurring radioactivity in a ceramic glazed brick.



Figure A11 Elevated gamma count rates from naturally occurring radioactivity in a ceramic glazed brick.



Figure A12 Some areas of slightly higher count rate on the RadSurvey were due to the proximity of naturally occurring radioactivity in brick.

Appendix 3 Gamma Spectroscopy Results



Test Report: **RM4412**

Radiochemical Analysis of Soil Samples

Prepared for Emma Leishman
Aurora Health Physics
January 2014



Radiochemical Analysis of Soil Samples

Customer: Aurora Health Physics
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Library Avenue
Harwell Oxford
Oxfordshire
OX11 0SG

Testing Facility: Environmental Scientifics Group
Unit 12
Moorbrook
Southmead Industrial Park
Didcot
Oxon
OX11 7HP

Quote Number: ENR-ANU-7512Rev3

Customer Reference: Maelor Gas Works

Laboratory Reference: RM4412

Samples Received: 18 December 2013

Sample Condition: Satisfactory, Ambient

Analysis Completed: 07 January 2014

Report Author:

A blue ink signature, likely belonging to Carla Madeley, written over a horizontal line.

Author's Name: Carla Madeley

Job Title: Analyst

Approved by: *M. Lane*

Date: 13/01/14

Approver's name: Melanie Lane

Job Title: Analyst

Report Date: 13 January 2014



Test Report RM4412: Page 1 of 8



Introduction

The samples were received in good condition and logged into the Environmental Scientifics Group sample receipt system.

Experimental

The samples were placed in containers to match the appropriate calibration geometries and then measured by high-resolution gamma ray spectrometry.

Radioactivity Analysis by Gamma Ray Spectrometry (SOP/2029 Issue 4)

The measurement technique is based on the use of high purity germanium (HPGe) detectors coupled to an Ortec gamma ray spectroscopy system. The gamma ray spectra are stored on a computer and analysed using the software programme Fitzpeaks for photopeak identification and quantification. The detectors are calibrated for efficiency using a mixed radionuclide standard, which covers an energy range of approximately 60-2000 keV. The efficiency of gamma rays between 30 keV and 120 keV are determined on an individual basis.

Application of decay corrections for the naturally occurring daughter radionuclides of uranium and thorium assumes that the series daughter radionuclides are all in secular equilibrium and therefore decay with the half-life of the first radionuclide in the series.

Results

Results are presented in the following tables. Result uncertainties for each analysis are stated in the results tables or beneath the tables where applicable.

It should be noted that tests/sampling marked with an asterisk "*" in this report are not included in the UKAS accreditation schedule for the laboratory.



High Resolution Gamma Ray Spectrometry Results

Customer Reference	Laboratory Reference	Be-7	K-40	Co-60	Cs-134	Cs-137	Tl-208	Pb-210	Pb-212	Bi-212
BH4	RM4412	<6	290 ± 27	<0.8	<0.9	<0.7	6.9 ± 0.86	<20	20 ± 1.8	20 ± 7.3
BH7	RM4413	<9	330 ± 38	<2	<2	<2	9.1 ± 1.3	<20	27 ± 2.6	39 ± 13
TP3	RM4414	<9	310 ± 35	<2	<2	<2	8.8 ± 1.5	<30	25 ± 2.5	<20
TP2	RM4415	<8	440 ± 43	<2	<2	<1	9.1 ± 1.2	<30	28 ± 2.5	37 ± 12
TP7	RM4416	<8	280 ± 32	<2	<2	<2	5.7 ± 1.1	<30	17 ± 1.9	<20
~~TP1~~	~~RM4417~~	~~<8~~	~~340 ± 35~~	~~<2~~	~~<2~~	~~<2~~	~~9.1 ± 1.2~~	~~<30~~	~~20 ± 1.8~~	~~20 ± 7.3~~
~~TP2~~	~~RM4418~~	~~<8~~	~~500 ± 50~~	~~<2~~	~~<2~~	~~<2~~	~~11 ± 2.1~~	~~<30~~	~~20 ± 1.8~~	~~20 ± 7.3~~
TP4	RM4419	<10	160 ± 27	<2	<2	<2	9.6 ± 1.4	<30	27 ± 2.7	<20
TP5	RM4420	<20	240 ± 38	<3	<2	<2	12 ± 1.8	<30	35 ± 3.6	<30

Notes:

- Results are presented as Bq.kg⁻¹ of sample as received.
- Detector calibrations are based upon homogeneous standard solutions. For quantification purposes the samples are assumed to be homogeneous.
- An asterisk * indicates that the analysis is not covered by UKAS accreditation.
- ²²⁶Ra has only one gamma ray at 186 keV and the major gamma ray from ²³⁵U also occurs at 186 keV. ²³⁵U can be measured by the lower abundance gamma ray at 144 keV and if a positive result for ²³⁵U is reported the ²²⁶Ra result will be unreliable and overestimated. However even if ²³⁵U is below the LoD there may still be a contribution to the ²²⁶Ra from ²³⁵U and the ²²⁶Ra result may be unreliable and overestimated. If an accurate result for ²²⁶Ra is required this is better obtained by radiochemical analysis.
- Results below and above the LoD are reported to 1 and 2 significant figures, respectively.

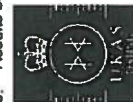


High Resolution Gamma Ray Spectrometry Results

Customer Reference	Laboratory Reference	Be-7	K-40	Co-60	Cs-134	Cs-137	Tl-208	Pb-210	Pb-212	Bi-212
TP32	RM4421	<10	420 ± 45	<2	<2	<2	9.5 ± 1.5	<20	33 ± 2.9	36 ± 14
BH24	RM4422	<20	760 ± 72	<2	<2	<2	17 ± 1.9	<30	52 ± 4	55 ± 18
TP51	RM4423	<20	160 ± 29	<2	<2	<2	4.6 ± 1.2	<30	12 ± 2.1	<20
BH11	RM4424	<20	600 ± 63	<3	<2	5 ± 1.6	14 ± 2	<30	45 ± 3.8	47 ± 19
BH1	RM4425	<8	370 ± 36	<2	<2	<2	8.3 ± 1.2	<30	25 ± 2.3	32 ± 11
TP8	RM4426	<9	110 ± 20	<2	<2	<2	2.9 ± 0.85	<30	7.3 ± 1.4	<20
BH6	RM4427	<9	320 ± 35	<2	<2	<2	8 ± 1.2	50 ± 19	28 ± 2.5	32 ± 12
TP15	RM4428	<20	310 ± 40	<3	<2	3.7 ± 1.4	7.9 ± 1.6	<30	24 ± 2.8	<30
TP28	RM4429	<9	250 ± 31	<2	<2	<2	7.2 ± 1.2	<30	23 ± 2.3	31 ± 12

Notes:

- Results are presented as Bq.kg⁻¹ of sample as received.
- Detector calibrations are based upon homogeneous standard solutions. For quantification purposes the samples are assumed to be homogeneous.
- An asterisk (*) indicates that the analysis is not covered by UKAS accreditation.
- 226Ra has only one gamma ray at 186 keV and the major gamma ray from 235U also occurs at 186 keV. 235U can be measured by the lower abundance gamma ray at 144 keV and if a positive result for 235U is reported the 226Ra result will be unreliable and overestimated. However even if 235U is below the LoD there may still be a contribution to the 226Ra from 235U and the 226Ra result may be unreliable and overestimated. If an accurate result for 226Ra is required this is better obtained by radiochemical analysis.
- Results below and above the LoD are reported to 1 and 2 significant figures, respectively.



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High Resolution Gamma Ray Spectrometry Results

Customer Reference	Laboratory Reference	Be-7	K-40	Co-60	Cs-134	Cs-137	Tl-208	Pb-210	Pb-212	Bi-212
~~W13~~	~~RM4432~~	~~18 ± 6.9~~	~~190 ± 14~~	~~<2~~	~~<2~~	~~<2~~	~~11 ± 1.1~~	~~<20~~	~~14 ± 1.7~~	~~<20~~
~~W3A~~	~~RM4433~~	~~25 ± 6.4~~	~~130 ± 21~~	~~<2~~	~~<1~~	~~3.3 ± 0.83~~	~~3.7 ± 0.84~~	~~58 ± 19~~	~~7.5 ± 1.3~~	~~<20~~
W13	RM4432	18 ± 6.9	240 ± 28	<2	<2	12 ± 1.5	5 ± 0.99	170 ± 34	14 ± 1.7	<20
W3A	RM4433	25 ± 6.4	130 ± 21	<2	<1	3.3 ± 0.83	3.7 ± 0.84	58 ± 19	7.5 ± 1.3	<20
W4	RM4434	<10	190 ± 27	<2	<2	<2	5 ± 1.1	<20	16 ± 2.1	<20
W5	RM4435	<9	200 ± 27	<2	<2	<2	5.1 ± 1.1	<30	15 ± 1.8	<20
W8	RM4436	<9	170 ± 25	<2	<2	31 ± 2.6	3.6 ± 0.92	140 ± 28	10 ± 1.7	<20
W3	RM4437	22 ± 7	200 ± 27	<2	<2	23 ± 2.1	3.6 ± 0.97	210 ± 37	11 ± 1.6	<20

Notes:

1. Results are presented as Bq kg⁻¹ of sample as received.
2. Detector calibrations are based upon homogeneous standard solutions. For quantification purposes the samples are assumed to be homogeneous.
3. An asterisk "*" indicates that the analysis is not covered by UKAS accreditation.
4. ²²⁶Ra has only one gamma ray at 186 keV and the major gamma ray from ²³⁵U also occurs at 186 keV. ²³⁵U can be measured by the lower abundance gamma ray at 144 keV and if a positive result for ²³⁵U is reported the ²²⁶Ra result will be unreliable and overestimated. However even if ²³⁵U is below the LoD there may still be a contribution to the ²²⁶Ra from ²³⁵U and the ²²⁶Ra result may be unreliable and overestimated. If an accurate result for ²²⁶Ra is required this is better obtained by radiochemical analysis.
5. Results below and above the LoD are reported to 1 and 2 significant figures, respectively.





High Resolution Gamma Ray Spectrometry Results

Customer Reference	Laboratory Reference	Pb-214	Bi-214	Ra-224	Ra-226*	Ac-228	Th-234	Pa-234m	U-235	Am-241
BH4	RM4412	16 ± 1.6	14 ± 1.7	<20	31 ± 12	21 ± 2.4	<30	<90	<4	<2
BH7	RM4413	24 ± 2.3	21 ± 3	<20	45 ± 15	30 ± 4	<20	<200	<4	<2
TP3	RM4414	23 ± 2.3	20 ± 2.5	<30	50 ± 17	29 ± 3.6	<30	<200	<5	<3
TP2	RM4415	21 ± 2	19 ± 2.4	<30	<20	28 ± 3.3	<30	<200	<2	<3
TP7	RM4416	17 ± 1.9	16 ± 2.3	<20	58 ± 15	17 ± 2.9	81 ± 23	<200	<4	<3
~~TP4~~	~~RM4417~~	~~14 ± 0.8~~	~~13 ± 1.3~~	~~78 ± 13~~	~~85 ± 23~~	~~64 ± 5.6~~	~~30~~	~~300~~	~~3~~	~~3~~
~~TP5~~	~~RM4418~~	~~38 ± 5.4~~	~~34 ± 4.9~~	~~30~~	~~300~~	~~14 ± 6~~	~~30~~	~~300~~	~~3~~	~~3~~
TP4	RM4419	39 ± 3.1	37 ± 3.6	<30	220 ± 28	27 ± 4.2	590 ± 61	480 ± 150	15 ± 4.1	<3
TP5	RM4420	51 ± 4.1	46 ± 4.7	<30	90 ± 24	36 ± 5.1	<30	<300	<6	<3

Notes:

- Results are presented as Bq.kg⁻¹ of sample as received.
- Detector calibrations are based upon homogeneous standard solutions. For quantification purposes the samples are assumed to be homogeneous.
- An asterisk "*" indicates that the analysis is not covered by UKAS accreditation.
- ²²⁶Ra has only one gamma ray at 186 keV and the major gamma ray from ²³⁵U also occurs at 186 keV. ²³⁵U can be measured by the lower abundance gamma ray at 144 keV and if a positive result for ²³⁵U is reported the ²²⁶Ra result will be unreliable and overestimated. However even if ²³⁵U is below the LoD there may still be a contribution to the ²²⁶Ra from ²³⁵U and the ²²⁶Ra result may be unreliable and overestimated. If an accurate result for ²²⁶Ra is required this is better obtained by radiochemical analysis.
- Results below and above the LoD are reported to 1 and 2 significant figures, respectively.



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High Resolution Gamma Ray Spectrometry Results

Customer Reference	Laboratory Reference	Pb-214	Bi-214	Ra-224	Ra-226*	Ac-228	Th-234	Pa-234m	U-235	Am-241
TP32	RM4421	26 ± 2.4	22 ± 3.1	<20	<20	33 ± 4.3	<30	<200	<2	<2
BH24	RM4422	33 ± 3.1	30 ± 3.5	<30	59 ± 19	54 ± 5.2	<40	<200	<6	<3
TP51	RM4423	17 ± 2.1	13 ± 3	<20	<20	16 ± 4.9	<30	<200	<2	<3
BH11	RM4424	34 ± 3.4	27 ± 4.1	57 ± 18	57 ± 23	48 ± 6	<30	<300	<6	<3
BH1	RM4425	15 ± 1.9	14 ± 2.2	<20	<20	23 ± 3.3	<30	<200	<2	<2
TP8	RM4426	30 ± 2.6	31 ± 3.1	<30	54 ± 16	8.8 ± 3.3	<30	<200	<4	<3
BH6	RM4427	32 ± 2.6	28 ± 3	<20	48 ± 18	28 ± 3.5	<30	<200	<5	<2
TP15	RM4428	15 ± 2.4	12 ± 3.4	<30	<40	23 ± 4.9	<30	<300	<2	<2
TP28	RM4429	21 ± 2.2	20 ± 2.6	<20	<30	22 ± 3.5	<30	<200	<2	<3

Notes:

- Results are presented as Bq.kg⁻¹ of sample as received.
- Detector calibrations are based upon homogeneous standard solutions. For quantification purposes the samples are assumed to be homogeneous.
- An asterisk "*" indicates that the analysis is not covered by UKAS accreditation.
- ²²⁶Ra has only one gamma ray at 186 keV and the major gamma ray from ²³⁵U also occurs at 186 keV. ²³⁵U can be measured by the lower abundance gamma ray at 144 keV and if a positive result for ²³⁵U is reported the ²²⁶Ra result will be unreliable and overestimated. However even if ²³⁵U is below the LoD there may still be a contribution to the ²²⁶Ra from ²³⁵U and the ²²⁶Ra result may be unreliable and overestimated. If an accurate result for ²²⁶Ra is required this is better obtained by radiochemical analysis.
- Results below and above the LoD are reported to 1 and 2 significant figures, respectively.

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High Resolution Gamma Ray Spectrometry Results

Customer Reference	Laboratory Reference	Pb-214	Bi-214	Ra-224	Ra-226*	Ac-228	Th-234	Pa-234m	U-235	Am-241
~~RM4430~~	~~RM4430~~	~~30 ± 3.0~~	~~20 ± 2.0~~	~~<30~~	~~47 ± 4.0~~	~~30 ± 3.0~~	~~<40~~	~~<200~~	~~<5~~	~~<2~~
~~RM4431~~	~~RM4431~~	~~30 ± 2.0~~	~~22 ± 0.3~~	~~<30~~	~~54 ± 2.2~~	~~42 ± 4.1~~	~~<40~~	~~<200~~	~~<5~~	~~<2~~
W13	RM4432	15 ± 1.9	12 ± 2.4	<20	<30	14 ± 3.3	<30	<200	<2	<2
W3A	RM4433	14 ± 1.7	13 ± 2	<20	<20	9.3 ± 3	<30	<200	<1	<2
W4	RM4434	17 ± 2.2	16 ± 2.4	<30	<20	18 ± 3.2	<20	<200	<2	<2
W5	RM4435	15 ± 1.8	14 ± 2.3	<30	<20	17 ± 3.1	<30	<200	<2	<2
W6	RM4436	8.6 ± 1.6	8.3 ± 2	<30	<20	12 ± 2.9	<30	<200	<2	<2
W3	RM4437	12 ± 1.7	11 ± 2.4	<30	<20	15 ± 4.1	<20	<200	<2	<2

Notes:

- Results are presented as Bq.kg⁻¹ of sample as received.
- Detector calibrations are based upon homogeneous standard solutions. For quantification purposes the samples are assumed to be homogeneous.
- An asterisk "*" indicates that the analysis is not covered by UKAS accreditation.
- ²²⁶Ra has only one gamma ray at 186 keV and the major gamma ray from ²³⁵U also occurs at 186 keV. ²³⁵U can be measured by the lower abundance gamma ray at 144 keV and if a positive result for ²³⁵U is reported the ²²⁶Ra result will be unreliable and overestimated. However even if ²³⁵U is below the LoD there may still be a contribution to the ²²⁶Ra from ²³⁵U and the ²²⁶Ra result may be unreliable and overestimated. If an accurate result for ²²⁶Ra is required this is better obtained by radiochemical analysis.
- Results below and above the LoD are reported to 1 and 2 significant figures, respectively

