Sellafield Ltd

Facility Characterisation Template – Technical Report

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Characterisation of metal in support of decommissioning a Reactor Site

Preparation and Approval

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Executive Summary

Calder Hall, located on the Sellafield Site in the North West of England, was the world's first commercial nuclear power station. It safely produced electricity for the national grid for 47 years before finally closing down in 2003. Since then, decommissioning activities have been taking place in order to reduce the hazard posed by the aged structures.

In preparation for the removal of the 16 heat exchanger structures at Calder Hall, a phase of decommissioning work has been initiated which involves the removal of over 2500te of pipework and structural steelwork surrounding the heat exchangers.

To support the decommissioning and optimised waste routing of the metal, a programme of characterisation has been executed by the Sellafield Ltd Facility Characterisation team. The strategy sought to maximise the quantity of metal for unrestricted release from the site. In order to achieve this, there were numerous challenges which required investigative work and technical justifications to underpin the waste sentencing decisions. These included:

- Depth profiling of metal to determine whether material in close proximity to the reactor was activated.
- Coupon sampling of pipework to determine bulk activity concentrations of tritium.
- Activity assessment of high radiation reactor gas pipework through modelling to avoid dose to sample team.
- Sampling of paint coating structural steelwork to quantify activity concentrations resulting from an accumulation of over 50 years of atmospheric deposition.
- Dose assessments on painted metal that underpinned the justification to release it from the site with minimal decontamination, despite trace levels of activity within the paint.

Despite the challenges, comprehensive characterisation has enabled in excess of 90% to be sentenced as Radioactive Substances Act (RSA) '93 exempt material with no or limited treatment, enabling huge safety, environmental and cost savings to be realised.

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Contents

1.0 Abbreviations

DQO	Data Quality Objectives
EO	Exemption Order
EPR	Environmental Permitting Regulations
HEx	Heat Exchanger
HP	High Pressure
IAEA	International Atomic Energy Authority
ILW	Intermediate Level Waste
LLW	Low Level Waste
LoD	Limit of Detection
LP	Low Pressure
NICoP	Nuclear Industry Code of Practice
RP	Radiation Protection
RSA	Radioactive Substances Act
SNLS	Sellafield Nuclear Licensed Site
SoLA	Substances of Low Activity
UCL	Upper Confidence Level

2.0 Definitions

RSA Exempt	An *article* or *substance* that is radioactive or contaminated under the Radioactive Substances Act 1993 (RSA 93) because it contains levels of specified radioelements above RSA 93 Schedule 1 exclusion limits or because it contains other radioelements wholly or partly attributable to either an artificial process or as a result of the disposal of radioactive waste, but in both cases at levels below relevant limits in Exemption Orders under the Act.
UCL_{95}	The value below which the true mean can be said to lie, with 95% confidence.

3.0 Introduction

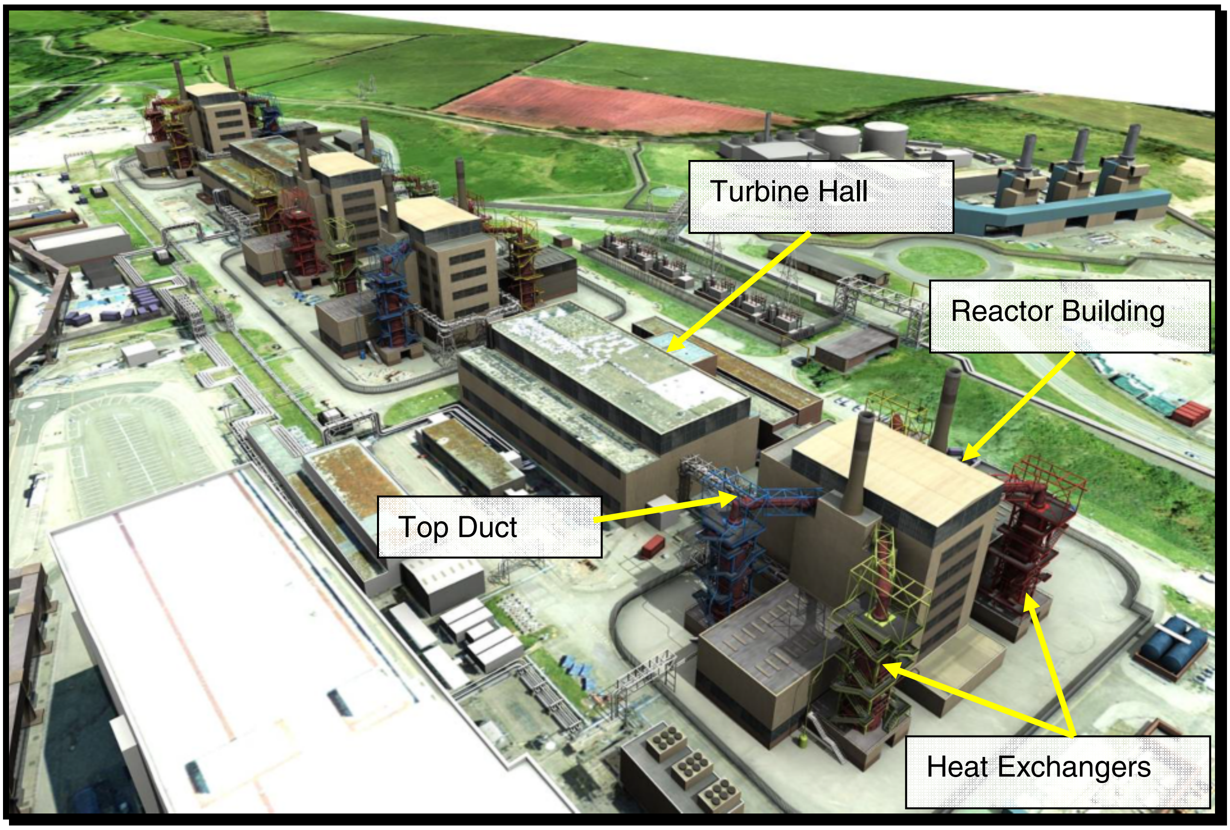
Calder Hall lies within the Sellafield Nuclear Licensed Site (SNLS), a large industrial site located near the Cumbrian coast in the North West of England. The site is just under 1 km from the Irish Sea coast, adjacent to the River Calder, at an altitude of approximately 20-30 metres (m) above Ordnance Datum. The SNLS comprises a large complex of nuclear plants, including spent fuel storage ponds, reprocessing plants, waste treatment plants and waste storage plants. Calder Hall represents approximately 27 hectares (ha) of the 300 ha SNLS.

Calder Hall was built and commissioned between 1953 and 1959 finally ceasing generation of electricity at the end of March 2003. The station comprised four identical gas cooled Magnox type reactors, each consisting of a graphite core enclosed in a cylindrical steel pressure vessel surrounded by a concrete biological shield. When operating, the reactors were cooled using carbon dioxide. Each reactor had four heat exchangers (or boilers), located outside the biological shield, which supplied steam to drive the turbines.

There were two turbine halls, each containing four 30 MW capacity steam turbine generating units, which were cooled by four cooling towers. In addition, there were a number of ancillary buildings on the site that were required to support the station during operations such as administration and welfare buildings, a chemistry laboratory, workshops and stores.

A number of facilities common to other Magnox Power Stations were not required at Calder Hall due to the availability of alternative facilities on the main Sellafield site, including; fuel cooling ponds, liquid radioactive effluent treatment plants and Intermediate Level Waste (ILW) storage facilities.

Picture 1. Calder Hall Site layout



Following the reactors being finally shutdown in 2003, a programme of hazard reduction was instituted. This included the removal and disposal of a significant proportion of the asbestos and oil inventory for the site.

A major part of the current phase of decommissioning involves the removal of metal from the site in preparation for the subsequent dismantling of the heat exchangers. In excess of 2500te of pipework and structural steelwork will be generated over the next 5 years as a result of decommissioning, which will require disposal.

Prior to removal of the metal, the radiological and non radiological characterisation of the material is paramount in order to determine the treatment and waste sentencing strategies.

Characterisation of the material is being performed by the Sellafield Ltd Facility Characterisation team, following a systematic defined process in line with the principles of the Data Quality Objective (DQO) methodology.

To date, all material has been assessed against the Substances of Low Activity (SoLA) Exemption Order (Ref. 1), which exempts waste from the provisions of the Radioactive Substances Act (RSA) 1993, providing that the total activity does not exceed 0.4 Bq/g. On the 1st April 2012, Sellafield Ltd will be implementing the Environmental Permitting Regulations (England and Wales) (Amendment) 2011 (Ref. 2), which specifies radionuclide specific limits, below which, items, materials and waste will be 'out of scope' and hence not classed as radioactive. These radionuclide specific limits are derived from Radiation Protection (RP) 122 (Ref. 3) and align to the limits adopted throughout the rest of Europe.

4.0 Scope

This paper details the characterisation programme undertaken to enable Calder Hall to decommission and sentence materials from the following areas:

- Heat exchanger top duct components
- Heat exchanger steam system pipework (external to the heat exchangers).
- Painted Structural Steelwork (stairways, walkways, handrails and gantries surrounding heat exchangers).

The paper assumes that the legislation in place is RSA'93, and does not consider the implications of EPR2011.

5.0 Report

In order to facilitate the safe removal of the 16 Calder Hall heat exchangers, a significant amount of preparatory decommissioning work is required to expose the cylindrical 300te vessels. Approximately 150 te of structural steelwork, pipes, valves, steam drums and ducting are required to be removed in a systematic manner to reveal the free standing heat exchangers.

Picture 2. Heat Exchanger with surrounding pipework, stairways and access platforms.

The key steps in the initial phase of decommissioning include:

1. Top duct elbow removal
2. Top duct bellows, mid section and pipebridge removal
3. Steam line removal including, small bore, large bore, steam drums, vent lines and valves.
4. Stairways, walkways, platforms and handrails removal.

In order to support and inform the above decommissioning activities, the metal was grouped into populations based on expected contamination mechanisms.

Preliminary scoping and data gathering identified three potential mechanisms for contamination of the metal and a potential for activation of material in close proximity to the reactor building. The potential contamination mechanisms were as follows:

- Direct contact with reactor gas (CO_2).
- Potential for tube leaks allowing reactor gas to enter the steam system.
- Atmospheric deposition of contamination resulting from historic aerial discharges across the Sellafield Site.

Each of the above contamination mechanisms together with activation had to be taken into account when characterising each population of material. The groups shown in Table 1 were defined.

Table 1. Contamination / activation mechanisms affecting the various metal components / groups.

	Contamination Mechanism / Activation			
	Direct contact with reactor gas	Direct contact with steam (with potential for contamination from reactor gas)	Atmospheric deposition	Activation
Top Duct Components (Elbows, Bellows, Mid Sections)	✓	✗	✓ (minor due to recent removal of insulation lagging pipework)	✓
Steam system pipework (including: small bore, large bore, steam drums, vent lines, valves)	✗	✓ (minor due to pressure differential)	✓ (minor due to recent removal of insulation lagging pipework)	✗
Painted structural steelwork (including: stairways, walkways, platforms, handrails, bridge surrounding top duct)	✗	✗	✓	✓ (potential at closest point to reactor)

The different contamination and potential activation mechanisms resulted in different characterisation strategies for the various metal components. These are described below.

5.1 Top duct components

The top duct components consist of gas pipework connecting the top of the heat exchanger to the reactor building. The duct is mild steel, typically 1.5 m in diameter with a wall thickness of approximately 10mm. The duct exits the heat exchanger via an ‘elbow’ which connects to a section of convoluted pipework referred to as a bellows unit. A mid section of straight duct spans the 15 m gap between the heat exchanger and reactor building with an additional bellows unit at the reactor end.

The bellows units acted as expansion joints to accommodate the significant temperature changes during reactor operation and prevent metal fatigue.

The top duct carried reactor gas (CO_2) before passing through the heat exchanger back to the reactor.

A total of approximately 30te of metal is associated with top duct components.

Picture 3. Top duct elbow being removed.

Picture 4. Top duct mid section removed from heat exchanger.

Picture 5. A bellows unit.

5.1.1 Expectations prior to characterisation.

As hot reactor gas had been passing through the duct and graphite dust was known to accumulate within the heat exchangers, significant contamination was expected on the internals of the pipework. Tritium was known to be a contaminant of concern and the hot environment was likely to have resulted in the highly mobile radionuclide permeating into the bulk of the metal.

Although activation of the metal was thought to be unlikely due to the distance from the reactor, there was no evidence available to discount the possibility. Hence the material was classed as potentially activated.

The metal components were expected to be Low Level Waste (LLW) and significant dose rates (mSv/h gamma) at contact with the externals of the duct indicated there was a potential for some parts to be Intermediate Level Waste (ILW).

It was unknown how easily the surface contamination would be removed and hence what treatment options may be applicable.

5.1.2 Characterisation objective.

There were numerous characterisation objectives for the top duct components which were required to determine both treatment and disposal options. These included:

- Derivation of a radionuclide fingerprint for the contamination.
- Determination of activation levels (if present).
- Determination of bulk tritium activity concentrations.
- Determination of the most effective decontamination method.
- Determination of total activity concentrations pre and post decontamination.

5.1.3 Characterisation.

In order to address so many objectives, the characterisation work was performed in a phased approach. The first phase was undertaken prior to removal of any of the top duct components and as there were numerous constraints associated with sampling, an alternative approach to drilling into the pipework was sought.

Optioneering identified man hole covers, used for access to the top ducts as representative sections of metal, which had been in situ for the lifetime of the reactor which could be easily removed and then investigated within a laboratory.

The man hole covers were solid mild steel plates, approximately 60cm in diameter and 4cm thick. Each man hole cover weighed approximately 90kg. Four man hole covers were obtained from 2 heat exchangers. These sections of metal provided sufficient material to carry out a number of decontamination trials, depth profiling and surface contamination assessments (including fingerprinting). The combination of data obtained informed the viability of treatment options and potential disposal options.

Picture 6. Example of man hole cover – as received at laboratory.

5.1.3.1 Decontamination trials

In order to investigate the nature of the surface contamination and ease of removal, a number of potential decontamination options were tested. These included:

- Chemical foam decontamination agent.
- Mechanical wire brushing.
- Mechanical grit blasting (replicating the Sellafield Ltd on site wheelabrater).

The effectiveness of the decontamination was measured by demarcating a test area on the surface of the metal and determining the count rate before decontamination and after defined periods of decontamination. The detector placed above the test area was heavily shielded with lead blocks to remove any background interference. Each decontamination method was performed for 1, 3 and 5 minutes before re-counting.

Results

The decontamination results are shown in Appendix 1. In summary:

- Chemical cleaning achieved a high decontamination factor between 54% and 100% but took a relatively long time to work. Also the results were inconsistent with some surfaces being cleaned better than others making the process somewhat unreliable.
- Mechanically cleaning by hand provided similar results to chemical cleaning. High decontamination factors of between 77% and 100% were achieved and over a much shorter period but the results were also inconsistent. Hand cleaning was unlikely to be a viable option from an ALARP perspective but trials indicated the results that could be achieved from a mechanised process.
- Abrasive techniques achieved consistent 100% decontamination in all cases with a short operation time. Further, abrasive techniques could be used as a second stage process to complete decontamination after chemical / mechanical cleaning with consistent 100% decontamination results.

5.1.3.2 Surface contamination levels and fingerprint derivation

In order to determine the surface contamination levels and understand the range of radionuclides present and their relative proportions, a section of the surface of each man hole cover was scraped to remove surface deposits and destructively analysed for a suite of expected radionuclides.

The analytical suite included:

Gross alpha
Gross beta
High Resolution Gamma Spectrometry (Co-60, Cs-137, Mn-54)
Fe-55
Ni-63
H-3
C-14

Radionuclides were reported in terms of Bq/cm^2

Results

The surface contamination levels were found to be broadly consistent between samples. Average surface contamination levels were calculated and a radionuclide fingerprint derived, which is shown in Table 2. As expected the fingerprint was found to be consistent with the Calder Hall Low Level Waste fingerprint (2x22) (Ref. 4).

Table 2. Radionuclide fingerprint for contamination associated with top duct components

	Average Surface Contamination (Bq/cm^2)	**Activity %**
Co-60	44.98	28.83
Cs-137	0.70	0.45
Mn-54	0.04	0.03
H-3	6.47	4.15
C-14	1.34	0.86
Fe-55	91.43	58.61
Ni-63	11.05	7.08
Total	156.01	100.00

5.1.3.3 Activation and tritiation (depth profiling)

Determination of activation and tritiation within the metal required samples to be taken from the body of the man hole cover, avoiding cross contamination from the surface. In order to achieve this, the man hole covers were sampled from the outer (non contaminated) sides after surface cleaning to minimise as far as possible any potential for cross contamination. The sampling involved slow speed drilling, whilst cooling, to generate swarf. Samples were collected at 3 depth intervals (0-14mm, 14-28mm and 28-42mm) ensuring that the drill did not penetrate the contaminated surface. Each individual sample was then analysed for activation products (including H-3) to determine whether activity was present at depth. This approach was repeated, but instead of stopping prior to penetrating the surface, swarf was obtained from the full depth of the cover. This allowed a comparison to be made between full depth activity levels and partial depth activity levels (i.e: activity levels within the base metal).

Picture 7. Depth profiling of man hole cover.

Results

The activity concentration of radionuclides for full and partial cores is shown in Appendix 2. The results demonstrate that the metal was found to be not activated. However, tritium had penetrated into the metal and was detected at levels up to 5 Bq/g averaged over the depth of the metal. Concentrations of tritium at such levels exceed the Substances of Low Activity (SoLA) exemption order limit.

5.1.3.4 Activity assessment through modelling

The surface contamination levels and bulk H-3 activity concentrations clearly highlighted that the top duct components were Low Level Waste. The metal was therefore identified for treatment and disposal using the Low Level Waste Repository (LLWR) Segregated Services Contract. In order to facilitate the use of the services, a Waste Characterisation Form (WCF) was required which provided a methodology for determining the activity concentration associated with sections of metal.

As the radionuclide fingerprint for the contamination was expected to be similar between the various top ducts and intrusive sampling to determine activity levels for each batch of metal would potentially result in significant dose issues for the samplers, a methodology was sought whereby radiation readings could be converted to total activity declarations.

The dose rate modelling software, Mercurad, was used to model sections of pipework and relate internal contamination levels to expected dose rate. This enabled an Activity Conversion Factor (ACF) to be calculated. Consequently, sections of top duct pipework can be routinely consigned for treatment and disposal following a gamma dose rate survey and conversion to total activity (MBq) using the derived ACF.

5.1.4 Top Duct Components – Waste Sentencing Decision

The top duct components have been classed as LLW, and will be sent for treatment through the LLWR Segregated Services contract. It is expected that the metal will be smelted in order to generate a product for unrestricted release and minimise the quantity of material requiring disposal as LLW.

5.1.5 Future characterisation work in support of top duct components.

It is expected that future opportunistic sampling of top duct components will be carried out in order to reaffirm that the fingerprint is appropriate for future disposals. Furthermore, activity declarations will be compared to activity concentrations quantified by the metal treatment facility, thereby enabling future refinements to the Activity Conversion Factor if required.

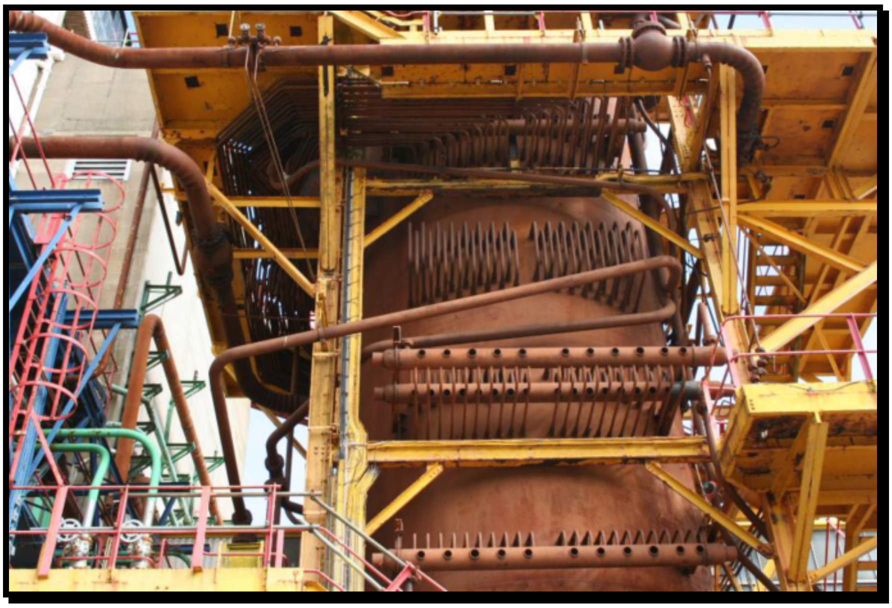
5.2 Steam System Pipework

The steam system consists of a myriad of pipework originating from the heat exchangers and eventually linking to the nearby Turbine Halls. There are both high and low pressure systems situated in the top and bottom half of each heat exchanger respectively. For each system, banks of small bore pipework exit the heat exchanger body and converge at header banks prior to linking to large steam drums. The steam drums are 10te cylindrical vessels which converted super heated water to steam, prior to exiting via large bore pipework and passing via pipebridge to the Turbine Hall.

A number of other additional pipes such as vent lines and drain lines were included as part of the steam system but were rarely used.

Approximately 60 te of metal per heat exchanger is associated with the steam system.

Picture 8. Small bore pipework exiting heat exchanger, combining at header banks.



Picture 9. Example of a header bank

Picture 10. Example of a steam drum

5.2.1 Expectations prior to characterisation

The steam system was a closed system which under normal operating conditions should not contain any contamination, as there was no mechanism for reactor based contaminants to pass from the reactor gas to the steam.

Although the design prevented contamination of the steam, over the lifetime of the plant there were a number of heat exchanger tube failures due to degradation of the metal. A tube failure would provide a route for gas and steam to come into contact, however, the steam system operated at significantly higher pressure than the gas system resulting in migration of steam to the gas. Consequently, in theory, there was minimal opportunity for contamination of steam system pipework. Despite this provenance, as a key contaminant of concern was tritium, the potential for encountering this highly mobile radionuclide could not be discounted. Activity concentrations however were not expected to exceed the criteria for exemption.

Previous characterisation of steam pipework within the Turbine Halls and pipebridges between Reactors and Turbine Halls had concluded that the metal was RSA Exempt with only trace levels of H-3 and C-14 being detected. This further supported the expectation that the steam pipework on the heat exchangers would also be exempt.

The steam system pipework was typically lagged with either asbestos or calcium silicate until relatively recently. Between 2006 and 2008 the lagging was removed and the pipework was fine cleaned with abrasive shot blasting. Hence, the potential for accumulation of activity resulting from atmospheric deposition was considered to be minimal.

5.2.2 Characterisation Objective

The objective of the steam system characterisation was to determine the average total activity concentration at the 95% confidence level in order to support the sentencing of the material.

Initially the objective was addressed on a heat exchanger basis and later rolled out to the entire steam system at Calder.

5.2.3 Characterisation

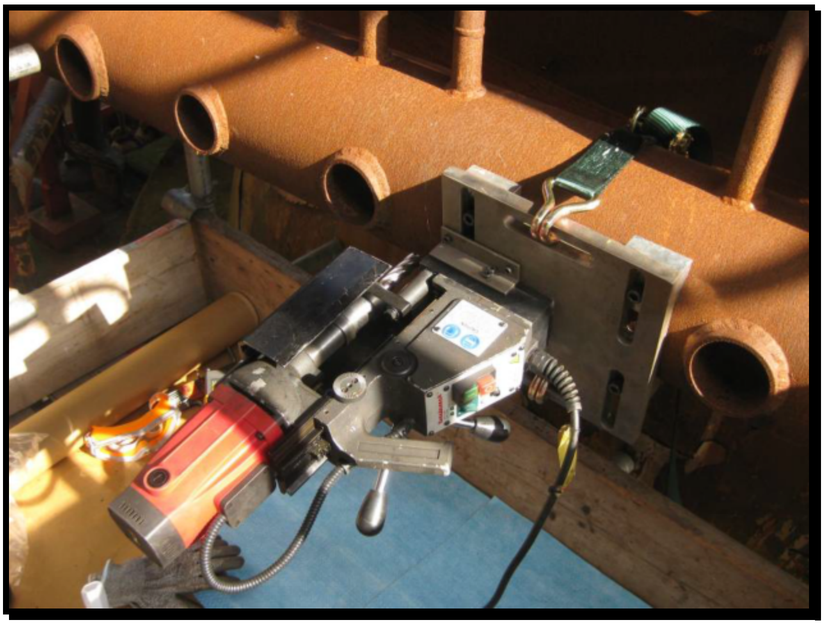
The characterisation initially focused on two Reactor 2 Heat Exchangers, as these were identified by the project team as a priority for decommissioning.

The data gathering stage identified that there was minimal potential for contamination, and if contamination were to be found, there was not likely to be significant difference in activity concentration throughout the steam system. The only identified potential difference was the Low Pressure (LP) and High Pressure (HP) system. The LP system had greater potential for contamination as the differential between steam and gas pressure was smaller.

As the steam system contained such a vast array of pipework, the characterisation sought to obtain samples from areas where numerous pipes converged, thereby, being more representative than a single pipe. The locations identified were header banks and steam drums.

Access to the header banks in order to safely sample was not straightforward in all cases, and hence, scaffolding was required to provide adequate working platforms for some locations. The metal pipework or drums were sampled using a magdrill mounted using a base plate. The metal was slowly cored whilst applying coolant in order to extract 1cm diameter coupons. Throughout the drilling operation the temperature was monitored with a laser thermometer to ensure that the metal did not exceed 20 ^{o}C, preventing loss of any volatiles, should they be present.

Picture 11. Mag drill attached to header bank using base plate specifically designed for pipework



In order to satisfy the characterisation objective, samples were analysed for a suite of radionuclides which aligned to potential reactor based contaminants. These include the activation products listed in section 5.1.3.2, as per top duct characterisation. The analytical service provider required a minimum of 2 coupons per sample to cover the analytical suite, as one coupon was required for C-14 / H-3 analysis and the other for the remaining analysis. In order to allow for a contingency, a total of 3 coupons were taken for each sample. The samples were analysed and results were quoted in the units of Bq/g.

Picture 12. Example of a sample, consisting of 3 cores.

Results

To date, the steam system pipework from only two heat exchangers have been characterised. This includes a total of 16 samples (48 increments). Furthermore, this is supported by an additional 28 steam pipework samples from other areas of the site (pipebridges and turbine halls).

As indicated by the provenance, the only radionuclides detected were H-3 and C-14, with only trace levels of C-14, comparable to the analytical limit of detection. Only 8 out of 44 samples contained detectable levels of H-3, again at very low levels.

The analytical data supported the provenance which suggested that the steam system pipework metal would be exempt.

5.2.4 Steam system pipework – waste sentencing decision.

The steam system pipework associated with the 2 heat exchangers which have been characterised to date, have been sentenced as exempt material, without any requirement for decontamination, subject to reassurance health physics monitoring checks. The material will be released off site for recycling.

5.2.5 Future characterisation work in support of steam system pipework

A programme of characterisation work is currently underway, which has involved obtaining samples from steam system pipework for the remaining 14 heat exchangers. Based on the findings to date, the steam drums have been targeted as the most representative areas for the entire steam system. Both HP and LP steam drums have been sampled and the laboratory are expected to report the results at the end of April 2012. Providing that the data supports the findings to date, a case will be made to sentence all steam system pipework as exempt material subject to no detectable activity being found above background levels when undertaking health physics monitoring. The data will be assessed against EPR2011, as the revised legislation is expected to be implemented in April 2012.

5.3 Painted structural steelwork

Each heat exchanger is surrounded by a network of stairways, walkways and gantries which were used to access the heat exchangers and top ducts for maintenance during their operational lifetime. The steelwork typically consists of 'I' beams, angle iron and chequer plate which are coated with numerous layers of paint which have accumulated over fifty years of maintenance. The metal is mild steel and a minimum of 5mm thick. In addition to the access platforms surrounding the heat exchangers, the pipebridges spanning between the reactor compounds and turbine halls also consist of painted angle iron / 'I' beams. There is estimated to be in excess of 1000te of painted structural steelwork associated with heat exchangers and pipebridges at Calder Hall.

Picture 13. Example of stairway

Picture 14. Example of access platforms

Picture 15. Upper level access platforms, gantries and stairways

5.3.1 *Expectations prior to characterisation*

The numerous layers of paint coating the Calder Hall steelwork have been exposed to atmospheric discharges over the lifetime of the facility and previous similar characterisation on the site has demonstrated that paint can accumulate low levels of radioactivity. Characterisation of paint has demonstrated that the activity levels typically exceed the exemption criteria, but when considering the metal and paint as a single entity the activity concentration is less than the exemption criteria.

For scenarios where there are multiple layers, each with different radiological characteristics, the Nuclear Industry Code of Practice (NICoP) for Clearance and Exemption (Ref. 5) can be used as a guide to determine whether or not the material is suitable for clearance as exempt material or whether the layers should be separated. Table 3 below is extracted from the NICoP, highlighting that the following statement needed to be addressed:

'Presumption of Separation and Segregation unless a justification can be made that removal is not reasonably practicable, the expenditure (whether in time, trouble or money) is grossly disproportionate to the safety and environmental benefits gained, and the overall impact of disposal is less than 10 μSv/yr'

Table 3. Table extracted from the NICoP detailing guidance for dealing with materials consisting of multiple layers.

Surface Layer (e.g. Paint, Laminate, or region of increased radionuclide concentration)	Bulk layer (e.g. Brick, blockwork, metal structure components)	Overall Average	Code Compliant Outcome
Average < relevant Exemption Order (EO) Limit	Average < relevant EO Limit	< EO Limit	No Radiological requirement to undertake Separation and Segregation, prior to sentencing as exempt waste, although commercial considerations (e.g. recycling or re-use options) should be considered.
Average > relevant EO Limit	**Average < relevant EO Limit**	**<EO Limit**	**Presumption of Separation and Segregation unless a justification can be made that removal is not reasonably practicable, the expenditure (whether in time, trouble or money) is grossly disproportionate to the safety and environmental benefits gained, and the overall impact of disposal is less than 10 μSv/yr**
Average < relevant EO Limit	Average > relevant EO Limit	> EO Limit	Unless commercial considerations (e.g. recycling or re-use options) for the exempt surface layer are sufficient to justify the safety and environmental impacts of separation and segregation it would be expected that material in this configuration would be sentenced as LLW en masse.
Average > relevant EO Limit	Average > relevant EO Limit	> EO Limit	Sentence as LLW.

5.3.2 Characterisation objectives

The objectives of the characterisation were as follows:

- Determine the mean total activity concentration at the 95% confidence level for the paint.
- Demonstrate that the ‘bare’ metal is not activated.
- Determine the mean total activity concentration at the 95% confidence level for the metal & paint.
- Calculate the dose impact for reuse and smelting of the painted metal without decontamination.

The above objectives were addressed per heat exchanger, but providing that one heat exchanger was not significantly different from another, data would be combined.

5.3.3 Characterisation

In accordance with the Calder Hall decommissioning programme a number of heat exchangers access structures and pipebridges were targeted for characterisation. The first phase of work included 3 heat exchangers from Reactor 2, 1 from Reactor 3 and 2 pipebridges.

The characterisation addressed the paint and metal as two separate layers:

Metal

Although it was expected that structural steelwork would not be activated due to the distance from the reactor core, the closest steelwork to the reactor core was targeted for sampling. Reactor 2 Heat Exchanger 8 top duct bridge was sampled as this had been removed from the heat exchanger intact, enabling easy access for sampling at prescribed locations moving away from the point closest to the reactor. In total, seven sections were sampled at 1m intervals. The identified sections were removed from the main gantry structure and sent for wheelabration, to remove all paint and expose bare metal. Coupon samples were taken using a rotabroach with coolant, to ensure the temperature of the metal did not exceed 20^{o}C and hence minimise H-3 loss. In addition to Reactor 2 Heat Exchanger 8, 3 random metal coupons were taken from Reactor 2 Heat Exchanger 5 90 foot gantry steelwork.

Each metal coupon sample was taken in triplicate. One coupon was digested for gross alpha, gross beta, gamma scan, Fe-55 and Ni-63 analysis. One coupon was placed in a pyrolyser and analysed for C-14 and H-3, and a third coupon was used as a contingency. Results were reported in Bq/g.

Picture 16. Top duct bridge removed from heat exchanger used to sample to investigate activation

Paint

Paint sampling was done using a multi incremental approach, in accordance with the assumption that there was not expected to be significant variability in activity levels across the population (except H-3, as H-3 was known to vary in concentration following previous characterisation work of asbestos surrounding heat exchangers. Scrapings were taken back to bare metal from numerous locations and bulked to form a sample. This was done in triplicate, producing 3 multi incremental samples of paint per population. The sample plan assumed that a surface area of 10cm^2 would equate to 2g of paint.

The paint samples were analysed for a comprehensive suite of radionuclides including gross alpha, gross beta, gamma scan, C-14, H-3, Fe-55, Ni-63, Pu (alpha), Pu-241, U and Sr-90, covering radionuclides found in the site aerial discharges fingerprint 2x140/2 (Ref. 6) and the Calder reactor fingerprint 2x22 (Ref. 4). Results were reported in Bq/g per radionuclide.

Results

Metal

Only one positive C-14 result was reported for all metal samples at 0.0035 Bq/g. All other radionuclides were reported as Limit of Detection (LoD). In the absence of any other detectable activity, the single C-14 detect appeared to be either a false positive (considering how close the value is to the limit of detection) or it could be contamination which was not removed by the wheelabrater. The absence of detectable activity confirmed the assumption of no activation.

Paint

The paint was found to be contaminated with a range of radionuclides, as expected, including activation products, fission products and actinides. Activity concentrations per area sampled were in general found to be consistent across all samples, with exception of a couple of samples which contained elevated H-3 up to 2.2 Bq/g. Total activity concentrations ranged from 0.29 Bq/g to 3.36 Bq/g. The samples with highest activity were found to be dominated by H-3 and it is the variability of H-3 which had most effect on the distribution of the data set. A summary of the total activity per sample for the 22 samples across the 6 areas is shown in Appendix 3, along with the distribution of the data. Total activities were derived from summation of analytical data for each sample.

Although activity levels in the paint were found to vary depending upon location, the variability was not considered to be significant, hence, all the data was treated as a single population for subsequent assessments.

The mean activity at the 95% confidence level was calculated for the entire population of paint samples using the Lands Test which is applicable for log normal distributions (Ref. 5).

$$UCL_{95} = 1.65\, Bq / g$$

Note: The UCL_{95} if a normal distribution is assumed was calculated to be 1.44 Bq/g. Hence, assuming a log normal distribution was worst case (Ref. 7).

Painted Metal

Assuming as a worst case the metal is 5 mm thick (density 7.8g/cm^3) and is typically coated with 2mm of paint (density 1g/cm^3) on both sides, for every gram of paint there will be approximately 10g of metal (Note: the metal was typically thicker than 5mm). Hence the bulk activity of painted metal was calculated to be 0.15 Bq/g, which is less that the SoLA exemption order limit.

5.3.4 Painted Structural Steelwork – Waste Sentencing decision.

The characterisation work confirmed that the paint was contaminated to levels in excess of the exemption criteria, but as the bare metal that the paint was adhered to was essentially ‘clean’, the overall painted metal could be demonstrated to be exempt.

In accordance with the NICoP guidance, the standard approach to dealing with this scenario would be to decontaminate, removing the contaminated layer of paint. The Sellafield site has the Wheelabration facility for this operation, but due to the multiple thick layers of paint, a trial batch of metal required up to 7 passes through the process to decontaminate fully. The processing difficulties combined with the significant quantities of steelwork had safety, environmental and cost implications which when combined with the relative insignificance of the radiological contamination, led to the approach being challenged.

In order to justify that the metal should not undergo full decontamination, the safety, environmental, cost and dose implications had to be addressed. The following issues were highlighted:

Safety – reducing lifting and cutting

Every time metal is processed through the wheelabrater, a lifting operation is required, reduction in processing significantly reduces conventional safety risk. Furthermore, if full decontamination is not required, a significant proportion of size reduction can be avoided, which is required to enable the grit blast to access intricate shapes.

Environmental – reducing secondary waste.

Reducing the processing of metal through the wheelabrater, also reduces the quantity of secondary waste (residue and grit) generated from the process. Potentially, up to 6 ISO containers of LLW could be avoided, saving valuable capacity at the LLWR.

Cost

The cost of processing metal through the on site wheelabrater is significant, particularly, if the metal requires processing 7 times in order to fully decontaminate. A reduction in the scale of decontamination for all Calder painted structural steelwork could potentially save several million pounds in operational costs.

Dose impact of not removing paint

In order to evaluate the dose impact of not removing the paint, Radiation Protection 89 (Recommended radiological protection criteria for the recycling of metals from the dismantling of nuclear installations, RP89, (Ref. 8)) has been used as a basis for performing the calculations. Although the limits stated within RP89 have not been embedded in UK legislation, the document is a useful tool for the realistic assessment of the different options of metal treatment from a radiation protection point of view.

The International Atomic Energy Authority (IAEA) suggests that in order to take account of exposures of individuals from more than one exempt practice, the exposure to the critical group from one such practice should be of the order of 10 μSv/y or less. As such, RP89 proposes radionuclide specific clearance levels derived from the most critical scenario which would lead to a derived dose of 10 μSv/y.

There are two scenarios for metal treatment / routing considered within RP89, one is recycling (smelting) and the second is direct reuse. The fate of the radionuclides and critical group for each scenario is different, resulting in different clearance levels depending on the chosen route for the metal. As expected, the surface clearance levels for direct reuse are either more restrictive or equal to those for recycling.

Clearance levels for scrap processing (smelting) are quoted in terms of both bulk activity (Bq/g) and surface contamination (Bq/cm^2). For reuse, only surface contamination limits apply. Tables 3.1 and 3.2 within RP89 provide activity concentration limits per radionuclide which correspond to the critical group being exposed to 10 μSv/y for smelting and reuse. The limits for the radionuclides detected within paint at Calder have been extracted from RP89 and summarised in Table 4 below.

Table 4. Clearance levels for metal recycling and direct reuse defined in RP89 Tables 3.1 and 3.2 resulting in a derived maximum dose of 10μSv/y.

Nuclide	Mass specific clearance levels for metal recycling (smelting) (Bq/g)	Surface specific clearance levels for reuse of metal (Bq/cm^2)
H-3	1000	10000
C-14	100	1000
Fe-55	10000	1000
Co-60	1	1
Ni-63	10000	1000
Sr-90	10	10
Sb-125	10	10
I-129	1	10
Cs-134	1	1
Cs-137	1	10
Eu-154	1	1
Pu-238	1	0.1
Pu-239	1	0.1
Pu-240	1	0.1
Pu-241	10	10
Am-241	1	0.1

As the contamination within the paint consists of a mixture of radionuclides, the cumulative dose impact needs to be considered. To determine whether a mixture of radionuclides is below the clearance level a simple summation formula should be used:

$$\sum_{i=1}^{n} \frac{C_i}{C_{Li}} < 1.0$$ ……………………Equation 1

C_i = the specific activity of radionuclide *i* in the material being considered.
C_{Li}= the specific clearance level of radionuclide *i* in the material.
n = the number of radionuclides in the mixture.

In the above expression, the ratio of the concentration of each radionuclide to the clearance level is summed over all radionuclides in the mixture. If this sum is less than one, the material complies with the clearance requirements.

Although the metal released from Calder is expected to go for smelting, there is potential for metal to be released for reuse, and hence both scenarios have been evaluated.

The most appropriate method for assessing against the bulk activity clearance limit applicable to the smelting scenario is to apply the combined metal and paint activity concentration (Bq/g) at the 95% confidence level to the above equation. The summation equates to 0.31 (log normal distribution as worst case). Hence, less than the level that would meet the 10 μSv/y dose limit.

The clearance criteria for direct reuse requires only surface contamination to be assessed. The surface specific clearance levels apply to the total surface activity concentration, fixed plus non fixed, and are intended as an average over moderate areas. In this context, moderate is interpreted to mean areas of several hundred square centimetres. RP89 recognises that surface contamination could include activity hidden under surface layers (eg: paint / rust). Hence, it is considered to be appropriate to compare the activity levels within the paint (converted to Bq/cm^2) to the reuse clearance criteria.

In order to convert the paint bulk activity (Bq/g) results to surface contamination levels, the surface area coverage per unit mass of paint was determined. Based on the paint being 2mm thick, it was estimated that 1g of paint covered 5 cm^2. The surface contamination per radionuclide for each sample was then calculated. Each result was then compared to the clearance limit and the summation per sample using Equation 1 was carried out. The surface contamination calculations were carried out on a sample basis rather than per population due to the limitations of averaging areas. The summation for every sample was less than 1, hence the painted steel was considered to be appropriate for reuse.

Overall treatment and sentencing decision

A technical justification was produced to enable Calder Hall painted structural steelwork to be released from the site for smelting or re-use without any decontamination, providing that there was no detectable activity found above background when reassurance surface monitoring. However, Sellafield Ltd has chosen to apply a cautious approach and subject the painted metal to a single pass through the wheelabration facility. The single pass removes any flaky material and ensures that the remaining surface layer is firmly adhered to the base metal when it leaves the site. This reduces the processing by a factor of 7 and reaps a significant proportion of the safety, environmental and cost benefits presented above.

5.3.5 Future characterisation work in support of Calder Hall painted structural steelwork

A programme of characterisation work is currently underway, which has involved obtaining samples of paint from all remaining heat exchangers, adopting the same multi incremental sampling strategy as that undertaken during the first phase of work. Once the analytical data has been reported by the laboratory it will be assessed for consistency with the existing data and if appropriate, justification will be made to sentence the material in line with the approach adopted to date. Furthermore, the data will be assessed in line with the requirements of EPR2011.

6.0 Conclusion

To date, characterisation of metal in support of decommissioning Calder Hall has concluded the following:

- None of the metal associated with top duct components, steam system pipework and painted structural steelwork surrounding heat exchangers is activated.
- Metal exposed to reactor gas is surface contaminated to LLW levels. However, the surface contamination is removable using a grit blasting technique.
- Metal exposed to reactor gas is tritiated to levels which exceed the Substances of Low Activity exemption order limit.
- Steam system pipework contains only trace levels of H-3 and C-14 and is considered suitable for release from the site as exempt material.
- Painted structural steelwork is considered to be exempt despite activity levels in the paint exceeding the SoLA exemption order limit.

The comprehensive characterisation programme executed by Sellafield Ltd's Facility Characterisation team has enabled in excess of 90% of the metal characterised to date, to be sentenced as exempt material with no or limited treatment, enabling huge safety, environmental and cost savings to be realised.

7.0 References

1. The Radioactive Substance (Substances of Low Activity) Exemption Order, SI No.1002, 1986 and amendment SI No. 647, 1992.
2. The Environmental Permitting (England and Wales) (Amendment) Regulations 2011.
3. Radiation Protection 122 – Practical Use of the Concepts of Clearance and Exemption.
4. Low Level Wastestream Characterisation Document for waste contaminated by atmospheric discharges on the Sellafield and Calder Sites, 2x140/2 – CC09_079_09_01
5. Nuclear Industry Code of Practice on Clearance and Exemption Principles Processes and Practices (NICoP) July 2005.
6. Wastestream Characterisation document for the disposal of Solid LLW from Calder Hall, 2x22 – CC08_155_09_01.
7. Overarching technical justification for clearance and exemption of painted structural steelwork at Calder Hall, FC_T_20_06_01.
8. Radiation Protection 89 – Recommended Radiological Protection Criteria for the Recycling of Metals from the Dismantling of Nuclear Installations.

8.0 Appendix

Appendix 1. Results from the mechanical and chemical decontamination of top duct man hole covers

MECHANICAL CLEAN – decontamination factors from material remaining (assumes 100% removal of surface deposit after 5 minutes grit blasting)				
Sample Number	Type of clean	Total time	Gamma count (less background)	Decontam. Factor for surface deposit
		(minutes)	Net counts	(% removal)
R2 CIRC5 Top	Before	0	19337	0
	Wire brush	1	7016	64
	Wire brush	3	3261	83
	Wire brush	5	2963	85
	Grit blast	1	2597	87
	Grit blast	3	0	100
R2 CIRC5 Bottom	Before	0	31548	0
	Wire brush	1	5685	82
	Wire brush	2	2987	91
	Wire brush	3	3092	90
	Wire brush	5	2328	93
	Grit blast	1	2634	92
	Grit blast	3	0	100
R2 CIRC6 Top	Before	0	61573	0
	Wire brush	1	21935	64
	Wire brush	3	13314	78
	Wire brush	5	14348	77
	Grit blast	1	7511	88
	Grit blast	3	0	100
R2 CIRC6 Bottom	Before	0	33729	0
	Wire brush	1	3466	90
	Wire brush	3	1785	95
	Wire brush	5	0	100
	Grit blast	1	0	100
	Grit blast	3	0	100

CHEMICAL CLEAN – decontamination factors from material remaining (assumes 100% removal of surface deposit after 5 minutes grit blasting)				
Sample Number	Type of clean	Total time	Gamma counts (less background)	Decontam. Factor for surface deposit
		(minutes)	Net counts	(% removal)
R2 CIRC5 Top	Before	0	23810	0
	Foam	30	14916	37
	Foam	60	11122	53
	Foam	120	11025	54
	Grit blast	1	3782	84
	Grit blast	3	0	100
R2 CIRC5 Bottom	Before	0	43138	0
	Foam	30	7761	82
	Foam	60	2406	94
	Foam	120	2919	93
	Grit blast	1	0	100
	Grit blast	3	0	100
R2 CIRC6 Top	Before	0	62067	0
	Foam	30	41854	33
	Foam	60	19911	68
	Foam	120	20976	66
	Grit blast	1	2587	96
	Grit blast	3	0	100
R2 CIRC6 Bottom	Before	0	27957	0
	Foam	30	7654	73
	Foam	60	1430	95
	Foam	120	0	100
	Grit blast	1	0	100
	Grit blast	3	0	100

Appendix 2. Analytical results from the full and partial coring of the man hole covers

	R2 CIRC 5 TOP Full	R2 CIRC 5 TOP Part	R2 CIRC 5 BTM Full	R2 CIRC 5 BTM Part
Reference	N0210	N0211	N0212	N0213
Units:	Bq/g	Bq/g	Bq/g	Bq/g
Gross Alpha	<0.06	<0.06	<0.05	<0.06
Gross Beta	<0.04	<0.04	<0.05	<0.08
Am-241	<0.08	<0.04	<0.13	<0.04
Co-60	<0.08	<0.05	<0.08	<0.05
Cs-137	<0.07	<0.05	<0.07	<0.05
H-3	<0.18	<0.19	2.39±0.20	0.75±0.13
C-14	<0.06	<0.06	<0.06	<0.06
Fe-55	<0.15	<0.16	<0.16	<0.16
Ni-63	<0.12	<0.12	<0.12	<0.12

	R2 CIRC 6 TOP Full	R2 CIRC 6 TOP Part	R2 CIRC 6 BTM Full	R2 CIRC 6 BTM Part
Reference	N0214	N0215	N0216	N0217
Units:	Bq/g	Bq/g	Bq/g	Bq/g
Gross Alpha	<0.06	<0.06	<0.06	<0.06
Gross Beta	<0.11	<0.04	0.07±0.04	0.08±0.05
Am-241	<0.04	<0.02	<0.05	<0.07
Co-60	<0.05	<0.04	0.09±0.03	<0.07
Cs-137	<0.05	<0.02	<0.05	<0.06
H-3	5.74±0.34	1.79±0.26	16.7±0.7	4.90±0.37
C-14	<0.07	<0.06	<0.08	<0.06
Fe-55	<0.16	<0.16	<0.16	<0.16
Ni-63	<0.12	<0.12	<0.12	<0.12

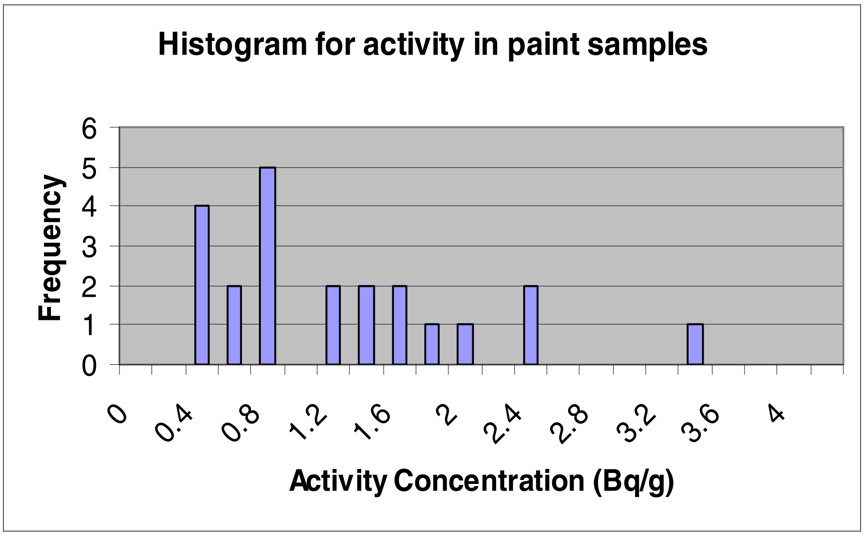
Appendix 3. Analytical data and assessment of results from paint sampling of painted structural steelwork surrounding heat exchagers.

Table 1. Total activity per paint sample for all 7 areas sampled.

Location	Sample Number	Total Activity (Bq/g)
R2 HEx 5	1	0.69
R2 HEx 5	2	1.16
R2 HEx 5	3	3.36
R2 HEx 8	1	2.36
R2 HEx 8	2	1.72
R2 HEx 8	3	2.23
R2 HEx 6	1	1.39
R2 HEx 6	2	1.46
R2 HEx 6	3	1.21
R3 HEx 3	1	1.90
R3 HEx 3	2	1.51
R3 HEx 3	3	0.74
R2 HEX 5 Stairways	1	1.11
R2 HEX 5 Stairways	2	0.48
R2 HEX 5 Stairways	3	0.80
R2 HEX 5 Stairways	4	0.61
R1 Pipebridge	1	0.32
R1 Pipebridge	2	0.46
R1 Pipebridge	3	0.39
R4 Pipebridge	1	0.37
R4 Pipebridge	2	0.79
R4 Pipebridge	3	0.29

The data can be shown pictorially using a histogram to show the distribution of total activity for all samples (Graph 1).

Graph 1. Histogram showing the activity concentration in paint samples across all areas sampled.



The graph indicates a skewed distribution of total activity. The skewed nature of the data set is predominantly attributable to varying H-3.

If the data is transformed by taking the natural logarithm of the total activity, the distribution shown in Graph 2 is found, demonstrating a log normal distribution.

Graph 2. Histogram showing the distribution of log transformed activity concentration for paint samples across all areas sampled.