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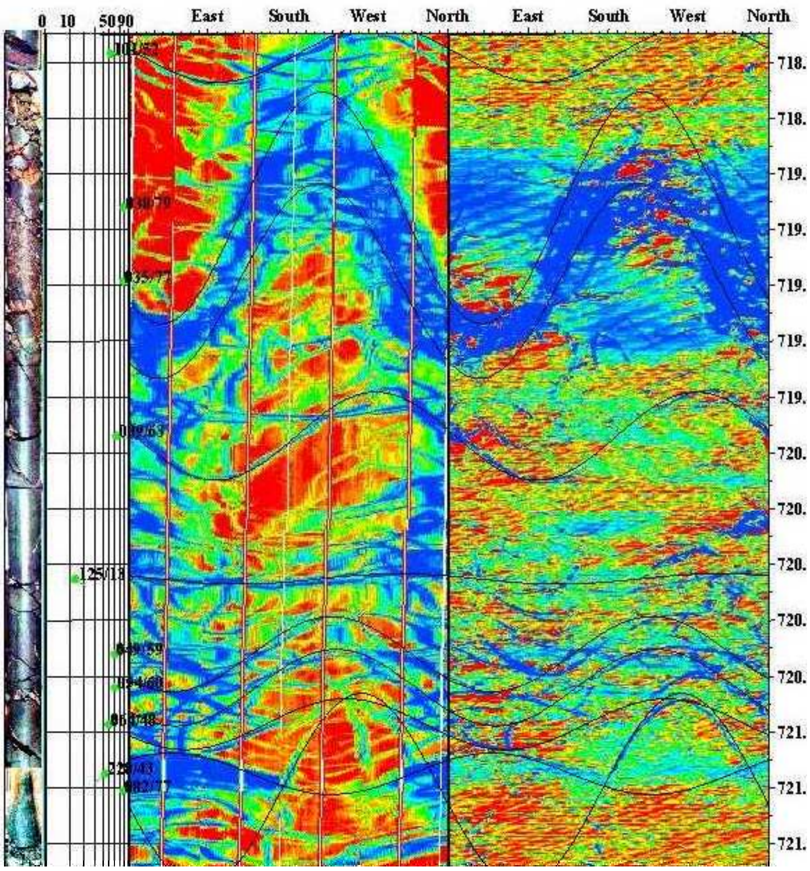
Sellafield borehole geophysical data: Acquisition Parameters, Environmental Corrections and QA status

A BGS report for United Kingdom Nirex Limited.

Internal Report CR/01/065N



BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT CR/01/065N

Sellafield borehole geophysical data: Acquisition Parameters, Environmental Corrections and QA status

A KINGDON, CJ EVANS & RJ CUSS. 2001

Front cover

FMS (left) and BHTV (right) Images with scanned core photograph of fractured Borrowdale Volcanic Group rocks, Sellafield Borehole PRZ1

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Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB

☎ 01491-838800 Fax 01491-692345

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU

☎ 01793-411500 Fax 01793-411501
www.nerc.ac.uk

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Summary

This report examines the borehole geophysical logging undertaken for Nirex investigations of the Sellafield Area as part of the UK radioactive waste management programme.

The report examines the logging undertaken in each borehole and also using each major type of logging tool studying the parameters applied during acquisition, calibration of the logging tools and corrections applied both during and after the acquisition process. It looks in detail at the borehole imaging logs used extensively in the Sellafield investigations

The report attempts to quantify the reliability of the logging by studying the repeatability of the logging from examining the correlations between over–lapping sections of logging data. It also examines the validity and effect of those corrections that were applied to the logging data post-acquisition.

1 Introduction

United Kingdom Nirex Limited (Nirex) is responsible for providing the United Kingdon with safe, environmentally sound options for the long–term management of radioactive wastes. In the period 1989 to 1997 Nirex investigated the area around the Sellafield Works in west Cumbria to determine it's potential to host a repository for disposal of solid intermediate-level and low-level radioactive wastes.

The investigations of the Sellafield area were latterly focussed on an area around Longlands Farm, West Cumbria, 3 km inland of the Sellafield Works, to assist in the planning for northwest of the village of Gosforth close to the Sellafield plant the construction of an underground laboratory or Rock Characterisation Facility (RCF). Had this study been successful the RCF would have been extended to form the basis of a repository. Consequently the area around the proposed RCF site was known as the Potential Repository Zone (PRZ). In 1994 Nirex was denied planning permission for the underground laboratory and in 1997 this decision was upheld at a planning inquiry.

As part of the geological, geophysical and hydrogeological investigations of the Sellafield area a series of deep boreholes were drilled to study the geological and fluid properties *in situ*; these boreholes were then logged with a suite of state of the art geophysical logs by Schlumberger. This report aims to define the status of the wireline logs that were acquired and processed. In particular this involves answering four questions:

1. What logs were acquired in each borehole in the Sellafield area?
2. What parameters were applied during the acquisition of these logs?
3. What significant post-acquisition processing was undertaken and which logs were these then applied to?
4. How repeatable are the measurements that were made?

1.1 THE SELLAFIELD AREA BOREHOLES

The Nirex investigations of the Sellafield area resulted in the drilling of 19 deep regional boreholes. The terminal depths of these boreholes varied from approximately 700 metres below surface to 1900 metres below surface. These were drilled to establish the regional geological structure and to determine the hydro-geological framework of this region. Geophysical logs and other data from these regional boreholes were referred to within BGS with the prefix NSF (for Nirex Sellafield) in front of the Nirex borehole number to prevent confusion with other boreholes. This scheme is used within this report.

In addition, a further 9 deep boreholes were drilled in the area around Longlands farm in the area designated as the Potential Repository Zone (PRZ). These were designated RCF, RCM and PRZ 1,2,3 respectively. Two other boreholes in the Sellafield area drilled in the area by others at an earlier date (Boonwood, Holmrook 13) were re-opened by Nirex during the Sellafield investigations but their logging was not undertaken in the same way and was carried out by other contractors specialising in logging of narrow diameter boreholes. These were peripheral to the main investigation and are not discussed here further. A map of the Sellafield Site showing the locations of the majority of the deep Sellafield boreholes is included at Figure 1. Table 1 lists the attributes of the Sellafield deep borehole, such as depths and spud dates.

Figure 1: Geological summary map showing the location of the Sellafield site and location of the Sellafield deep boreholes, Cumbria, UK.

This map also marks the outline of the Potential Repository Zone (PRZ)

Note some boreholes omitted for clarity:

- RCM1 & RCM2 adjacent to RCF3,
- RCM1 adjacent to RCF1
- PRZ1 adjacent to Sellafield 2
- Boreholes 7, 8, 9, 10, 13: A and B boreholes adjacent

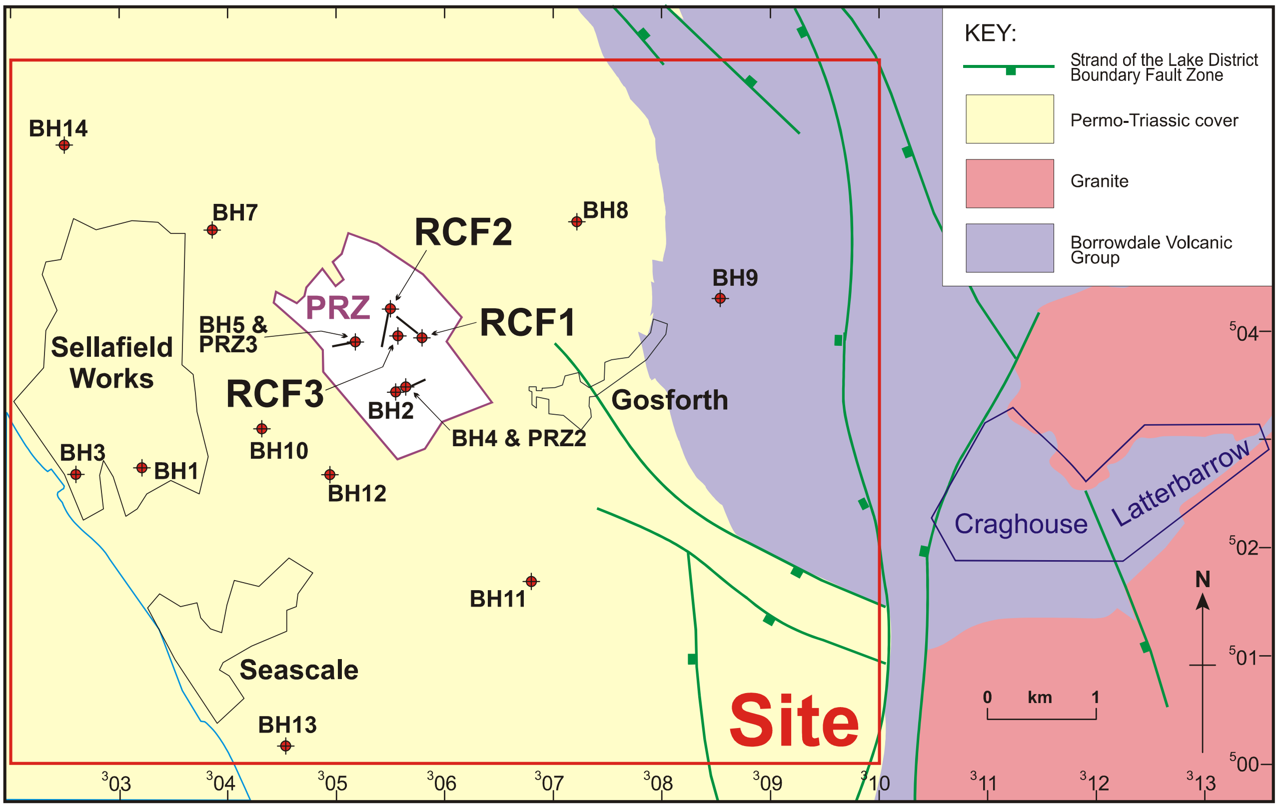

Table 1: Sellafield deep borehole spud dates and attributes

Borehole	Datum	Datum height	Length (m)	Cored length (m)	Spud date	Deviation
1	RT	25.50	773.04	324.04	1989	Deviated
1A	RT	25.50	1189.00	83.09	1989	Deviated from BH1 with cored intervals below 815m
2	RT	65.20	1610.00	1576.95	25-Aug-1990	Vertical
3	RT	15.63	1950.52	1256.92	7-Dec-1990	Vertical
4	RT	73.58	1260.00	849.00	16-Apr-1991	Vertical
5	RT	85.50	1260.00	1103.00	26-Aug-1991	Vertical
7A	RT	53.06	1010.00	549.00	3-Dec-1991	Vertical
7B	RT	53.10	471.00	407.00	3-Mar-1992	Vertical
8A	RT	166.79	1000.00	792.00	28-Jun-1993	Vertical
8B	GL	165.00	244.95	229.80	22-Jun-1993	Vertical
9A	RT	120.30	500.00	485.00	10-Jun-1994	Vertical
9B	GL	116.58	150.00	140.30	16-May-1995	Vertical
10A	RT	40.48	1607.86	1387.86	12-Apr-1992	Vertical
10B	GL	35.70	252.29	231.11	3-Sep-1992	Vertical
10C	GL	35.51	253.00	20.82	3-Sep-1992	Vertical
11A	RT	50.64	1170.00	369.00	8-Feb-1993	Vertical
12A	RT	44.60	1150.00	842.88	16-Jun-1992	Vertical
13A	RT	23.51	1740.00	639.00	17-Apr-1993	Vertical
13B	GL	18.46	295.70	259.87	3-Jun-1993	Vertical
14A	RT	46.20	873.00	538.00	7-Dec-1992	Vertical
16	RT	41.01	595.00	527.55	9-Dec-1996	Vertical
RCF1	RT	102.10	1150.00	770.00	29-Aug-1993	Deviated
RCF2	RT	100.07	1149.50	724.00	12-Oct-1993	Deviated
RCF3	RT	88.27	990.00	725.18	12-Oct-1993	Vertical
RCM1	RT	88.26	990.00	939.00	14-Feb-1994	Vertical
RCM2	RT	89.50	990.00	879.38	22-Nov-1993	Vertical
RCM3	RT	102.12	1035.00	630.50	13-Nov-1993	Deviated
PRZ1	ST	64.61	775.25	536.60	6-Dec-1994	Inclined
PRZ2	ST	72.91	560.00	325.00	19-Sep-1994	Inclined
PRZ3	ST	84.93	775.00	540.00	1-Jun-1994	Inclined
Boonwood	GL	81.90	540.50	n/a	1907	Vertical – Old iron ore exploration borehole
Holmrook 13	GL	48.90	524.26	n/a	1960	Vertical – Old iron ore exploration borehole

All boreholes were logged by at least a minimum standard suite of logging tools: acoustic and resistivity borehole imaging, resistivity logs, acoustic velocity logs and neutron-density-gamma logs; the specific tools used varied with both generational changes in tool technology and on account of varying borehole conditions through the course of these investigations.

The earliest of the boreholes, Sellafield 1 and Sellafield 1A (a side-track at depth from Sellafield 1), pre-date the main phase of the Sellafield investigations. A significantly different suite of logging tools, and earlier generations of some of the tools, were used in these boreholes when compared to the subsequent standard set of tools and thus these boreholes are not considered in this report. Any statements including the phrase or implying "all boreholes" refer to boreholes drilled from 1990 onward. In addition the borehole that was to be designated as Sellafield 6 was planned but never drilled.

A borehole by borehole description of all of the geophysical logging tools used in each logging run within each borehole is included as Appendix 1. Schlumberger undertook all geophysical logging of the Nirex deep boreholes considered in this report. Any other logging that might have been conducted in these boreholes by any logging contractor other than Schlumberger is outside the remit of this report. This report contains reference to Schlumberger tools using their trade marks.

1.2 QA REPORTS ON LOGS

Gibb and Partners Ltd. and Geoscience Ltd undertook quality assurance for all Schlumberger logging activities for Nirex. These activities included physical observation of the actual acquisition process and reporting of the acquisition parameters as it was undertaken. Schlumberger logging procedures for any given logging run are detailed in individual logging reports. These were supplied as Appendix F - Geophysical Logging Acquisition Reports – to each of the reports to NIREX produced for each borehole, and include paper copies of the individual logs.

Standard calibration tests were applied to all logging tools at the wellhead, before and after the logging run in some cases, to ensure the tool was calibrated to within acceptable limits. The details of these calibrations for a single logging run in borehole NSF9B are included in Appendix 1. Table 2 below reproduces the logging QA parameters used in the NSF9B borehole as an example.

Table 2: Logging QA parameters for Nirex Sellafield 9B (NIREX, 1996)

DSI Acquisition parameters	FMD, P&S, STONELEY and UPPER DIPOLE modes of the DSI were recorded The value of Delta-T Shear used to compute the outputs VPVS and PR is that obtained from the Upper Dipole mode. The coherence of the real time STC processing for the Upper Dipole mode data is in places very low and the resulting Delta-T Shear questionable. Reference should be made to the labelling on the STC Coherence Plot for the Upper Dipole data before using values of Delta-T Shear, VPVS or PR from the Field Prints.
FMI Acquisition parameters	The FMI was run with constant EMEX and automatic gain in high range. The parameters XGMO and XVOL were both changed after starting the log and are incorrect in the parameter listings attached to the log, which contains start parameters. No changed parameter summary is attached because both files on the print are derived from playbacks of the data, during which the acquisition changed

2 Conventional Logging Tools

One of the tasks this report seeks to clarify is the question of accuracy and precision of the logging measurements undertaken in Sellafield. There is little quantitative information about the accuracy of individual logging tools in the scientific literature and the principal logging operators have not published much information on this subject. Errors reported in this section of the report are taken from Evans, 1995. These error values were derived from the scientific literature and also discussions with logging professionals from Schlumberger and other organisations from the period of the Sellafield site investigations as detailed in that report.

It should also be noted that all of the tools described here were originally designed and optimised for operation in hydrocarbon exploration. They are thus best suited for operation in clastic and limestone environments, as these are the predominant reservoir lithologies encountered by the hydrocarbon industries. The post-Ordovician lithologies encountered in the Sellafield investigations clastic are thus all within the optimum lithologies of the logging tools.

However the Ordovician volcanic rocks present in the sequence sampled by many of the deep boreholes are not within the ideal operating criteria for any of the logging tools. This does not mean that they do not provide meaningful data but the values for physical properties recorded by such tools are, in some instances, outside the ideal limits for which they have been configured. Where this presents an important factor for a particular tools or type of tools this is made clear in the text below.

2.1 DIPOLE SHEAR SONIC IMAGER (DSI)

2.1.1 Velocity logging

The early boreholes NSF2 and 3, and upper sections of NSF4 and NSF5, were logged using a simple velocity logging tool DST.

This was superseded by the DSI (Dipole Shear Sonic Imager) from the deep sections of boreholes NSF 4 and 5 onward.

The key advance demonstrated by the DSI is its acquisition of both compressional and shear sonic velocity measurements (typically displayed in terms of interval transit time in μft^{-1}) plus derived properties including Young's Modulus and Poisson's Ratio.

Through the course of the Nirex investigations, the Stoneley wave processed fracture properties (fracture occurrence and fracture width) attainable from the DSI, were deemed of increasing importance. They improved the understanding of which fractures, identified from borehole imaging, were likely to be open and thus might allow flow of groundwater. This tool has some acoustic imaging capabilities, but these were largely unused in the logging of the Nirex boreholes.

Table 3: Dipole Sonic Imager technical specification (Schlumberger website 2001)

Specification	**Value**
Temperature Rating	350° F (175° C)
Pressure Rating	20000 PSI (138 MPa)
Tool Size	3.625 in (9.2 cm)
Minimum Hole Size	5.5 in (13.9 cm)
Maximum Hole Size	21 in (53.3 cm)
Tool Length	51 ft (15.5m)
Digitiser sampling interval limits	Variable from 10 to 32,700 µsec per sample
Maximum Logging Speed	
On 8 waveform set (single mode)	3600 $fthr^{-1}$
All 6 modes simultaneously without 6" Δt	1000 $fthr^{-1}$
All 6 modes simultaneously with 6" Δt	900 $fthr^{-1}$
Digitiser precision	12 bits
Acoustic bandwidth	
Dipole and Stoneley	80 Hz to 5 kHz
High-frequency monopole	8 to 30 Hz
Combinability	All MAXIS & any resistivity tools
Repeatability	
Dipole Shear < 500 $\mu secft^{-1}$	5%
Monopole Shear < 150 $\mu secft^{-1}$	3%
Stoneley < 700 $\mu secft^{-1}$	3%
STC Compressional < 170 $\mu secft^{-1}$	2%

2.1.2 Bed Resolution

The DSI uses a standard Schlumberger logging increment of 6 inches (15.24 cm) but this is an over-simplification of its actual resolution. Narrow beds (1 foot or less) will only be detectable if they show a significant acoustic velocity contrast with the surrounding beds, accurate bed resolution for strata with similar acoustic properties of thickness less than 0.5 – 1 metre are not realistic. Borehole imaging tools (especially FMS / FMI) are required for identifying narrower bedding.

2.1.3 Wellhead calibration

Wellhead calibration tests are carried out on the Gamma ray tool which is run in combination with the DSI tool but not on the DSI tool itself. Wellhead calibration information for borehole NSF9B is provided at Figure 2.

2.1.4 POST–ACQUISITION CORRECTIONS

No additional corrections were applied to the logs from the DSI tool other than those which were included on the mechanical properties tape. These are discussed in section 3.4 below.

2.2 LITHO-DENSITY TOOL (LDL)

The Litho-density tool measures density using measurements of the Compton Scattering of a ^{137}Cs gamma source, the scattering being proportional to rock density.

Density logs are conventionally recorded in gcm^{-3} units. There are however disagreements as to the exact degree of correlation between the actual bulk density and that recorded by this tool. Accurate density values are reliant upon a high degree of coupling between the logging sonde and borehole wall. In poor borehole conditions, particularly where there are instances of significant caving, then the results recorded will be inaccurate; fully cored boreholes such as those drilled for the Sellafield investigations are ideal for minimising this effect as the drilling method generally produces smoother borehole walls with less caving than non-coring drilling. However, what is clear is that density logging provides a good indication of the generalised likely bulk density even if there is some discrepancy over the actual values.

2.2.1 Errors and thresholds

Schlumberger list the following as the repeatability of the litho-density tool. No thresholds are supplied and no clear guidance exists enabling them to be found from other sources.

Table 4: Litho-Density logger technical specification (Evans, 1995)

Density (LDL)	± 0.02 gcm^{-3} at 2.5 gcm^{-3}

2.2.2 Bed Resolution

Measurement increment for the litho-density tool is nominally 6 inches (15.24 cm). In common with other logging tools the litho-density tool does not really measure point densities and the data are averaged over some inches either side of the actual nominal depth. This is not a constant volume but will depend upon the formation and conditions encountered and the logging speed.

2.2.3 Wellhead calibration

Source and receiver calibration tests were carried out at the wellhead to ensure successful data acquisition. The calibration results from borehole NSF9B are included below at Figure 3.

2.3 NEUTRON LOGGING TOOLS

Neutron logging tools measure the moderation of emitted neutrons to identify the proton content of a material. In a downhole setting, protons are almost entirely indicative of the presence of hydrogen in the form of water or hydrocarbons. Neutron logging tools measure porosity in Neutron Porosity Units (PU), which are equivalent to percentage porosity in water saturated limestone. Standard logging corrections exist to allow these to be corrected for dolomitic and clastic sediments.

In the geological environment investigated by the Nirex boreholes, where hydrocarbon occurrence is insignificant, the response of neutron logging is therefore entirely due to water within the formation. Although very largely this will be accounted for by saturated porosity in sediments and fluid filled (i.e. open) fractures in the borehole succession, a small percentage could also be made up of water trapped within the formation in forms such as: water of crystallisation in some minerals; interstitial water in clays; water adhered to mineral grains, etc.

Though in most cases the neutron porosity records a level close to actual porosity, in some circumstances the non-porosity elements can be substantial. The neutron porosity records the presence of water in a formation, but provides no information on the mobility of that water (i.e. the permeability).

As with all logging tools, the CNL tool was designed specifically for working in oil-field conditions where the predominant lithologies are sandstone, limestone and “shale” (mudstones). As nearly all Sellafield area formations (with the obvious exception of the Carboniferous Limestone) are non-calcareous, a correction needs to be applied for clastic rocks, such as the Sherwood Sandstone Group, which is detailed on standard log correction charts. This makes a small variation in the recorded porosity of perhaps 2-3 PU in most cases. No correction for acidic igneous rocks, such as the predominant Borrowdale Volcanics Group Lithologies is available, and Schlumberger have used the same correction as for clastic rocks in their own post-processing of logs.

Although neutron logging results are nominally recorded as percentage water content, this must be seen as a scaled average for several feet of the borehole and, in fractured media, a single open fracture will significantly skew the values recorded.

A single generation of tools, the Schlumberger Compensated Neutron logging tool (CNL), was used throughout the investigations. The use of this instrument is essential in any attempt to understand the bulk density properties of the rock and the relative high porosity sections. Neutron logs are not ideally calibrated to basement crystalline rock conditions as absolute values of porosity can fall below the minimum realistic threshold value of the tool giving inaccurate readings. Porosity measurements below 5 PU must be treated as potentially inaccurate, whilst measurements below 2 PU simply mean “very low porosity”. None the less the tool provided significant insight on the presence of fracture zones in the deep basement sections.

2.3.1 Errors and Thresholds

Schlumberger list the following repeatability errors and thresholds for the Compensated Neutron log.

Table 5: Compensated Neutron logger technical specification (Evans, 1995)

Neutron porosity	± 1 PU from 0-20 PU ± 2 PU from 30 - 45 PU ± 6 PU above 45 PU

2.3.2 Bed Resolution

Measurement increment for the Compensated Neutron tool is nominally 6 inches (15.24 cm). In common with other logging tools, the Compensated Neutron tool does not really show point porosity and the data are averaged over some inches either side of the actual nominal depth. This is not a constant volume but will depend upon the formation and conditions encountered, and the logging speed. The borehole condition can exert a significant effect upon this with highly caved boreholes delivering significantly higher porosity values tending to very high readings in seriously caved zones. Rocks with porosities in excess of 30-35% are seldom naturally present at any significant depth below surface as above that point rocks become mechanically unstable. There is no reliable algorithm for quantifying or correcting for this effect but if the compensated neutron logs are examined in combination with a dual caliper log then such zones of significant caving can be identified and anomalously high values for neutron porosity can be discarded for any numerical modelling.

2.3.3 Wellhead Calibration

Source and receiver calibration tests are carried out at the wellhead to ensure successful data acquisition. The calibration results for the Compensated Neutron Logger from borehole header NSF9B are included as Figure 3.

2.3.4 Environmental Corrections

The neutron porosity tool is unusually sensitive to the environmental conditions within the borehole. In particular, measurements are affected by the fluid parameters. Temperature, pressure, fluid density (i.e. barite content) and salinity can all have an effect upon the measuring sensitivity of this tool. However, these corrections are well understood and detailed in the standard Schlumberger logging chart-books and petrophysical software. It should be noted, however, that these effects only have a significant biasing where conditions are significantly more extreme than at Sellafield.

As neutron logging tools measure the presence of water, the sensors must be in contact with the borehole wall to produce data about the formation rather than the properties of the fluid being circulated in the borehole. This is achieved by the sensor of the compensated neutron logging tool being clamped against the borehole wall during acquisition. The efficiency of this clamping will depend upon both the borehole diameter (measured using the caliper log) and the degree of ellipticity of the borehole. These effects are described as “stand-off” and can be compensated for using an algorithm specific to that tool. In the case of the Schlumberger CNL tool, this correction is routinely applied automatically during the acquisition process.

2.4 NGT (NATURAL GAMMA TOOL)

The Natural Gamma spectrometry tool measures the total gamma radiation naturally emitted from the logged formations. This tool was used in all logging runs in all the boreholes to ensure proper depth correlation of all logs. The NGT tool also allows the individual gamma spectrometry data from potassium, thorium and uranium to be shown, which could prove useful in identifying lithological units where limited coring is undertaken. Although this data was routinely acquired, the spectrometry curves were not used widely during the Sellafield investigations because high recovery of core rendered this unnecessary. However, they were used to derive the lithostratigraphy of the basement succession.

2.4.1 Errors & Thresholds

Below are Schlumberger figures for repeatability of NGT measurements.

Table 6: Gamma Ray logger technical specification (Evans, 1995)

Gamma Ray	± 7%

Schlumberger do not issue individual repeatability criteria for the U, Th and K spectra as they say these are affected by too many factors (NIREX, 1996).

2.4.2 Bed Resolution

In common with other logs, the NGS has a standard logging increment of 6 inches (15.24 cm) but this must be seen as a vertical average over a larger interval; the length of this interval depends upon borehole conditions, formations logged and logging speed. No clear thresholds of this range have been published and over-interpretation is a significant danger. Schlumberger 1981 suggest that a practical minimum for interval of this averaging is approximately 1 foot but this depends heavily upon the logging speed.

2.4.3 Wellhead Calibration

Master calibration of NGS tools is undertaken at a test facility in Clamart, France. Wellhead calibration is undertaken using a flexible calibrator containing the naturally radioactive monazite (Schlumberger 82) containing thorium and uranium and their daughter products. Source and receiver calibration tests are carried out at the wellhead to ensure successful data acquisition. The calibration results from borehole header NSF9B are included below at Appendix 2.

2.4.4 Environmental factors

Borehole effects can have a significant biasing effect on the NGS data recorded in particular:

- Density of the borehole fluid (e.g. higher barite concentration of the drilling mud can cause attenuation);
- Tool centring within the borehole;
- Volume of fluid surrounding the sonde within the borehole ;

2.4.5 Time constant

Gamma spectrometry depends on random radioactive decay. Count rates vary about a mean value, which varies over time, thus requiring averaging to gain consistent measurements, this period is known as the time constant. An appropriate logging rate is therefore critical to ensure repeatable gamma logging measurements. The logging rate is recorded routinely upon the log header.

2.5 RESISTIVITY LOGGING.

Resistivity logging is used for determining pore fluid properties and in porosity determination.
All resistivity logs are configured to record a number of resistivity channels which measure the properties of the fluids at varying distances into the formation from the borehole wall. “Shallow” and “deep” resistivity logs were used from all resistivity logging tools during the Nirex investigations. It should be noted that the terms “shallow” and “deep” are relative and not absolute. “Shallow” logs are configured to test the formations in the borehole wall immediately beyond the mud cake (a layer of solid borehole mud that builds up adhered to the borehole surface), but in the zone where borehole fluids have invaded the formation. The “deep” resistivity logs are configured to test the formation fluids beyond this invaded zone, where the fluids are assumed to be native to the formation.
The depth of penetration of these logs is strongly dependant upon the borehole conditions and cannot be given meaningful absolute values, but for “shallow” logs this is of the order of a several centimetres whilst for “deep” logs this may reach several metres. The depth of invasion is determined by the permeability of the rocks. In sedimentary rocks this is largely controlled by the porosity and connectivity of the sedimentary pores so called “primary porosity” and also the effects of borehole fracturing. In crystalline rocks which have no primary porosity, invasion depth is controlled solely by the degree of fracturing. Invasion depth is not necessarily symmetrical.
In sedimentary rocks without significant fracturing, asymmetry from sedimentary structures (e.g. cross beds) can affect the degree of invasion. In crystalline rocks the stress field and the response of the fractures to that field may also cause invasion asymmetry. However this asymmetry can only be measured with a directional resistivity logging tool such as the ARI which was not widely used in the Nirex investigations (see below). The authors of this report could not find any

references available in the Nirex investigations to a serious study of invasion asymmetry using the ARI.

Almost all boreholes within the Sellafield investigations were logged using the DLL (laterolog) tool, from which are derived the shallow and deep laterolog logging channels LLS and LLD. However, two early boreholes were logged using induction logs (NSF2 and 4) in the Borrowdale Volcanics Group (BVG) succession. This logging tool produces shallow and deep induction logs ILS and ILD, without significant variance from the laterolog results, and a phaser induction log was also used on a single occasion (NSF16A) which produced logging channels IDMH (medium penetration) and IDPH (deep penetration). No clear advantages were found in these logging tools over laterologs and where these logs overlapped with laterologs the measurements were seen to be very close in absolute values.

The relationships between the responses of shallow and deep penetrating laterologs were used to study the properties of the ground water and identify zones of low groundwater flow which were potentially suitable for the repository.

Some later boreholes were logged using the Advanced Resistivity Imaging tool (ARI) (often in addition to more conventional laterologs), a deep-focussed resistivity imager, which acted as a generational improvement from laterologs. This later tool allowed a closer logging increment and three-dimensional understanding of the resistivity properties.

2.5.1 Micro-spherically focussed logs (MSFL)

MSFL logs are shallow (a few centimetres penetration), spherically focussed resistivity logs provided as part of the standard Schlumberger resistivity logging package. Only very limited use of these logs was made. These logs are intended for analysis of mud cake and reservoir invasion in oil industry settings.

2.5.2 Errors & Thresholds Downhole Laterologs (DLL)

Table 7: Deep Laterolog technical specification (Evans, 1995)

Resistivity (DLL)	20% from 0.2 to 1 ohm.m 5% from 1 to 2000 ohm.m 10% from 2000 to 5000 ohm.m 20% from 5000 to 40000 ohm.m

2.5.3 Wellhead Calibration

Source and receiver calibration tests are carried out at the wellhead to ensure successful data acquisition. The calibration results from borehole header NSF9B are included below at Figure 4.

2.5.4 Environmental corrections

Bit size and stand off corrections are automatically undertaken by the DLL tools during the acquisition process. Absolute values of the resistivity will also be affected by both fluid salinity and mud weight but these issues were of limited significance during the Sellafield investigations.

3 Borehole Imaging Logs

Probably the most significant advance in the technology of geotechnical site investigation made during the Sellafield area investigations was the routine use of borehole imaging, and in particular FMS / FMI logging. Borehole image logs produce an image of a proportion / the whole internal circumference of the borehole wall. Unlike conventional wireline log interpretation which results in the derivation of purely geophysical parameters, borehole image processing allows an immediate understanding of the subsurface environment. In sedimentary environments, this can include understanding of sedimentary architecture and the study of void or vug spaces in calcareous rocks. In basement or igneous rocks with limited or no primary porosity, borehole imaging logs provide unique data on the structural style and secondary porosity architecture.

Borehole image logging represents a significant advance in allowing an immediate and direct understanding of the subsurface structure. Discontinuities such as fault and veins can be individually identified and orientated. The degree of fracturing provides a similar direct link to understanding the rock strength properties of the subsurface. Increasingly the subsurface stress field (shown by borehole breakouts) can also be visualised and understood using borehole imaging.

When used in combination with geological logging of drill core, it becomes possible to understand the detailed properties and orientation of fracture / fault features in the subsurface and to identify potential flowing features. None of the innovative work undertaken in these fields for the Sellafield area investigations would have been possible without continuous borehole imaging.

3.1 FORMATION MICRO-IMAGER / MICRO-SCANNER IMAGING TOOLS

The Formation Micro-Imager / Micro-scanner (FMI / FMS) logging tools use a number of individual electrodes on four perpendicular pads or flaps to build an image of the borehole wall. The pads are sprung from the logging sonde to ensure a proper contact with the wall. In the 6 inch diameter boreholes typically drilled during the Nirex investigations 85% plus borehole wall coverage was possible, whereas the earlier FMS tool achieved around 40% coverage in 6 inch diameter boreholes. HFMS, a later narrow hole variant of the original FMS tools, achieved similar 50% borehole wall coverage in some of the later 4.5 inch diameter boreholes.

FMS was designed for acquiring borehole images in oil-field conditions, very different from those found in the fractured igneous / volcaniclastic basement rocks underlying the Sellafield area. Acquisition standards for FMS / FMI in fractured basement media improved significantly during the course of the Nirex investigations as the Schlumberger field engineers gained greater experience of the acquisition parameters. Calibration settings for the Formation MicroScanner tools for Sellafield 9B are shown at Figure 5.

When properly acquired, veins as narrow as 0.25 mm thickness can be imaged if filled with a highly conductive material such as hematite (regarded as highly conductive as compared with say silica), though 1 mm thickness veins are the minimum resolution if filled with more common vein minerals (for the Sellafield area) such as quartz or calcite and were individually identifiable on the borehole images. In later boreholes only significant borehole caving (mostly associated with very large fault features of a decimetre scale) prevented acquisition of interpretable logs. Local stress changes around the borehole (induced by drilling) may produce a pattern of micro-fractures that are different from in-situ fracturing. However detailed analysis of the fracture patterns for the structural atlas volume (Barnes, 1996) did not reveal large scale stress induced fracturing patterns.

Theoretically resistivity logging tools used in combination with other logging tools should reveal information about the nature and extent of mud invasion. However there is no clear evidence that significant mud invasion was detected using FMS or FMI tools during the Nirex investigations which were largely interpreted for evidence of fracturing and sedimentary architecture.

3.1.1 Borehole Televiewer (BHTV)

Acoustic borehole images were acquired for all boreholes in the Sellafield Investigations initially using the Schlumberger ATS (Acoustic TeleScanner) tool (a simple BHTV) and later with the Schlumberger UBI (Ultrasonic borehole Imager) tool following problems of image orientation in early boreholes. Image quality was similar for both of these tools. Calibration settings for the Ultrasonic borehole Imager tool for Sellafield 9B are shown at Figure 6.

These investigations highlighted the fact that the acoustic images were perhaps an order of magnitude poorer in identifying fractures than resistivity methods. In waveform transit time mode the response from BHTV tools was further attenuated (in terms of image quality) when compare with FMI logging so that only the very largest features are identifiable from them.

3.2 LOG CORRECTIONS

Errors can be introduced during log acquisition. However acquisition parameters have a surprisingly small effect upon the quality of image data derived from most of the standard imaging tools. These logging tools are surprisingly unaffected by acquisition conditions and most are acquired without settings being altered by the operator from standard acquisition parameters.

3.3 POORLY RESOLVED IMAGES AND THE EFFECTS OF BOREHOLE INVASION AND STRESS INDUCED FRACTURING.

There is no evidence that the acoustic imaging tools used in the Sellafield investigations (BHTV, UBI) can in anyway distinguish zone of borehole invasion in any way that could meaningfully assist interpretation of other logs.

Generally the resistivity imaging undertaken in these boreholes produced extremely high quality images, one of the particular successes of the Sellafield investigations. No detailed investigation has been made of where there was a statistically valid link between zones of poor image recovery and zones of mud invasion. To undertake such an investigation would be very time consuming and is beyond the scope of this report. However, in the opinion of the authors who acted as principal interpreters of borehole imaging (focussed on discontinuity interpretation) there is no clear relationship between invaded zones and zones of poor resistivity imaging

Poorly resolved resistivity images occurred in three main situations:

1. In mechanically damaged sections of borehole walls where contact between the sensor pads on the imaging tools with the borehole walls was insufficient for acquisition of images. Examples are “wash outs” of the borehole walls for example in zones below casing shoes. These instances decreased through the course of the investigations as the increased experience of the drillers led to improved boreholes quality and borehole image logs were acquired sooner after the completion of drilling ensuring the borehole wall was still in a pristine state.
2. In major fault zones (identified by cross correlation with core) where the failure of image resolution was due to apparent sticking of the sensors against the borehole walls and very significant variations in the resistivity contrasts. This effect could potentially be partially

remediated by acceleration correction of the images through the damaged zones though in seriously affected zones which were often associated with mechanical failure of the borehole wall and consequent poor contacts between the sensors and the borehole surface. However this reprocessing is time consuming and expensive and is thus beyond the scope of this report. This factor became increasingly less significant through the course of the Sellafield investigation as the Schlumberger logging engineers became increasingly experienced at acquiring high quality borehole images in faulted intervals. For example the logging of borehole Sellafield 9B was conducted almost entirely through a major fault zone with a very high fracture frequency (Kingdon and Rogers, 1996) but it was possible to match almost every individual discontinuity visually identifiable on the core with borehole images.

3. Continuous zones of highly consistent mud rocks with only limited internal resistivity contrasts.

The FMI tool is configured for identification of borehole surface properties and not for deep penetration of the formation. Identification of invaded zones from FMI images would thus be highly subjective and also time consuming. They are thus beyond the scope of the report.

From the high degree of correlation obtained between fracture intensity identified from borehole images and fracture logging of the core there appears to be no indication of large scale drilling induced fracturing. The authors were responsible for analysing all Sellafield borehole images acquired in boreholes drilled post-1990 for discontinuity orientation analysis. In all of these borehole images there was no evidence of discontinuities in the borehole images which were not present in the core. This implied that borehole drilling stress induced fracturing was not a significant effect. A systematic study of the relationship of drilling induced borehole fracturing would require a significant study of borehole images and detailed observation of the core, which is beyond the scope of this report.

4 Schlumberger post-acquisition processed geophysical logging data

During the course of the Sellafield investigation Nirex commissioned a number of post-acquisition processed data sets. These are datasets derived directly from logging data which require post–acquisition processing at a processing centre away from the log acquisition site. These tapes were typically supplied one to two months post-acquisition.

4.1 FMS / FMI STATIC AND DYNAMIC FILTERED IMAGES AND FMS/FMI DIPMETER PROCESSING

These two datasets are obtained by simple post-processing of the FMS / FMI resistivity imaging tools. The static and dynamic images are a required input dataset for some simpler borehole imaging interpretation packages that are not capable of undertaking the filtering themselves (though in the period since the Sellafield area investigations were undertaken this has largely become redundant).

Resistivity borehole imaging tools were originally derived from dipmeter-type logging tools; the technology is identical, dipmeters have 1 or 2 button electrodes on each orthogonal pad whereas FMS or FMI tools have a greater number of button electrodes per pad. Resistivity post-acquisition processing simply calculates the dip angle and azimuth at regular intervals through a sedimentary succession in an automated manner. This service is largely redundant now owing to full image interpretation of the FMS / FMI images, but allows direct comparison of the FMS record with older dipmeter data.

4.2 DSI WAVEFORM SONIC PROCESSING

This uses the sonic waveform capability of the Dipole Shear Imager (DSI) to provide additional data derived from the velocity logs and is of some value.

4.3 MECHANICAL PROPERTIES POST-PROCESSED DATA

The mechanical properties processing data tape uses a combination of logs combined to derive standard physical properties such as density and Young's modulus.

In common with the ELAN petrophysical processing tape (see below) this service is a proprietary log property data processing product. As a consequence the specific derivation of each component is not listed on the tape headers and so the status of the properties cannot be accurately defined.

4.4 "ELAN" PETROPHYSICAL PROCESSED DATA

ELAN petrophysical processing was a data processing service offered by Schlumberger to Nirex during the course of the Sellafield investigations. This processing claimed to correct a number of the more commonly used logs for known environmental effects. This data is important as the supposedly environmentally corrected data was used as a significant component of the geotechnical and petrophysical studies of the rock mass, including the acoustic impedance inversion of the 3D seismic survey for rock mass and fluid properties.

The environmental corrections applied appear to be those documented in the Schlumberger “Log Interpretation Volume” (Schlumberger, 1989), using standard charts for the correction. Despite extensive searches there are apparently no peer-reviewed publications relating to this service available in the scientific literature. The exact nature of the corrections is commercially confidential to Schlumberger. Notably they no longer offer this service, though ELAN petrophysical processing is available as an add-on module to Schlumberger’s GeoFrame geophysical log interpretation software.

4.5 CRITICAL EVALUATION OF ELAN ENVIRONMENTALLY CORRECTED LOGS

At Nirex’s request the data used for the “Rock Mass” evaluation used in the RCF area was based on environmentally corrected log data from the ELAN petrophysical tapes rather than “raw” field data. As described above, it was not clear what environmental corrections were actually applied.

Therefore, in an attempt to study the nature of these corrections, data from the ELAN petrophysical processed data for Sellafield borehole RCF3 was compared directly with field acquisition data tapes. This borehole is chosen for a number of reasons

1. The borehole was logged using a standard suite of borehole logs.
2. The data from this borehole is known to have been properly acquired with no unusual errors in the acquisition process.
3. The borehole is very close to being vertical thus eliminating any potential biasing created by borehole deviation.

This evaluation has been undertaken for two of the most common logs: NPHI (neutron porosity) and RHOB (Density).

Corrections were assessed in three ways.

1. Logs were plotted overlaying one another to visually demonstrate the differences.
2. An arithmetic difference (field log – post-processed log) was calculated and plotted both as a complete log section, but also as a histogram of values.
3. A cross plot was made of both logs with a regression calculated between the log values.

4.5.1 ELAN processed Neutron Porosity data

Field derived and ELAN processed porosity data from borehole RCF3 were overlain and cross plotted as shown in Figure 7, this shows there is a very high regression coefficient of over 0.98. Overlaying of the field and ELAN processed Neutron porosity data shows that there is a consistent DC shift of mean value -1.79 (±0.847) NPU. This is close to the shift that would be expected for the “lithology correction” from limestone to sandstone NPU included in standard logging charts. This shift remains consistent through both the sedimentary and basement (Borrowdale Volcanic Group) succession, implying that the processing was not done with specific consideration of the lithologies involved.

Larger variations than this consistent 2 NPU difference are almost solely restricted to a small number of highly fractured zones (590 to 620 mbRT). This suggests that a caliper correction algorithm is applied in such zones to account for lack of adequate contact with the borehole wall in zones of caving.

4.5.2 ELAN processed Density data

Field derived and ELAN processed density data from borehole RCF3 were overlain and cross plotted (Figure 8). These data are very close with a regression coefficient of 0.98 and a mean variation of 0.001 ± 0.020 gcm^{-3}.

Critical examination of these data suggests that significant variation are only visible in highly fractured zones of the borehole (e.g. 590 to 620 mbRT) where the ELAN petrophysical software is simply deleting data spikes where lack of adequate contact with the borehole wall in zones of caving prevent accurate recording of density log data.

4.6 LITERATURE SEARCHES ON ENVIRONMENTAL CORRECTION TO GEOPHYSICAL LOGS

Despite the widespread usage of geophysical logs, critical analysis of the main tools and data types is surprisingly sparse. Corrections for many of the main environmental parameters are available to logging contractors, but are commercially confidential. As they have not been tested by the wider community, they must therefore be the subject of considerable scepticism.

5 Repeatability of logs in the Sellafield Investigations

The actual repeatability of logs acquired for the Sellafield investigations were tested using data acquired for PRZ1 run 2, approximately 200 to 770 metres below the drilling platform for this inclined hole known as the slip table (mbST). These were compared directly with the logging run repeat sections for the same logging run. This was done to ensure that all other parameters including logging sonde set up and configuration remain identical, and also to ensure that the latest versions of the tools were used in comparisons.

5.1 SONIC VELOCITY LOGGING

The compressional sonic velocity logging run (on the x-axis) for PRZ1 logging run 2 was crossplotted against the repeat section for this run over the interval 493-596 mbST (Figure 9). The repeat section is designated is displayed on the y-axis.

Figure 10 shows the crossplot for the sonic logs of PRZ1 run 2 as above but with the depth of the points down section represented by the colour sale to the right of the cross-plots. This shows significant scatter in the data and a regression value of only 0.89. There are significant variations between the two logging passes, particularly in the interval 520-530 mbST, which account for the majority of the data scatter demonstrated in Figure 11 which shows the same data but with depth of points (as mbST) rather than density of points plotted as the z-axis. This implies that the logs repeatability is generally good but can be disturbed in localised areas by borehole effects such as caving etc. Examination of the perpendicular caliper log showing variations in the borehole diameter through this interval demonstrate the validity of these findings.

5.2 DENSITY LOGGING

The main density logging run for PRZ1 logging run 2 was crossplotted (on the x-axis) against the repeat section of the same run (on the y-axis) as Figure 11. The interval of the repeat section covered a depth range of approximately 498-600 mbST. The repeat section is displayed as the y-axis.

As Figure 11 shows, the density logs showed a very close correlation between the two runs with a regression coefficient of 0.97, well within the accepted margin of error.

5.3 GAMMA RAY LOGGING

In Figure 12 the gamma ray logging run GR for PRZ1 logging run 2 (acquired simultaneously with the FMI logging) was crossplotted (on the x-axis) against the repeat section of the same run (on the y-axis) as. The interval of the repeat section covered a depth range of approximately 495 to 585 mbST. The repeat section is displayed as the y-axis.

The spectral gamma ray logging run SGR for PRZ1 logging run 2 (acquired simultaneously with the UBI) was crossplotted (on the x-axis) against the repeat section of the same run as Figure 13. The interval of the repeat section covered a depth range of approximately 498-600 mbST. The repeat section is displayed as the y-axis.

As seen in Figure 12 the total gamma ray logs show a reasonable correlation between the two runs with a regression coefficient of 0.95, just within the accepted margin of error of ±7%. The spectral gamma ray logs (Figure 13) for the same succession shows a poor correlation with a regression coefficient of only 0.75.

Unusually for the Schlumberger logging data, the log data provided for PRZ1 did not come with a “definitive” gamma logging run acquired as part of the litho-density compensated neutron logging run. Because of the statistical nature of gamma ray emission and the low count in individual energy channels, achievement of spectral gamma ray logging that is reliable is highly dependant upon the logging speed. The slower the logging speed the longer that the tool can count, thus permitting a repeatable and statistically accurate count in each of the individual spectral channels.

5.4 RESISTIVITY LOGS

Three resistivity logs were directly compared with the repeat sections for PRZ1 logging run 2: deep laterolog (LLD), shallow laterolog (LLS) and micro-spherically focussed log (MSFL). These are displayed as log-log crossplots with the repeat sections as the Y-axis. The depth interval of the repeat section is approximately 498-598 mbST in all cases.

Crossplotted results of these logs are shown as Figure 14 (LLD), Figure 15 (LLS) and Figure 16 (MSFL)

The laterolog plots show a very high correlation between the original and repeat sections with regression coefficients for the deep laterolog of 0.99, shallow laterolog of 0.99.

The poorer correlation of the MSFL with regression correlation coefficients of only 0.75 is probably due to the shallow focus of the tool which essentially samples the borehole environment itself (including any mud-cake) rather than the formation drilled through. The shallow nature of the tested environment makes it extremely susceptible to disturbance including the action of the repeat logging and is therefore not a significant cause for concern. MSFL logs should be interpreted qualitatively rather than quantitatively.

6 Conclusion

From the beginning of the Nirex investigations of the Sellafield area, the geophysical borehole logs were used as one of the fundamental data sources for the entire site evaluation program. The high quality of the logging undertaken formed a fundamental part of the evaluation process of the site and was incorporated into all of the key modelling results: geophysical, structural and hydrogeological.

One of the key conclusions that is not easily demonstrated in a report such as this is that the logging engineers working on acquisition inevitably become more experienced at acquiring such logs through the course of an investigation. In the case of the Sellafield investigations this meant that, for example, clear and full interpretable borehole image logs were acquired in later boreholes, such as Sellafield 9b, through zones which would not have been imaged using the same tool earlier in the investigative process.

The high degree of repeatability demonstrated for almost all of the key logging tools (shown in Figure 9 to Figure 16) demonstrates the validity of applying geophysical borehole logging to even the non-standard lithologies sampled in the NIREX investigations. The only logging tool which does not produce a statistical meaningful regression from this exercise was the micro-spherically focussed log. As this tool is specifically designed to sample the mud cake on the surface of the borehole, which is by definition ephemeral. This is a highly satisfactory result.

The validity of the post-acquisition processed log data is more problematical. Accurate assessment of the “ELAN” post-processed data is hampered by the complete lack of information within the scientific literature regarding the basis on which such corrections are made. The very high regression coefficient between raw and processed data of over 0.98 for both Neutron porosity logging data and Density logging data strongly implies that this processing does not add anything meaningful to the raw data. Indeed the ELAN processed Neutron porosity data shows only a consistent DC shift of mean value -1.79 (±0.847) NPU and that the processed density data is identical to the source data except for the removal of a number of data spikes. The authors therefore would recommend that if the Sellafield data is to be integrated with any other logging data then the high quality raw data is used in preference. The fact that the full acquisition details parameters are available on the log headers (and digital records) will ensure that the data can be integrated seamlessly with any other geophysical logs without disturbance from unknown correction algorithms.

7 References

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8 Figures

Figure 2 to Figure 6 show calibration information and settings for each logging tool used in the acquisition of borehole NSF9B is shown below

Figure 2: Sellafield 9B DSI Acquisition parameters and calibration results

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CALIBRATION SUMMARY

MAXIS 500 Field Log

Calibration and Check Summary

Measurement	Nominal	Master	Before	After	Change	Limit	Units
Scintillation Gamma-Ray - L Wellsite Calibration - Detector Calibration							
Before: Jun 22 09:34 1995							
Gamma Ray Background	30.00	N/A	35.59	N/A	N/A	N/A	GAPI
Gamma Ray (Jig - Bkg)	162.2	N/A	162.2	N/A	N/A	14.74	GAPI
Gamma Ray (Calibrated)	165.0	N/A	167.9	N/A	N/A	15.00	GAPI

Scintillation Gamma-Ray - L / Equipment Identification

Primary Equipment:		
Scintillation Gamma Cartridge	SGC - SA	807
Scintillation Gamma Detector	SGD - TAA	3536
Auxiliary Equipment:		
Scintillation Gamma Housing	SGH - K	1226
Gamma Source Radioactive	GSR - U/Y	122

Scintillation Gamma-Ray - L Wellsite Calibration

Detector Calibration

Phase	Gamma Ray Background GAPI	Value	Phase	Gamma Ray (Jig - Bkg) GAPI	Value	Phase	Gamma Ray (Calibrated) GAPI	Value
Before		35.59	Before		162.2	Before		167.9
	0 (Minimum) 30.00 (Nominal) 120.0 (Maximum)			147.4 (Minimum) 162.2 (Nominal) 176.9 (Maximum)			150.0 (Minimum) 165.0 (Nominal) 180.0 (Maximum)	

Before: Jun 22 09:34 1995

COMPANY:	UK Nirex Ltd.	BOTTOM LOG INTERVAL	139.5 M
	Commercial In Confidence	SCHLUMBERGER DEPTH	144.5 M
WELL:	Borehole 9B	DEPTH DRILLER	150 M
FIELD:	Sellafield		
COUNTY:	Cumbria	DRILL FLOOR	
COUNTRY:	U.K.	GROUND LEVEL	116.576 M

Schlumberger

Maxis Image Log Scale 1:200
DSI-GR
Sonic Transit Times

Figure 3: Sellafield 9B Litho-Density Logger & Compensated Neutron Logger Acquisition parameters and calibration results

Schlumberger

CALIBRATION SUMMARY

MAXIS 500 Field Log

Calibration and Check Summary

Measurement	Nominal	Master	Before	After	Change	Limit	Units
Litho Density - D Wellsite Calibration - Background Measurement							
Master: Jun 13 16:01 1995 Before: Jun 22 06:31 1995 After: Jun 22 08:42 1995							
LL Background	20.00	17.01	16.95	16.95	0.0005284	1.000	CPS
LU Background	76.00	65.72	65.40	65.18	-0.2441	1.000	CPS
LS Background	57.00	49.87	49.65	49.53	-0.1215	1.000	CPS
LITH Background	5.500	4.881	4.740	4.771	0.03089	0.3000	CPS
SS1 Background	16.00	13.34	13.93	13.98	0.05252	0.5000	CPS
SS2 Background	11.00	9.385	9.384	9.416	0.03214	0.5000	CPS
Litho Density - D Wellsite Calibration - Tool Quality Control Information HV							
Master: Jun 13 16:01 1995 Before: Jun 22 06:31 1995 After: Jun 22 08:42 1995							
LSHV Background	1500	1220	1219	1210	-9.660	N/A	V
SSHV Background	1500	1172	1171	1165	-6.290	N/A	V
Litho Density - D Wellsite Calibration - Detectors Resolution From BKG Measurments							
Master: Jun 13 16:01 1995 Before: Jun 22 06:31 1995 After: Jun 22 08:42 1995							
LS Resolution Background	8.000	8.446	8.450	8.436	-0.01393	N/A	
SS Resolution Background	8.000	8.638	8.600	8.583	-0.01600	N/A	
Litho Density - D Wellsite Calibration - Caliper Calibration							
Before: Jun 22 08:29 1995							
Caliper Small Ring	6.376	N/A	6.327	N/A	N/A	N/A	IN
Caliper Large Ring	8.000	N/A	7.954	N/A	N/A	N/A	IN
Compensated Neutron - G Wellsite Calibration - Zero Measurement							
Master: Jun 11 19:51 1995 Before: Jun 22 06:28 1995 After: Jun 22 08:34 1995							
CNTC Background	1.000	0.2824	0	0	0	N/A	CPS
CFTC Background	0	3.163	0	0.2631	0.2631	N/A	CPS
CNEC Background	1.000	0	0	0	0	N/A	CPS
CFEC Background	0	0	0	0	0	N/A	CPS
Compensated Neutron - G Wellsite Calibration - Jig Measurement							
Master: Jun 11 21:16 1995 Before: Jun 22 06:50 1995 After: Jun 22 08:45 1995							
CNTC Jig	2928	2928	2928	2937	8.348	N/A	CPS
CFTC Jig	1245	1245	1228	1231	3.618	N/A	CPS
CNTC/CFTC (Jig)	2.350	2.350	2.385	2.385	-0.0032294	N/A	
CNEC Jig	660.8	660.8	659.8	657.2	-2.637	N/A	CPS
CFEC Jig	580.8	580.8	578.0	578.2	0.1351	N/A	CPS
CNEC/CFEC (Jig)	1.138	1.138	1.141	1.137	-0.004827	N/A	
Compensated Neutron - G Wellsite Calibration - Apparent Porosity Change At 20 PU							
After: Jun 22 08:45 1995							
Norm. Thermal Porosity Change	0	N/A	N/A	-0.003289	N/A	N/A	
Norm. Epi. Porosity Change	0	N/A	N/A	-0.1565	N/A	N/A	
Natural Gamma Spectroscopy - C Wellsite Calibration - Background Measurement							
Master: Jun 13 04:03 1995 Before: Jun 22 06:31 1995 After: Jun 22 06:56 1995							
WINDOW 1 Background	100.0	81.10	79.95	85.13	5.180	100.0	CPS
WINDOW 2 Background	50.00	9.461	23.31	26.57	3.257	50.00	CPS
WINDOW 3 Background	10.00	2.766	6.606	7.826	1.220	10.00	CPS
WINDOW 4 Background	6.000	0.6019	1.204	1.372	0.1679	6.000	CPS
WINDOW 5 Background	10.00	0.7310	1.283	1.224	-0.05823	10.00	CPS
SGR Background	30.00	11.68	29.39	31.95	2.555	N/A	GAPI
Natural Gamma Spectroscopy - C Wellsite Calibration - Normalized Jig Measurement							
Master: Jun 13 03:56 1995 Before: Jun 22 06:44 1995 After: Jun 22 09:42 1995							
WINDOW 1 Jig	376.0	371.8	373.3	373.4	0.06204	22.56	CPS
WINDOW 2 Jig	167.0	161.3	162.6	166.8	4.156	10.02	CPS
WINDOW 3 Jig	24.00	22.75	23.72	23.46	-0.2558	1.440	CPS
WINDOW 4 Jig	14.00	13.79	13.58	13.96	0.3772	2.800	CPS
WINDOW 5 Jig	22.50	21.44	21.18	21.79	0.6233	4.500	CPS
SGR Jig	160.0	159.1	160.0	161.3	1.336	7.000	GAPI

The CNT Master Calibration Was Done With The Following Parameters

NCT-B Water Temperature 18.0 DEGC
Thermal Housing Size 3.375 IN.
Epithermal Housing Size 3.375 IN.

The NGT PCSL Value is set to -32.460 KEV

Litho Density - D / Equipment Identification

Primary Equipment:			
Nuclear Services Cartridge	NSC - E	2739	PRP-01
Powered Gamma Detector	PGD - G	4656	PRP-01
Gamma Source Radioactive	GSR - J	10735	FED-01
Auxiliary Equipment			
Density Resistivity Sonde	DRS - C	6905	PRP-01
Electronics Cartridge Housing	ECH - MKA	2735	PRP-01
Powered Detector Housing	PDH - L	4907	PRP-01

Litho Density - D Wellsite Calibration

Background Measurement

Phase	LL Background CPS	Value	Phase	LU Background CPS	Value	Phase	LS Background CPS	Value
Master		17.01	Master		65.72	Master		48.67
Before		16.95	Before		65.40	Before		48.65
After		16.96	After		65.16	After		49.53
	15.00 (Minimum) 20.00 (Nominal) 25.00 (Maximum)			58.00 (Minimum) 76.00 (Nominal) 94.00 (Maximum)			45.00 (Minimum) 57.00 (Nominal) 73.00 (Maximum)	
Phase	LITH Background CPS	Value	Phase	SS1 Background CPS	Value	Phase	SS2 Background CPS	Value
Master		4.961	Master		13.94	Master		9.385
Before		4.740	Before		13.93	Before		9.394
After		4.771	After		13.98	After		9.416
	4.000 (Minimum) 5.600 (Nominal) 7.000 (Maximum)			12.00 (Minimum) 16.00 (Nominal) 19.50 (Maximum)			8.000 (Minimum) 11.00 (Nominal) 13.50 (Maximum)	

Master: Jun 13 16:01 1995 Before: Jun 22 08:31 1995 After: Jun 22 08:42 1995

Litho Density - D Wellsite Calibration

Detectors Resolution From BKG Measurments

Phase	LS Resolution Background	Value	Phase	SS Resolution Background	Value
Master		8.446	Master		8.533
Before		8.450	Before		8.506
After		8.438	After		8.598
	5.000 (Minimum) 8.000 (Nominal) 11.50 (Maximum)			5.000 (Minimum) 8.000 (Nominal) 11.50 (Maximum)	

Master: Jun 13 16:01 1995 Before: Jun 22 08:31 1995

After: Jun 22 08:42 1995

Compensated Neutron - G / Equipment Identification

Primary Equipment:			
Compensated Neutron Cartridge	CNC - GA	172	ORN-01
Neutron Logging Source	NLS - KL	2320	ORN-01
Neutron Source Radioactive	NSR - F	2320	ORN-01
Compensated Neutron Box	CNB - AB	2040	ORN-01
Neutron Detector without Alpha Source	CND - NA		ORN-01
Compensated Neutron Box	CNB - AB	2040	ORN-01
Auxiliary Equipment:			
Compensated Neutron Housing	CNH - G	200	ORN-01
Neutron Calibration Tank	NCT - B	1	SHOP

Compensated Neutron - G Wellsite Calibration

Zero Measurement

Phase	CNTC Background CPS	Value	Phase	CFTC Background CPS	Value
Master		0.3024	Master		3.163
Before		0	Before		0
After		0	After		0.2631
	-0.010000 (Minimum) 1.000 (Nominal) 5.000 (Maximum)			-0.010000 (Minimum) 0 (Nominal) 5.000 (Maximum)	
Phase	CNEC Background CPS	Value	Phase	CFEC Background CPS	Value
Master		0	Master		0
Before		0	Before		0
After		0	After		0
	-0.010000 (Minimum) 1.000 (Nominal) 5.000 (Maximum)			-0.010000 (Minimum) 0 (Nominal) 5.000 (Maximum)	

Master: Jun 11 19:51 1995 Before: Jun 22 08:28 1995

After: Jun 22 08:34 1995

Compensated Neutron - G Wellsite Calibration
Jig Measurement

Phase	CNTC Jig CPS Value	CFTC Jig CPS Value	CNTC/CFTC (Jig) Value
Master	2926	1245	2.350
Before	2926	1228	2.385
After	2937	1231	2.385
(Minimum)	2780	1183	2.310
(Nominal)	2926	1245	2.350
(Maximum)	3073	1307	2.390

Phase	CNEC Jig CPS Value	CFEC Jig CPS Value	CNEC/CFEC (Jig) Value
Master	660.6	580.8	1.138
Before	659.8	578.0	1.141
After	657.2	578.2	1.137
(Minimum)	627.6	551.7	1.098
(Nominal)	660.6	580.8	1.138
(Maximum)	693.6	609.8	1.178

Master: Jun 11 21:16 1995 Before: Jun 22 06:50 1995 After: Jun 22 08:45 1995

Compensated Neutron - G Wellsite Calibration
Apparent Porosity Change At 20 PU

Phase	Norm. Thermal Porosity Change Value	Norm. Epi. Porosity Change Value
After	-0.003269	-0.1565
(Minimum)	-0.6000	-0.6000
(Nominal)	0	0
(Maximum)	0.6000	0.6000

After: Jun 22 08:45 1995

Natural Gamma Spectroscopy - C / Equipment Identification

Primary Equipment:			
NGT Cartridge	NGC - C	1658	PRP-01
NGT Sonde	NGD - A	1656	PRP-01
Auxiliary Equipment:			
NGT Cartridge Housing	NGCH - A	1649	PRP-01
NGT Sonde Housing	NGH - B	1642	PRP-01
Gamma Source Radioactive	GSR - U	122	702

Natural Gamma Spectroscopy - C Wellsite Calibration
Background Measurement

Phase	WINDOW 1 Background CPS Value	WINDOW 2 Background CPS Value	WINDOW 3 Background CPS Value
Master	31.10	9.461	2.768
Before	79.95	23.31	6.608
After	85.13	26.57	7.828
(Minimum)	0	0	0
(Nominal)	100.0	50.00	10.00
(Maximum)	400.0	200.0	40.00

Phase	WINDOW 4 Background CPS Value	WINDOW 5 Background CPS Value	SGR Background GAPI Value
Master	0.6019	0.7310	11.68
Before	1.204	1.283	29.39
After	1.372	1.224	31.95
(Minimum)	0	0	0
(Nominal)	6.000	10.00	30.00
(Maximum)	24.00	40.00	120.0

Master: Jun 13 04:03 1995 Before: Jun 22 06:31 1995 After: Jun 22 08:56 1995

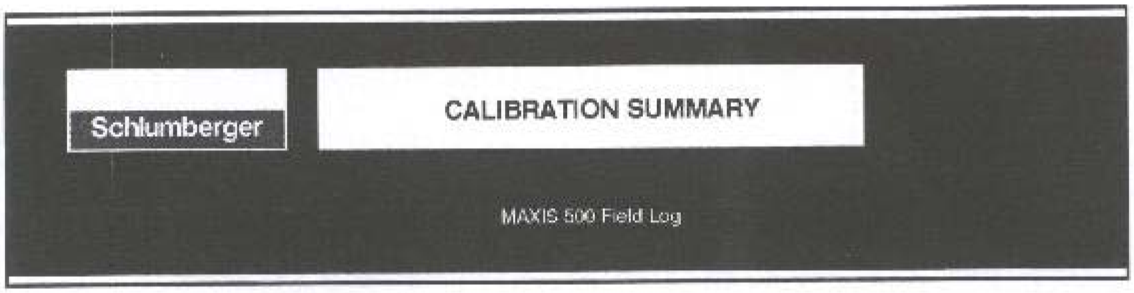
Natural Gamma Spectroscopy - C Wellsite Calibration
Normalized Jig Measurement

Phase	WINDOW 1 Jig CPS Value	WINDOW 2 Jig CPS Value	WINDOW 3 Jig CPS Value
Master	371.8	161.3	22.75
Before	373.3	162.6	23.72
After	373.4	166.8	23.46
(Minimum)	354.0	155.0	21.50
(Nominal)	376.0	167.0	24.00
(Maximum)	398.0	179.0	26.50

Phase	WINDOW 4 Jig CPS Value	WINDOW 5 Jig CPS Value	SGR Jig GAPI Value
Master	13.79	21.44	159.1
Before	13.58	21.16	160.0
After	13.96	21.79	161.3
(Minimum)	12.50	20.00	148.0
(Nominal)	14.00	22.50	160.0
(Maximum)	15.50	25.00	172.0

Master: Jun 13 03:58 1995 Before: Jun 22 06:44 1995 After: Jun 22 08:42 1995

Figure 4: Sellafield 9B Deep laterolog acquisition parameters and calibration results



Calibration and Check Summary

Measurement	Nominal	Master	Before	After	Change	Limit	Units
DUAL LATEROLOG - E Wellsite Calibration - DLT ELECTRONICS CALIBRATION Laterolog Measurement							
Before: Jun 22 03:59 1995 After: Jun 22 04:36 1995							
MEASURED LLD	31.62	N/A	32.31	32.33	0.02493	0.8000	OHMM
MEASURED LLS	31.62	N/A	32.09	32.10	0.004410	0.8000	OHMM
Scintillation Gamma-Ray - L Wellsite Calibration - Detector Calibration							
Before: Jun 22 03:29 1995							
Gamma Ray Background	30.00	N/A	32.23	N/A	N/A	N/A	GAPI
Gamma Ray (Jig - Bkg)	165.4	N/A	165.4	N/A	N/A	15.04	GAPI
Gamma Ray (Calibrated)	165.0	N/A	165.0	N/A	N/A	15.00	GAPI

DUAL LATEROLOG - E / Equipment Identification

Primary Equipment:

Auxiliary Equipment:

Dual Laterolog Electrode	DLE - F	724
Dual Laterolog Sonde	DLS - F	780
Dual Laterolog Housing	DLH - CB	2786
Dual Laterolog Cartridge	DLC - D	771
Laterolog Control Module	LCM - AA	1721

DUAL LATEROLOG - E Wellsite Calibration

DLT ELECTRONICS CALIBRATION Laterolog Measurement

Phase	MEASURED LLD OHMM Value	MEASURED LLS OHMM Value
Before	32.31	32.09
After	32.33	32.10
Minimum / Nominal / Maximum	29.00 / 31.62 / 40.00	29.00 / 31.62 / 40.00

Before: Jun 22 03:59 1995 After: Jun 22 04:36 1995

DUAL LATEROLOG - E Wellsite Calibration

DLT Electronics Calibration Plus Measurement

Phase	Deep Current Plus UA Value	Deep Voltage Plus MV Value	Groningen Voltage Plus MV Value
Before	340.2	10.99	10.96
After	337.4	10.91	10.97
Minimum / Nominal / Maximum	317.5 / 342.5 / 367.5	9.830 / 10.83 / 11.83	9.830 / 10.83 / 11.83

Phase	Shallow Current Plus UA Value	Shallow Voltage Plus MV Value
Before	341.1	10.95
After	341.4	10.98
Minimum / Nominal / Maximum	317.5 / 342.5 / 367.5	9.830 / 10.83 / 11.83

Before: Jun 22 03:55 1995 After: Jun 22 04:35 1995

DUAL LATEROLOG - E Wellsite Calibration

DLT Electronics Calibration Zero Measurement

Phase	Deep Current Zero UA Value	Deep Voltage Zero MV Value	Groningen Voltage Zero MV Value
Before	-0.1252	6.228E-05	-0.007907
After	-0.1295	-7.864E-05	-0.008064
Minimum / Nominal / Maximum	-1.000 / 0 / 1.000	-0.1000 / 0 / 0.1000	-0.1000 / 0 / 0.1000

Phase	Shallow Current Zero UA Value	Shallow Voltage Zero MV Value
Before	-0.1025	-0.007828
After	-0.1183	-0.008561
Minimum / Nominal / Maximum	-1.000 / 0 / 1.000	-0.1000 / 0 / 0.1000

Figure 5: Sellafield 9B Formation MicroScanner acquisition parameters and calibration results

Full-Bore Scanner - B / Equipment Identification

Primary Equipment:		
FullBore Scanner Sonde	FBSS - B	761
FullBore Scanner Sonde Upper part	FBSH - A	761
FullBore Scanner Sonde Cartridge	FBSC - B	761
GPIT Cartridge - A	GPIC - A	962
Insulating Sub	AH - 185	726
FullBore Scanner Control Cartridge	FBCC - A	769
Auxiliary Equipment:		
Electronics Cartridge Housing	ECH - MRA	3987

Full-Bore Scanner - B Wellsite Calibration

Caliper Calibration

Phase	Caliper #1 Small Jig IN	Value	Phase	Caliper #2 Small Jig IN	Value
Before		5.102	Before		4.880
	4.590 (Minimum) 5.400 (Nominal) 6.210 (Maximum)			4.590 (Minimum) 5.400 (Nominal) 6.210 (Maximum)	
Phase	Caliper #1 Large Jig IN	Value	Phase	Caliper #2 Large Jig IN	Value
Before		7.990	Before		7.851
	6.800 (Minimum) 8.000 (Nominal) 9.200 (Maximum)			6.800 (Minimum) 8.000 (Nominal) 9.200 (Maximum)	

Before: Jun 22 12:33 1995

Scintillation Gamma-Ray - L / Equipment Identification

Primary Equipment:		
Scintillation Gamma Cartridge	SGC - SA	807
Scintillation Gamma Detector	SGD - TAA	3536
Auxiliary Equipment:		
Scintillation Gamma Housing	SGH - K	1226
Gamma Source Radioactive	GSR - U/Y	122

Scintillation Gamma-Ray - L Wellsite Calibration

Detector Calibration

Phase	Gamma Ray Background GAPI	Value	Phase	Gamma Ray (Jig - Bkg) GAPI	Value	Phase	Gamma Ray (Calibrated) GAPI	Value
Before		31.42	Before		159.4	Before		165.0
	0 (Minimum) 30.00 (Nominal) 120.0 (Maximum)			144.9 (Minimum) 159.4 (Nominal) 173.9 (Maximum)			150.0 (Minimum) 165.0 (Nominal) 180.0 (Maximum)	

Before: Jun 22 12:32 1995

COMPANY:	UK Nirex Ltd.	Commercial In Confidence	BOTTOM LOG INTERVAL	144.1 M
			SCHLUMBERGER DEPTH	144.5 M
WELL:	Borehole 9B		DEPTH DRILLER	150 M
FIELD:	Sellafield			
COUNTY:	Cumbria		DRILL FLOOR	
COUNTRY:	U.K.		GROUND LEVEL	116.576 M

Schlumberger

Maxis Image Log Scale 1:40
FMI-GR
Formation Micro Imager

Figure 6: Sellafield 9B Ultrasonic Borehole Imager acquisition parameters and calibration results.

Schlumberger

CALIBRATION SUMMARY

MAXIS 500 Field Log

Calibration and Check Summary

Measurement	Nominal	Master	Before	After	Change	Limit	Units
General Purpose Inclinometer Wellsite Calibration - CROUZET ACCELEROMETER PROM HAS BEEN READ CORRECTLY							
Before: Jun 22 15:04 1995							
TEMPERATURE REFERENCE :	N/A	N/A	20	N/A	N/A	N/A	DEGC
YEAR OF CALIBRATION :	N/A	N/A	93	N/A	N/A	N/A	
MONTH OF CALIBRATION :	N/A	N/A	7	N/A	N/A	N/A	
SERIAL NUMBER :	N/A	N/A	272	N/A	N/A	N/A	
General Purpose Inclinometer Wellsite Calibration - CROUZET MAGNETOMETER PROM HAS BEEN READ CORRECTLY							
Before: Jun 22 15:04 1995							
TEMPERATURE REFERENCE :	N/A	N/A	18	N/A	N/A	N/A	DEGC
YEAR OF CALIBRATION :	N/A	N/A	92	N/A	N/A	N/A	
MONTH OF CALIBRATION :	N/A	N/A	4	N/A	N/A	N/A	
SERIAL NUMBER :	N/A	N/A	159	N/A	N/A	N/A	
Natural Gamma Spectroscopy - C Wellsite Calibration - Background Measurement							
Master: Jun 13 04:03 1995 Before: Jun 22 15:09 1995							
WINDOW 1 Background	100.0	31.10	93.88	N/A	N/A	100.0	CPS
WINDOW 2 Background	50.00	9.481	31.75	N/A	N/A	50.00	CPS
WINDOW 3 Background	10.00	2.763	10.11	N/A	N/A	10.00	CPS
WINDOW 4 Background	6.000	0.6019	1.676	N/A	N/A	6.000	CPS
WINDOW 5 Background	10.00	0.7310	1.652	N/A	N/A	10.00	CPS
SGR Background	50.00	11.68	36.38	N/A	N/A	N/A	GAPI
Natural Gamma Spectroscopy - C Wellsite Calibration - Normalized Jig Measurement							
Master: Jun 13 03:58 1995 Before: Jun 22 15:17 1995							
WINDOW 1 Jig	370.0	371.8	356.3	N/A	N/A	22.56	CPS
WINDOW 2 Jig	167.0	161.3	158.7	N/A	N/A	10.02	CPS
WINDOW 3 Jig	24.00	22.75	22.30	N/A	N/A	1.440	CPS
WINDOW 4 Jig	14.00	13.79	13.61	N/A	N/A	2.800	CPS
WINDOW 5 Jig	22.50	21.44	21.28	N/A	N/A	4.500	CPS
SGR Jig	180.0	164.?	160.0	N/A	N/A	7.000	GAPI

The NGT PCBL Value is set to -32.460 KEV

General Purpose Inclinometer / Equipment Identification

Primary Equipment:		
GPIT Cartridge - A	GPIC - AC	302
Auxiliary Equipment:		
GPIT Housing	GPIH - A	309

Background Measurement

Phase	WINDOW 1 Background CPS	Value	Phase	WINDOW 2 Background CPS	Value	Phase	WINDOW 3 Background CPS	Value
Master		31.10	Master		9.46'	Master		2.766
Before		93.68	Before		31.75	Before		10.11
	0 (Minimum) 100.0 (Nominal) 400.0 (Maximum)			0 (Minimum) 50.00 (Nominal) 200.0 (Maximum)			0 (Minimum) 10.00 (Nominal) 40.00 (Maximum)	
Phase	WINDOW 4 Background CPS	Value	Phase	WINDOW 5 Background CPS	Value	Phase	SGR Background GAPI	Value
Master		0.6019	Master		0.7310	Master		11.69
Before		1.676	Before		1.552	Before		34.38
	0 (Minimum) 6.000 (Nominal) 24.00 (Maximum)			0 (Minimum) 10.00 (Nominal) 40.00 (Maximum)			0 (Minimum) 30.00 (Nominal) 120.0 (Maximum)	

Master: Jun 13 04:03 1995 Before: Jun 22 15:09 1995

Natural Gamma Spectroscopy - C Wellsite Calibration

Normalized Jig Measurement

Phase	WINDOW 1 Jig CPS	Value	Phase	WINDOW 2 Jig CPS	Value	Phase	WINDOW 3 Jig CPS	Value
Master		371.8	Master		161.3	Master		22.75
Before		358.3	Before		158.7	Before		22.30
	354.0 (Minimum) 376.0 (Nominal) 398.0 (Maximum)			155.0 (Minimum) 167.0 (Nominal) 179.0 (Maximum)			21.50 (Minimum) 24.00 (Nominal) 26.50 (Maximum)	
Phase	WINDOW 4 Jig CPS	Value	Phase	WINDOW 5 Jig CPS	Value	Phase	SGR Jig GAPI	Value
Master		13.79	Master		21.44	Master		164.7
Before		13.61	Before		21.29	Before		160.0
	12.50 (Minimum) 14.00 (Nominal) 15.50 (Maximum)			20.00 (Minimum) 22.50 (Nominal) 25.00 (Maximum)			148.0 (Minimum) 160.0 (Nominal) 172.0 (Maximum)	

Master: Jun 13 03:58 1995 Before: Jun 22 15:17 1995

Natural Gamma Spectroscopy - C Wellsite Calibration

Quality Control Values

Phase	DHYF Jig Y	Value	Phase	Quality Windows Ratio Jig	Value
Master		1306	Master		2.304
Before		1307	Before		2.257
	1088 (Minimum) 1450 (Nominal) 1813 (Maximum)			2.150 (Minimum) 2.240 (Nominal) 2.330 (Maximum)	

Master: Jun 13 03:58 1995 Before: Jun 22 15:17 1995

Natural Gamma Spectroscopy - C Wellsite Calibration

Quality Control Values Check

Phase	Thorium peak Form Factor Jig	Value
Before		0.1998
	-0.2000 (Minimum) 0 (Nominal) 0.2000 (Maximum)	

Before: Jun 22 15:17 1995

COMPANY:	UK Nirex Ltd.	Commercial In Confidence	BOTTOM LOG INTERVAL	139.3 M
			SCHLUMBERGER DEPTH	144.5 M
WELL:	Borehole 9B		DEPTH DRILLER	150 M
FIELD:	Sellafield			
COUNTY:	Cumbria		DRILL FLOOR	
COUNTRY:	U.K.		GROUND LEVEL	116.575 M

Key to Figure 7 to Figure 16

- Dotted lines parallel to regression line mark data within ± 1 Standard Deviation of the regression (where shown)
- All units are specified on axes
- Colour coding represents the number of points represented by each pixel (except where marked)
    - Red / Orange Colours: = High density
    - Green / Blue Colours: Low density
    - A diagram specific key is shown in each diagram

Figure 7: Crossplot of Uncorrected Neutron Porosity Logs against "ELAN Environmentally Corrected" Neutron Porosity, Borehole RCF3, Logging Run 2

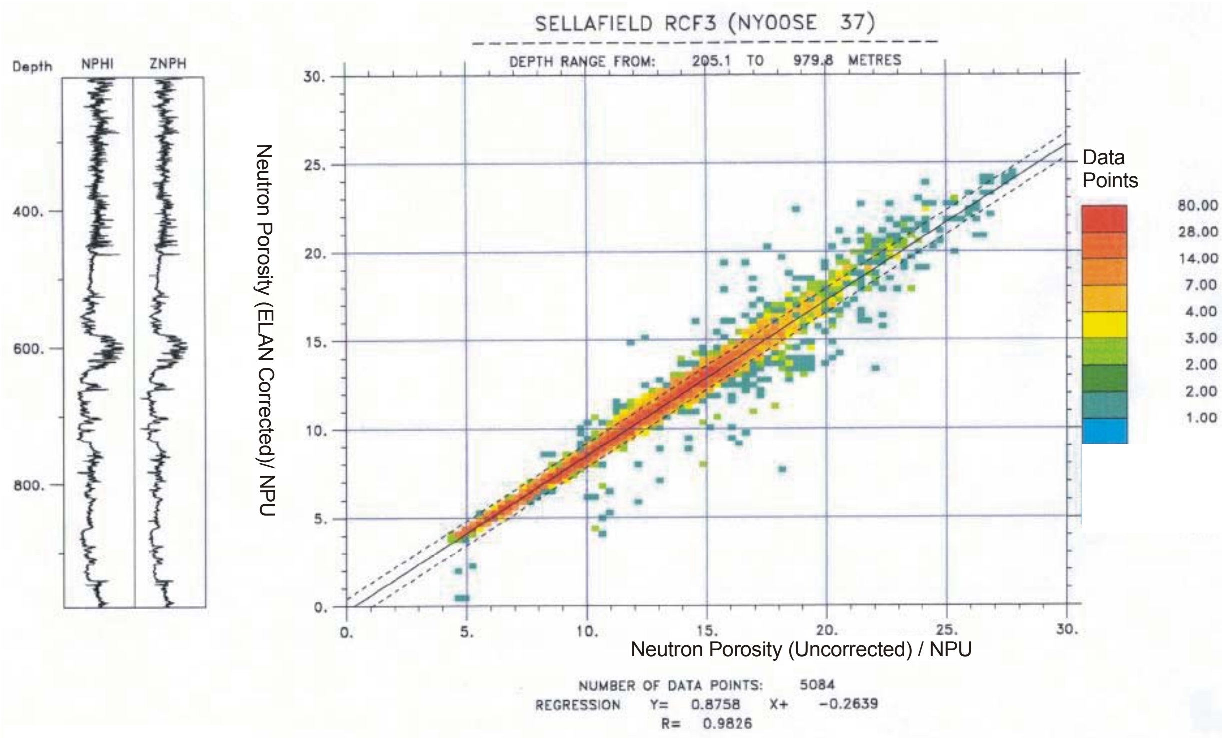


Figure 8: Crossplot of Uncorrected Density Logs against "ELAN Environmentally Corrected" Density Logs, Borehole RCF3 Logging Run 2 (205.1-979.8 mbRT)

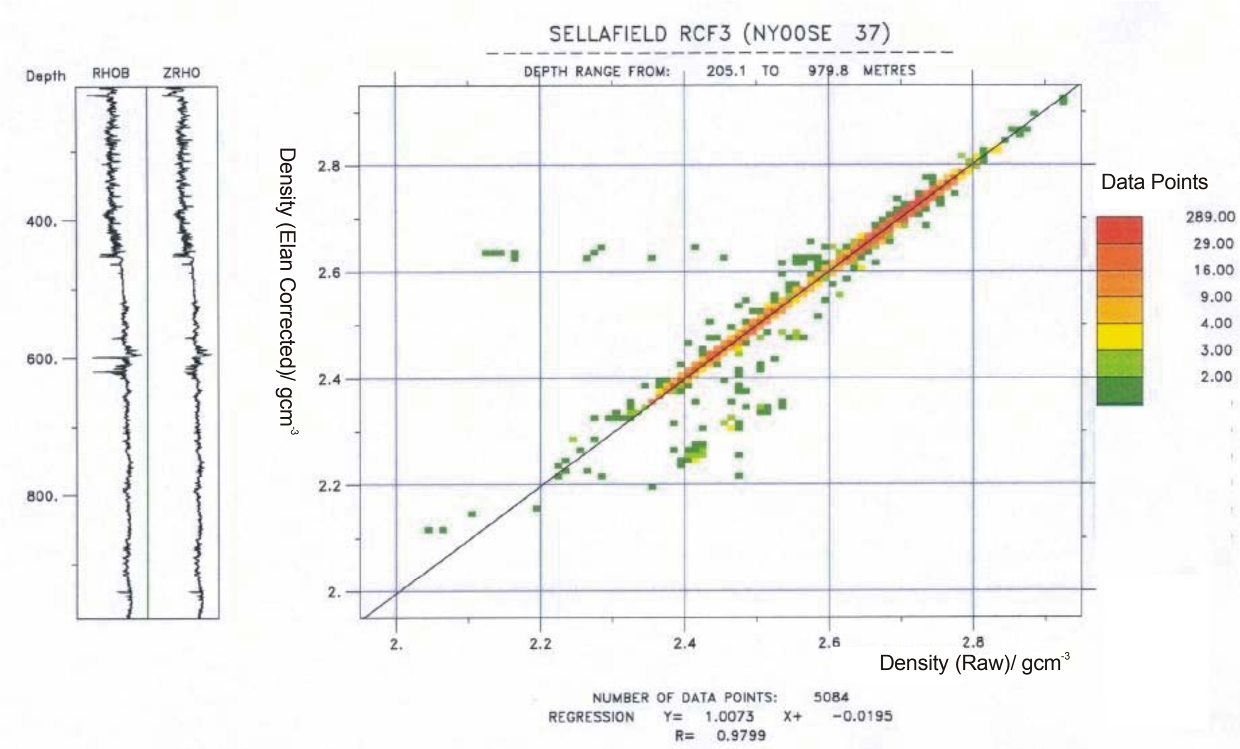


Figure 9: Crossplot of Compressional Velocity Logs Repeatability

Borehole PRZ1, run 2, 493.6-596.8 mbST (x: main acquisition run, y: repeat section)

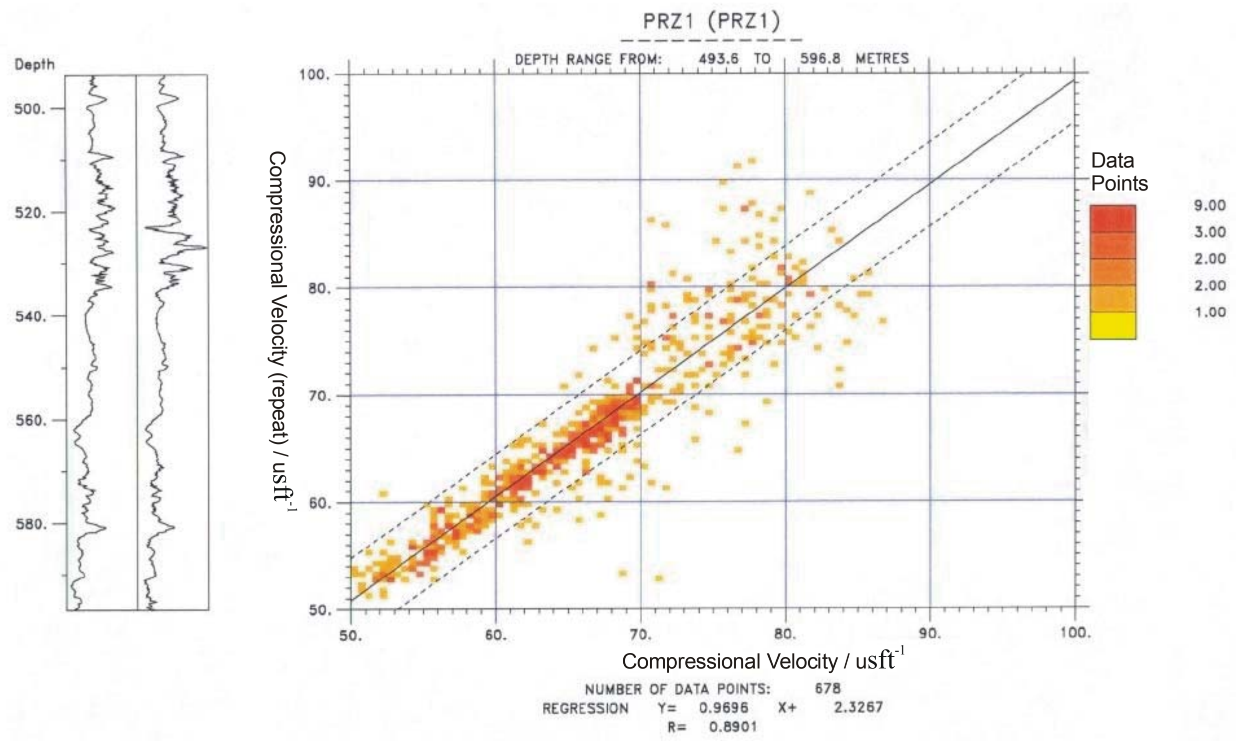


Figure 10: Crossplot of Compressional Velocity Logs Repeatability (depth as z-axis)

Borehole PRZ1, run 2, 493.6-596.8 mbST (x: main acquisition run, y: repeat section)

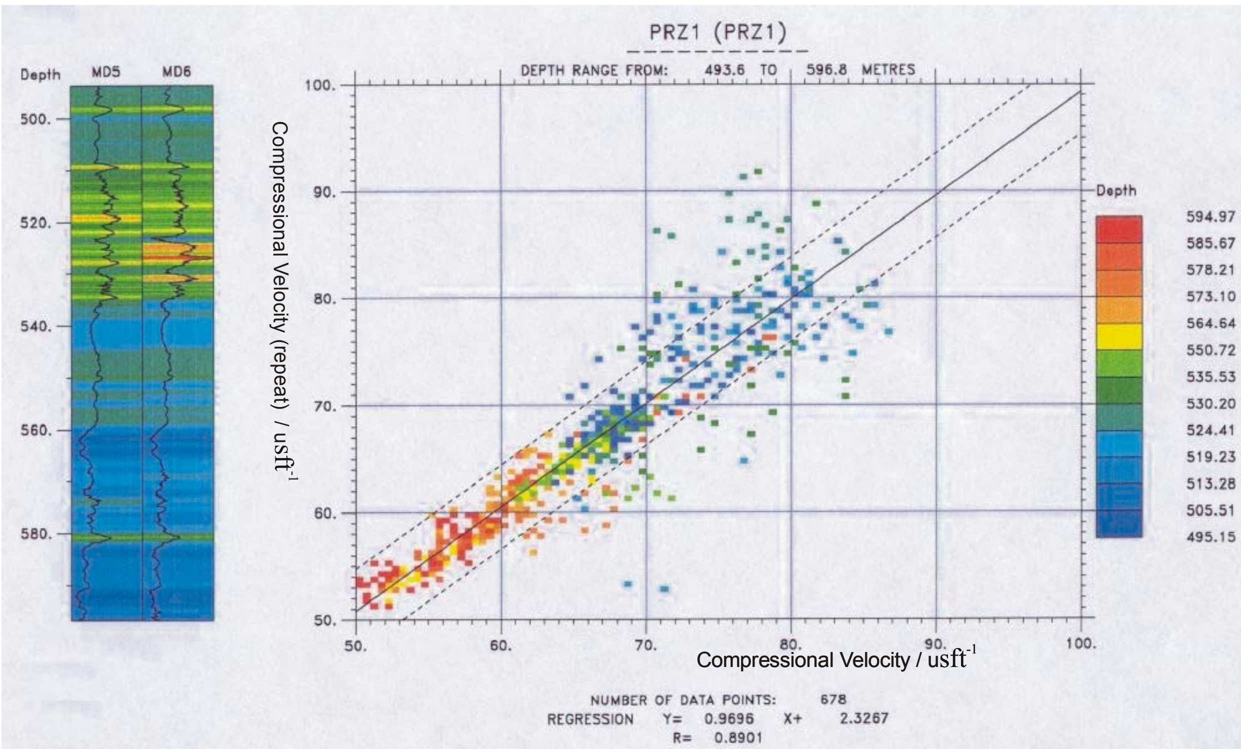


Figure 11: Crossplot of Density Log repeatability,

PRZ1 run 2, 498-600 mbST (x: main acquisition run, y: repeat section)

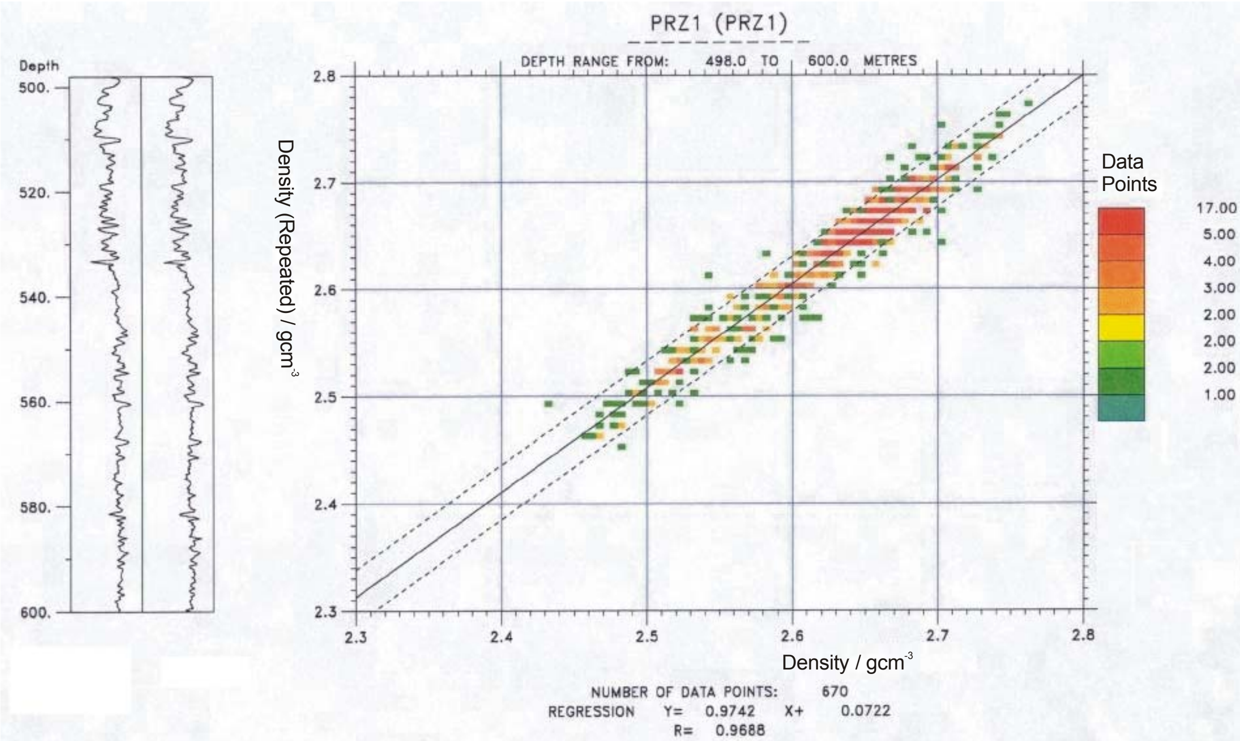


Figure 12: Crossplot of Gamma Ray Log repeatability,

PRZ1 run 2, 492.9-588.4 mbST (x: main acquisition run, y: repeat section)

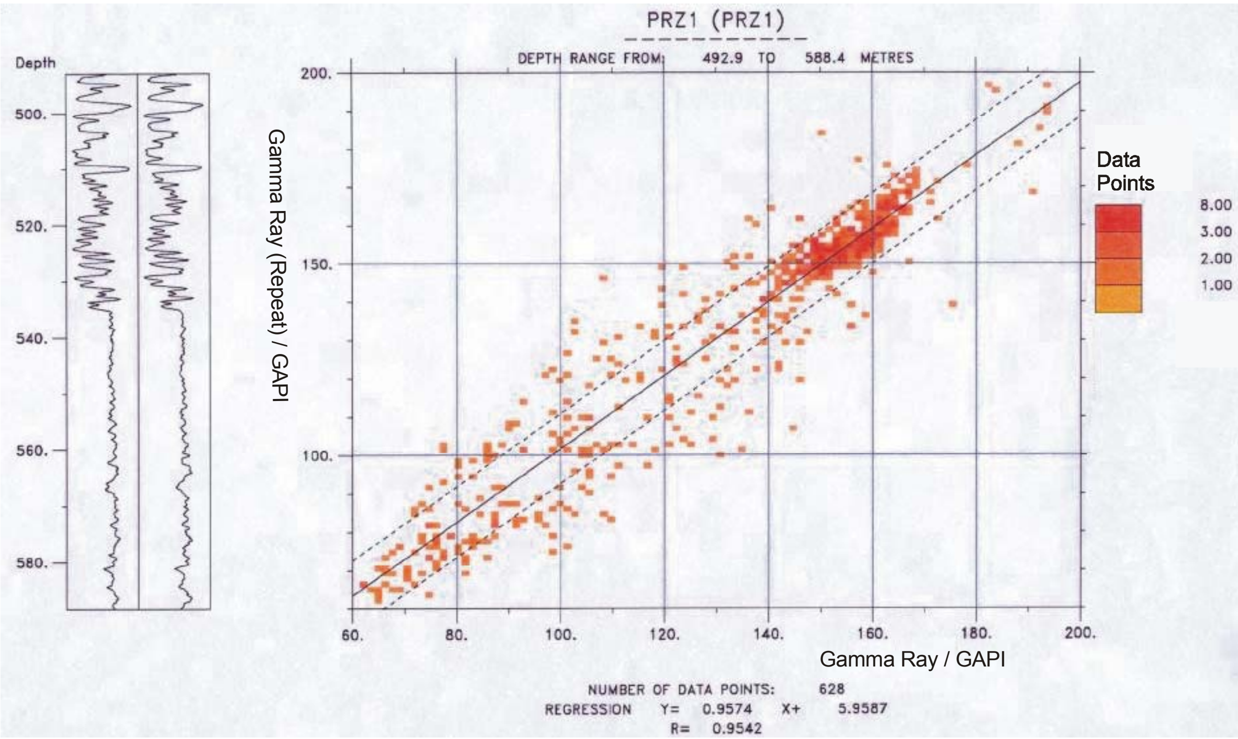


Figure 13: Crossplot of Spectral Gamma Ray Log repeatability

PRZ1 run 2, 536.3 – 589.2 mbST (x: main acquisition run, y: repeat section)

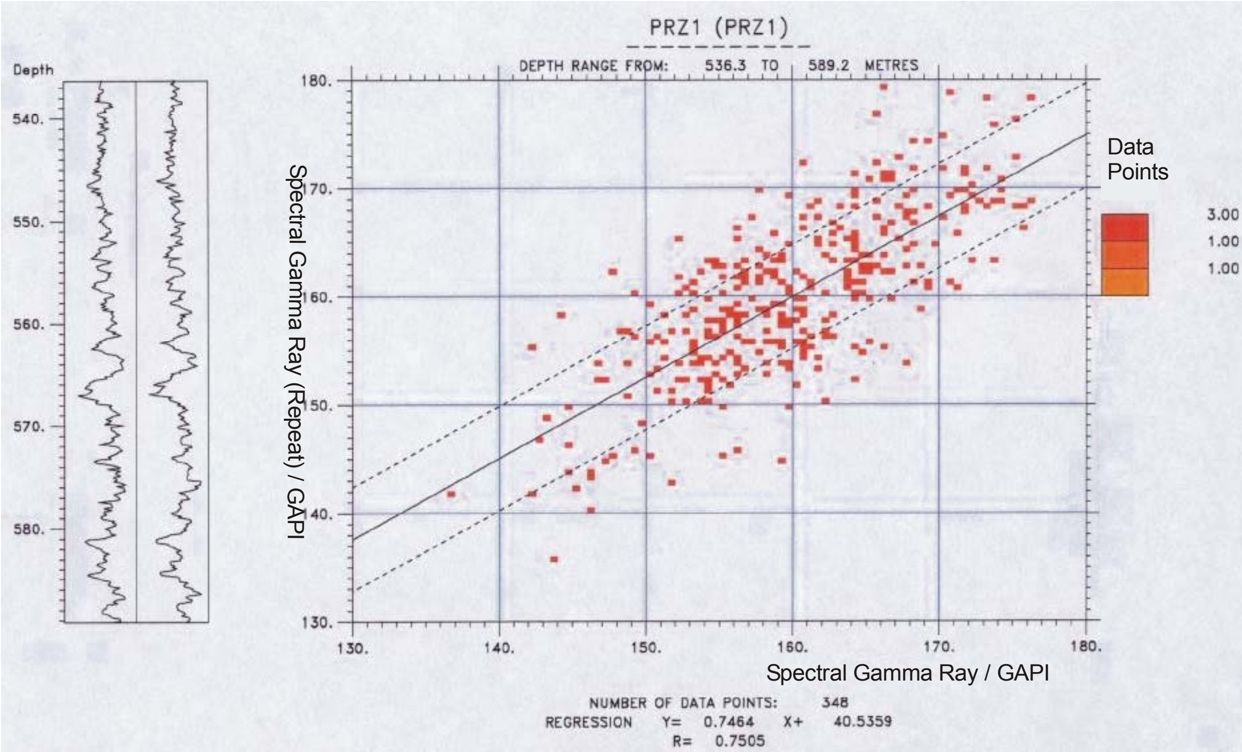


Figure 14: Crossplot of Deep Laterolog repeatability,

PRZ1 run 2, 498.6-597.6 mbST (x: main acquisition run, y: repeat section, logarithmic axes)

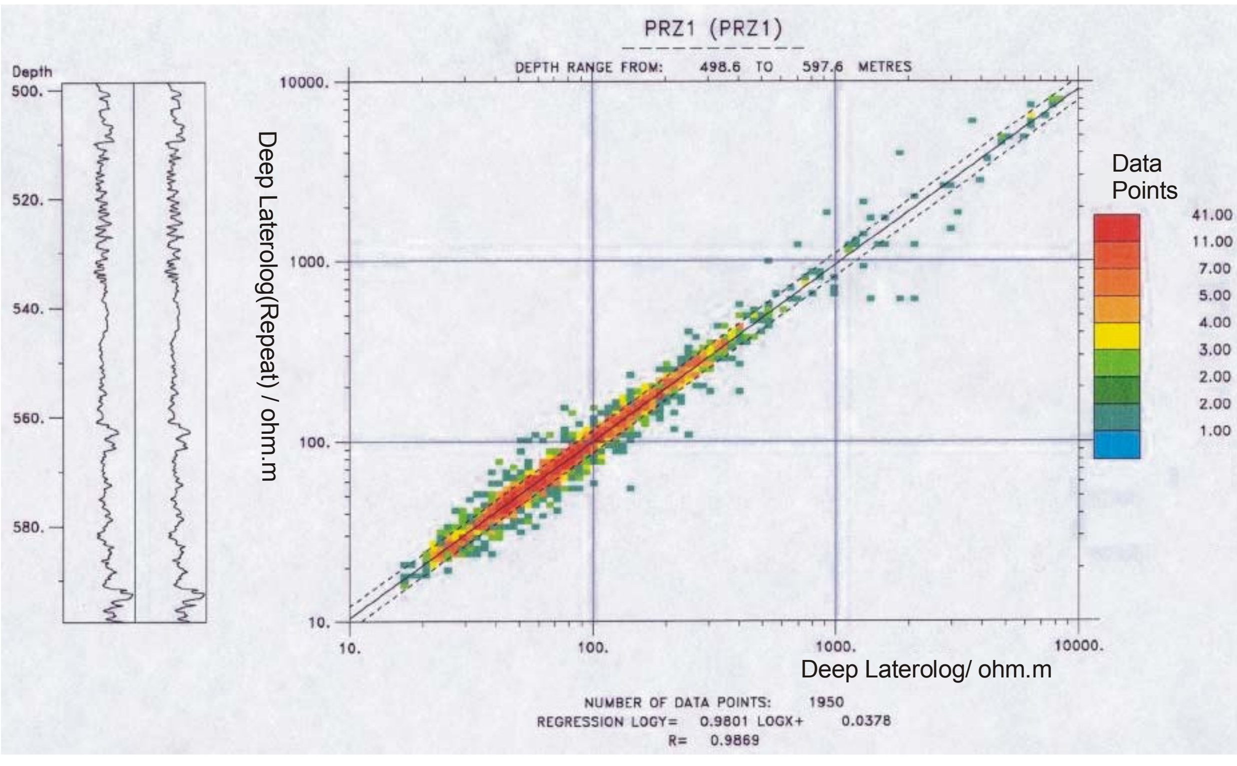


Figure 15: Crossplot of Shallow Laterolog repeatability

PRZ1 run 2, 498.6-597.6 mbST (x: main acquisition run, y: repeat section, logarithmic axes)

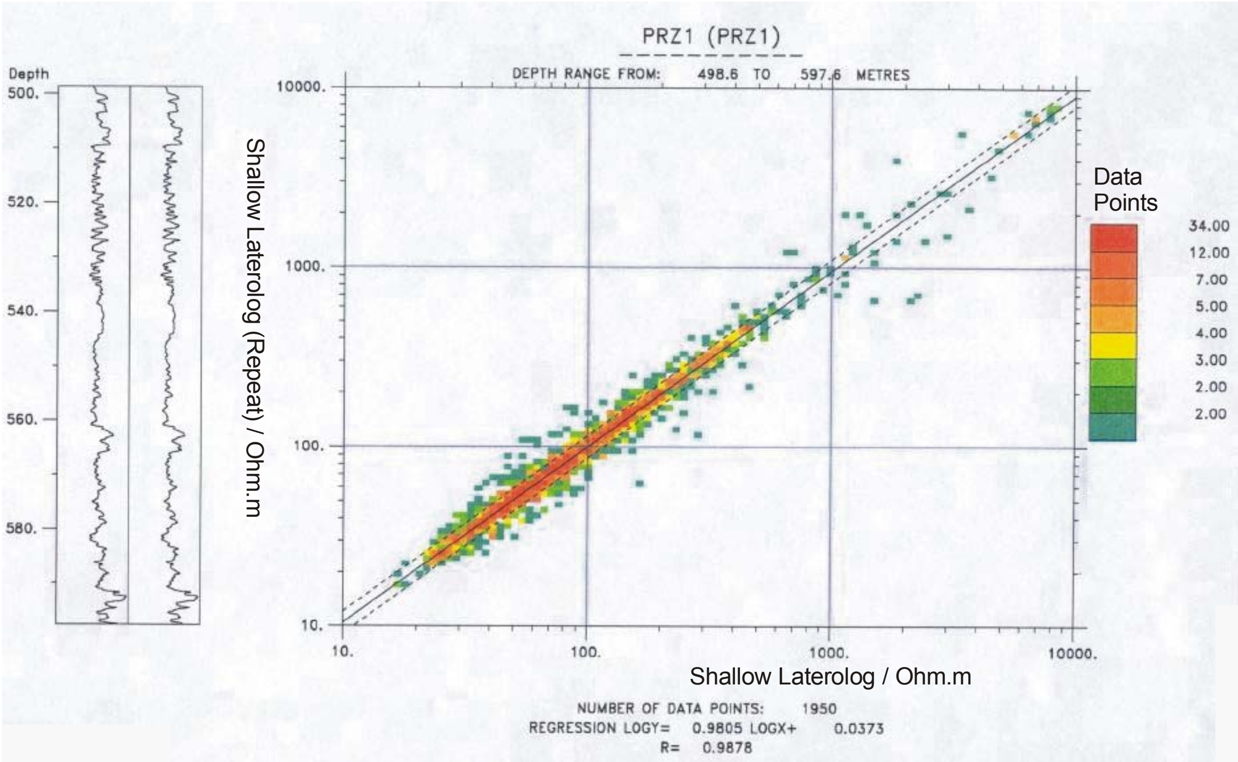
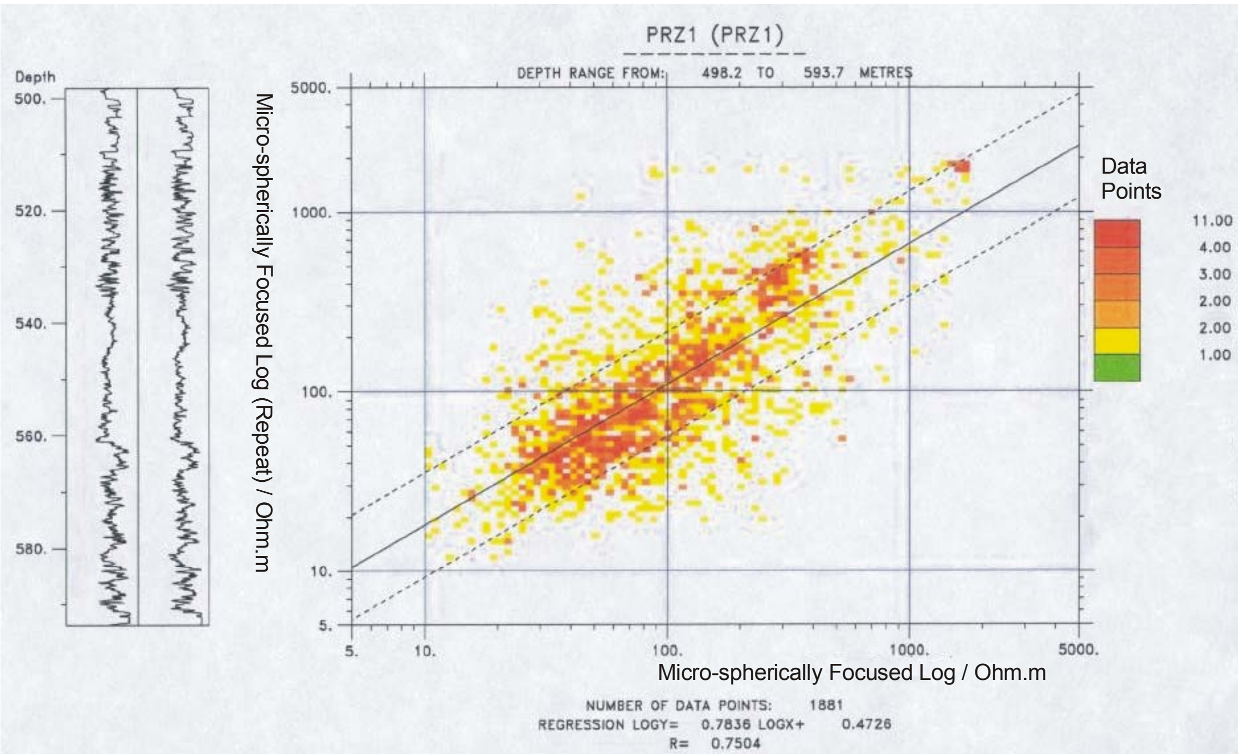


Figure 16: Crossplot of Micro-Spherically Focussed Log repeatability,

PRZ1 run 2, 498.2-593.7 mbST (x: main acquisition run, y: repeat section, logarithmic axes)



Appendix 1 Tables of Borehole logging tools used at Sellafield

Table 8: Schlumberger logging tools used in Sellafield Investigations

Tool Used	Logging measurement	Sellafield Usage	Unit
Radioactivity & Nuclear			
LDL	Density	All boreholes	gcm^{-3}
CNL	Neutron 'porosity'	All boreholes	NPU ("%")
GR	Total Gamma ray Count	All boreholes	API
NGS	Spectral Gamma	All boreholes	API
NGS	Potassium, Thorium and Uranium Spectrum Curves	All boreholes	%, ppm, ppm
Resistivity tools			
DLL	Resistivity: Deep, medium, shallow	Most boreholes	Ohm.m
DITE	Resistivity: Deep, medium, shallow	A few boreholes	Ohm.m
PI	Resistivity: Deep, medium, shallow	A few boreholes	Ohm.m
MSFL	Resistivity: micro	All boreholes	Ohm.m
ARI	High resolution & Imaging	A few boreholes	Ohm.m
Sonic Velocity			
SDT	Sonic: P &S wave velocity	Before 1992	microseconds/foot
DSI	Sonic: P &S wave velocity + Stoneley wave fracture	1992 onward	microseconds/foot
Borehole Imaging Tools			
BHTV / ATS	Imaging: Acoustic	Until 1993	
UBI	Imaging: Acoustic	Replaced BHTV in 1993	
FMS	Imaging: Resistivity	Before 1992	
HFMS	Imaging: Resistivity	Narrow holes: post 1994	
FMI	Imaging: Resistivity	Replaced FMS after 1992	
Other tools			
CBL	Cement Bond log	Cased sections	
USI	Casing inspection	Cased sections	
Temperature	Temperature	Early boreholes	
BGT	Caliper and borehole geometry	Early boreholes	
Fluid Conductivity	Fluid	Early boreholes	
GLT	Geochemical: mineral proportions	Most boreholes	

Table 9: Description of post-acquisition processed data

Post Processed Logs	Derivation	Explanation
Dipmeter	FMI/ FMS	Dipmeter interpretation from resistivity imaging tools in sedimentary successions
Static / Dynamic Images	FMI/ FMS	Static and dynamic filtered images of resistivity imaging tools
ELAN Petrophysical	Multiple Logs	Conventional logs "Environmentally corrected" using Schlumberger's ELAN software
Mechanical Properties	Multiple Logs	Conventional logs processed for mechanical property data by Schlumberger
DSI Sonic Waveform	DSI	Sonic waveform processing of DSI sonic logs
DSI Fracture Processed	DSI	Unknown

Table 10: Logging tools used in Sellafield 2

Sellafield 2: Logging Run 1	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	33	175
Neutron	CNL	33	175
Sonic	SDT	33	173
Spectral Gamma	NGS	33	175
Sellafield 2: Logging Run 2	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Conductivity	Conductivity	140	507
Density	LDL	154	509
Geochemical	GLT	154	507
Imaging: Acoustic	BHTV	154	507
Imaging: Resistivity	FMS	171	509
Neutron	CNL	154	509
Resistivity	DITE-MSFL	154	507
Sonic	SDT	154	507
Spectral Gamma	NGS	154	509
Sellafield 2: Logging Run 3 - 5	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Caliper	BGT	154	494
Cement Bond	CBL	10	491
Temperature	Equilibrium Temperature	10	490
Caliper	BGT	507	1068
Temperature	Equilibrium Temperature	0	505
Sellafield 2: Logging Run 6	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	490	1609
Geochemical	GLT	490	1608
Imaging: Acoustic	BHTV	490	1608
Imaging: Resistivity	FMS	490	1609
Neutron	CNL	490	1609
Resistivity	DLL-MSFL	490	1609
Sonic	SDT	490	1606
Spectral Gamma	NGS	490	1609
Sellafield 2: Logging Run 7	Tool Used	Top (mbRT)	Base (mbRT)
Imaging: Acoustic	BHTV	665	1458
Imaging: Resistivity	FMS	665	1458
Sellafield 2: Logging Run 8 - 10	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Temperature	Equilibrium Temperature	490	1599
Temperature	Equilibrium Temperature	20	1604
Temperature	Equilibrium Temperature	20	1605
Temperature	Equilibrium Temperature	15	1602
Fluid	Fluid Conductivity	9	1605
Sellafield 2: Logging Runs 11 -13	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Temperature	Equilibrium Temperature	15	1595
Temperature	Equilibrium Temperature	440	1605
Temperature	Equilibrium Temperature	440	1605
Sellafield 2: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
Dipmeter	FMI	171	508
ELAN Petrophysical	Multiple Logs	155	402
ELAN Petrophysical	Multiple Logs	400	1593
FMS Static / Dynamic Images	FMS	170	508
FMS Static / Dynamic Images	FMS	490	1609
FMS Static / Dynamic Images	FMS	651	1470
Mechanical Properties	Multiple Logs	30	402
Mechanical Properties	Multiple Logs	400	1593

Table 11: Logging tools used in Sellafield 3

Sellafield 3: Logging Run 2	Tool Used	Top (mbRT)	Base (mbRT)
Density	LDL	155	692
Geochemical	GLT	155	692
Imaging: Acoustic	BHTV	155	692
Imaging: Resistivity	FMS	155	692
Neutron	CNL	155	692
Resistivity	DITE-MSFL	155	691
Sonic	SDT	155	690
Spectral Gamma	NGS	155	692
Sellafield 3: Logging Run 5	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	670	1306
Geochemical	GLT	670	1304
Imaging: Acoustic	BHTV	670	1305
Imaging: Resistivity	FMS	670	1302
Neutron	CNL	670	1306
Resistivity	DITE-MSFL	670	1305
Sonic	SDT	670	1302
Spectral Gamma	NGS	670	1306
Sellafield 3: Logging Run 7	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Casing	USI	566	1280
Cement Bond	CBL	566	1280
Density	LDL	1291	1949
Imaging: Acoustic	BHTV	1291	1948
Imaging: Resistivity	FMS	1291	1947
Neutron	CNL	1291	1949
Resistivity	DLL-MSFL	1291	1940
Sonic	DSI	1291	1943
Spectral Gamma	NGS	1291	1949
Sellafield 3: Logging Run 8	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Geochemical	GLT	1291	1939
Sellafield 3: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
Dipmeter	FMI	1295	1946
Sonic Waveform	SDT	142	692
DSI Sonic Waveform	DSI	675	1299
DSI Sonic Waveform	DSI	1280	1950
ELAN Petrophysical	Multiple Logs	161	674
ELAN Petrophysical	Multiple Logs	1293	1929
FMS Static / Dynamic Images	FMS	156	689
FMS Static / Dynamic Images	FMS	664	1304
FMS Static / Dynamic Images	FMS	1437	1851
Mechanical Properties	Multiple Logs	161	682
Mechanical Properties	Multiple Logs	669	1289
Mechanical Properties	Multiple Logs	1293	1989

Table 12: Logging tools used in Sellafield 4

Sellafield 4: Logging Run 1	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	156	410
Geochemical	GLT	156	409
Imaging: Acoustic	BHTV	156	393
Imaging: Resistivity	FMS	156	410
Neutron	CNL	156	410
Resistivity	PI-MSFL	156	409
Sonic	DSI	20	406
Sonic	SDT	156	406
Spectral Gamma	NGS	156	410
Sellafield 4: Logging Run 2	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	393	1258
Geochemical	GLT	393	1260
Imaging: Acoustic	BHTV	393	1260
Imaging: Resistivity	FMI	393	1259
Neutron	CNL	393	1258
Resistivity	DLL-MSFL	393	1255
Sonic	DSI	393	1253
Spectral Gamma	NGS	393	1258
Temperature	Equilibrium Temperature	20	390
Sellafield 4: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
Dipmeter	FMI	156	410
DSI Sonic Waveform	DSI	150	409
DSI Sonic Waveform	DSI	393	1252
ELAN Petrophysical	Multiple Logs	156	402
ELAN Petrophysical	Multiple Logs	394	1251
FMS Static / Dynamic Images	FMS	156	410
FMI Static / Dynamic Images	FMI	396	1259
Mechanical Properties	Multiple Logs	155	402
Mechanical Properties	Multiple Logs	400	1251

Table 13: Logging tools used in Sellafield 5

Sellafield 5: Logging Run 1	Tool Used	Top (mbRT)	Base (mbRT)
Density	LDL	7	155
Neutron	CNL	7	155
Sonic	SDT	24	155
Spectral Gamma	NGS	7	155
Sellafield 5: Logging Run 2	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	153	444
Geochemical	GLT	153	442
Imaging: Acoustic	BHTV	153	441
Imaging: Resistivity	FMS	153	444
Neutron	CNL	153	444
Resistivity	DLL-MSFL	153	440
Sonic	DSI	153	438
Spectral Gamma	NGS	153	444
Sellafield 5: Logging Run 4	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	426	1258
Geochemical	GLT	426	1256
Imaging: Acoustic	BHTV	426	1256
Imaging: Resistivity	FMI	426	1259
Neutron	CNL	426	1258
Resistivity	DLL-MSFL	426	1254
Sonic	DSI	426	1250
Spectral Gamma	NGS	426	1258
Sellafield 5: Logging Run 5	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Caliper	BGT	426	830
Casing	USI	6	426
Imaging: Acoustic	BHTV	426	828
Sellafield 5: Logging Run 6	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Casing	USI	320	829
Cement Bond	CBL	315	826
Imaging: Acoustic	BHTV	838	1245
Imaging: Resistivity	FMI	838	1245
Sellafield 5: Logging Run 7	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Conductivity	Conductivity	10	1260
Sellafield 5: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
DSI Sonic Waveform	DSI	153	438
DSI Sonic Waveform	DSI	425	1252
ELAN Petrophysical	Multiple Logs	153	456
ELAN Petrophysical	Multiple Logs	425	1253
FMS Static / Dynamic Images	FMS	157	445
FMI Static / Dynamic Images	FMI	429	1262
Mechanical Properties	Multiple Logs	153	437
Mechanical Properties	Multiple Logs	425	1253

Table 14: Logging tools used in Sellafield 7A

Sellafield 7A: Logging Run 1	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	28	268
Imaging: Acoustic	BHTV	28	267
Imaging: Resistivity	FMI	28	269
Neutron	CNL	28	268
Sonic	DSI	28	261
Spectral Gamma	NGS	28	268
Sellafield 7A: Logging Run 2	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Casing	USI	6	250
Cement Bond	CBL	10	249
Density	LDL	227	460
Geochemical	GLT	250	457
Imaging: Acoustic	BHTV	250	454
Imaging: Resistivity	FMI	250	459
Neutron	CNL	227	460
Resistivity	DLL-MSFL	250	451
Sonic	DSI	250	451
Spectral Gamma	NGS	227	460
Sellafield 7A: Logging Run 3	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Casing	USI	208	443
Cement Bond	CBL	208	443
Density	LDL	443	1009
Geochemical	GLT	443	1008
Imaging: Acoustic	BHTV	443	1007
Imaging: Resistivity	FMI	443	1007
Neutron	CNL	443	1009
Resistivity	DLL-MSFL	443	1006
Sonic	DSI	443	1003
Spectral Gamma	NGS	443	1009
Sellafield 7A: Logging Run 4	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Temperature	Equilibrium Temperature	6	1006
Sellafield 7A: Logging Run 5	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Temperature	Equilibrium Temperature	7	1000
Sellafield 7A: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
Dipmeter	FMI	30	269
Dipmeter	FMI	440	1006
DSI Sonic Waveform	DSI	28	258
DSI Sonic Waveform	DSI	248	459
DSI Sonic Waveform	DSI	440	1009
ELAN Petrophysical	Multiple Logs	443	1006
FMI Static / Dynamic Images	FMI	30	269
FMI Static / Dynamic Images	FMI	253	459
FMI Static / Dynamic Images	FMI	441	1006
Mechanical Properties	Multiple Logs	250	450
Mechanical Properties	Multiple Logs	443	997

Table 15: Logging tools used in Sellafield 7B

Sellafield 7B: Logging Run 1	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	64	469
Geochemical	GLT	64	468
Imaging: Acoustic	BHTV	64	466
Imaging: Resistivity	FMI	64	470
Neutron	CNL	64	469
Resistivity	DLL-MSFL	64	465
Sonic	DSI	64	460
Spectral Gamma	NGS	64	469
Sellafield 7B: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
Dipmeter	FMI	67	470
DSI Sonic Waveform	DSI	62	470
ELAN Petrophysical	Multiple Logs	63	455
FMI Static / Dynamic Images	FMI	67	469
Mechanical Properties	Multiple Logs	63	455

Table 16: Logging tools used in Sellafield 8A

Sellafield 8A: Logging Run 1	Tool Used	Top (mbRT)	Base (mbRT)
Casing	USI	15	197
Cement Bond	CBL	15	197
Density	LDL	202	999
Geochemical	GLT	202	998
Imaging: Acoustic	UBI-NGS	202	990
Imaging: Resistivity	HFMS	202	999
Neutron	CNL	202	999
Resistivity	DLL-MSFL	202	996
Sonic	DSI	202	994
Spectral Gamma	NGS	202	999
Sellafield 8A: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
DSI Sonic Waveform	DSI	202	995
ELAN Petrophysical	Multiple Logs	202	986
FMS Static / Dynamic Images	FMS	34	1003
FMS Static / Dynamic Images	FMS	208	997
Mechanical Properties	Multiple Logs	202	993

Table 17: Logging tools used in Sellafield 8B

Sellafield 8B: Logging Run 1	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	31	245
Imaging: Acoustic	UBI-NGS	31	245
Imaging: Resistivity	FMI	31	245
Neutron	CNL	31	245
Resistivity	DLL-MSFL	31	245
Sonic	DSI	31	245
Spectral Gamma	NGS	31	245
Sellafield 8B: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
Dipmeter	FMI	34	180
DSI Sonic Waveform	DSI	31	237
FMI Static / Dynamic Images	FMI	34	240
Mechanical Properties	Multiple Logs	31	231

Table 18: Logging tools used in Sellafield 9A

Sellafield 9A: Logging Run 1	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	45	250
Geochemical	GLT	29	250
Imaging: Acoustic	UBI-NGS	29	250
Imaging: Resistivity	FMI	29	250
Neutron	CNL	45	250
Resistivity	ARI-MSFL	45	250
Sonic	DSI	45	250
Spectral Gamma	NGS	45	250
Sellafield 9A: Logging Run 2	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Casing	USI	17	230
Cement Bond	CBL	17	230
Density	LDL	232	494
Density	LDL	232	500
Geochemical	GLT	232	497
Imaging: Acoustic	UBI-NGS	232	500
Imaging: Resistivity	HFMS	232	499
Imaging: Resistivity	HFMS	232	500
Neutron	CNL	232	494
Neutron	CNL	232	500
Resistivity	ARI-MSFL	232	500
Sonic	DSI	232	500
Spectral Gamma	NGS	232	494
Spectral Gamma	NGS	232	500
Sellafield 9A: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
DSI Sonic Waveform	DSI	29	245
DSI Sonic Waveform	DSI	232	494
ELAN Petrophysical	Multiple Logs	29	242
ELAN Petrophysical	Multiple Logs	233	486
FMI Static / Dynamic Images	FMI	33	249
Mechanical Properties	Multiple Logs	29	242
Mechanical Properties	Multiple Logs	233	486

Table 19: Logging tools used in Sellafield 9B

Sellafield 9B: Logging Run 1	Tool Used	Top (mbRT)	Base (mbRT)
Density	LDL	27	144
Imaging: Acoustic	UBI-NGS	27	140
Imaging: Resistivity	FMI	27	144
Neutron	CNL	27	144
Resistivity	DLL-MSFL	27	140
Sonic	DSI	27	140
Spectral Gamma	NGS	27	144
Sellafield 9B: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
DSI Sonic Waveform	DSI	14	137

Table 20: Logging tools used in Sellafield 10A

Sellafield 10A: Logging Run 1	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	32	219
Neutron	CNL	32	219
Resistivity	DLL-MSFL	32	215
Sonic	DSI	32	215
Spectral Gamma	NGS	32	219
Sellafield 10A: Logging Run 2	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Cement Bond	CBL	7	200
Density	LDL	200	1054
Geochemical	GLT	200	1052
Imaging: Acoustic	BHTV	200	1051
Imaging: Resistivity	FMI	200	1054
Neutron	CNL	200	1054
Resistivity	DLL-MSFL	200	1050
Sonic	DSI	200	1053
Spectral Gamma	NGS	200	1054
Sellafield 10A: Logging Run 3	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Casing	USI	7	200
Imaging: Acoustic	BHTV	242	961
Imaging: Resistivity	FMS	242	961
Sellafield 10A: Logging Run 4	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Casing	USI	6	1033
Cement Bond	CBL	12	1033
Density	LDL	1033	1607
Geochemical	GLT	1033	1605
Imaging: Acoustic	BHTV	1033	1606
Imaging: Resistivity	FMI	1033	1606
Neutron	CNL	1033	1607
Resistivity	DLL-MSFL	1033	1602
Sonic	DSI	1033	1606
Spectral Gamma	NGS	1033	1607
Sellafield 10A: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
Dipmeter	FMI	142	1052
DSI Fracture Processed	DSI	200	1049
DSI Sonic Waveform	DSI	1033	1602
ELAN Petrophysical	Multiple Logs	200	1045
ELAN Petrophysical	Multiple Logs	1038	1594
FMI Static / Dynamic Images	FMI	200	1054
FMI Static / Dynamic Images	FMI	1033	1606
FMS Static / Dynamic Images	FMS	242	961
Mechanical Properties	Multiple Logs	200	1040
Mechanical Properties	Multiple Logs	1038	1593

Table 21: Logging tools used in Sellafield 10B

Sellafield 10B: Logging Run 1	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	23	252
Geochemical	GLT	23	249
Imaging: Acoustic	BHTV	23	249
Imaging: Resistivity	FMI	23	251
Neutron	CNL	23	252
Resistivity	DLL-MSFL	23	252
Sonic	DSI	23	252
Spectral Gamma	NGS	23	252
Sellafield 10B: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
DSI Sonic Waveform	DSI	22	244
ELAN Petrophysical	Multiple Logs	23	252
FMI Static / Dynamic Images	FMI	27	252
Mechanical Properties	Multiple Logs	23	238

Table 22: Logging tools used in Sellafield 11A

Sellafield 11A: Logging Run 1	Tool Used	Top (mbRT)	Base (mbRT)
Density	LDL	36	218
Neutron	CNL	36	218
Resistivity	DLL-MSFL	36	214
Sonic	DSI	36	217
Spectral Gamma	NGS	36	218
Sellafield 11A: Logging Run 2	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Casing	USI	6	200
Cement Bond	CBL	9	198
Density	LDL	201	799
Geochemical	GLT	201	800
Imaging: Acoustic	UBI-NGS	201	780
Imaging: Resistivity	FMI	201	790
Neutron	CNL	201	799
Resistivity	DLL-MSFL	201	795
Sonic	DSI	201	798
Spectral Gamma	NGS	201	799
Casing	USI	10	778
Cement Bond	CBL	5	780
Sellafield 11A: Logging Run 3	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	780	1159
Geochemical	GLT	780	1167
Imaging: Acoustic	UBI-NGS	780	1050
Imaging: Resistivity	FMI	780	1160
Neutron	CNL	780	1159
Resistivity	DLL-MSFL	780	1165
Sonic	DSI	780	1165
Spectral Gamma	NGS	780	1159
Sellafield 11A: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
Dipmeter	FMI	784	855
DSI Sonic Waveform	DSI	200	795
DSI Sonic Waveform	DSI	780	1160
ELAN Petrophysical	Multiple Logs	198	800
ELAN Petrophysical	Multiple Logs	780	1156
FMI Static / Dynamic Images	FMI	205	789
FMI Static / Dynamic Images	FMI	784	1159
Mechanical Properties	Multiple Logs	25	1166

Table 23: Logging tools used in Sellafield 12A

Sellafield 12A: Logging Run 1	Tool Used	Top (mbRT)	Base (mbRT)
Density	LDL	109	549
Geochemical	GLT	110	547
Imaging: Acoustic	BHTV	110	548
Imaging: Resistivity	FMI	110	550
Neutron	CNL	109	549
Resistivity	DLL-MSFL	110	545
Sonic	DSI	110	542
Spectral Gamma	NGS	109	549
Sellafield 12A: Logging Run 3	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Casing	USI	5	529
Cement Bond	CBL	100	528
Density	LDL	529	1139
Geochemical	GLT	529	1146
Imaging: Acoustic	BHTV	529	1147
Imaging: Resistivity	FMI	529	1148
Neutron	CNL	529	1139
Resistivity	DLL-MSFL	529	1144
Sonic	DSI	529	1144
Spectral Gamma	NGS	529	1139
Sellafield 12A: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
DSI Sonic Waveform	DSI	88	545
DSI Sonic Waveform	DSI	525	1145
ELAN Petrophysical	Multiple Logs	109	533
ELAN Petrophysical	Multiple Logs	529	1136
FMI Static / Dynamic Images	FMI	110	549
FMI Static / Dynamic Images	FMI	535	1147
Mechanical Properties	Multiple Logs	109	533
Mechanical Properties	Multiple Logs	529	1131

Table 24: Logging tools used in Sellafield 13A

Sellafield 13A: Logging Run 1	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Casing	USI	250	1101
Cement Bond	CBL	250	1101
Density	LDL	251	1101
Geochemical	GLT	251	1101
Imaging: Acoustic	UBI-NGS	251	1101
Imaging: Resistivity	FMI	251	1101
Neutron	CNL	251	1101
Resistivity	DLL-MSFL	251	1101
Sonic	DSI	251	1101
Spectral Gamma	NGS	251	1101
Sellafield 13A: Logging Run 2	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Casing	USI	10	1101
Cement Bond	CBL	10	1101
Density	LDL	1081	1741
Geochemical	GLT	1081	1741
Imaging: Acoustic	UBI-NGS	1081	1741
Imaging: Resistivity	FMI	1081	1741
Neutron	CNL	1081	1741
Resistivity	DLL-MSFL	1081	1741
Sonic	DSI	1081	1741
Spectral Gamma	NGS	1081	1741
Sellafield 13A: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
Dipmeter	FMI	248	1089
Dipmeter	FMI	1085	1640
DSI Sonic Waveform	DSI	250	1090
DSI Sonic Waveform	DSI	1080	1733
ELAN Petrophysical	Multiple Logs	250	1082
ELAN Petrophysical	Multiple Logs	1080	1723
FMI Static / Dynamic Images	FMI	248	1089
FMI Static / Dynamic Images	FMI	670	1741
Mechanical Properties	Multiple Logs	254	1082
Mechanical Properties	Multiple Logs	1081	1723

Table 25: Logging tools used in Sellafield 13B

Sellafield 13B: Logging Run 1	Tool Used	Top (mbRT)	Base (mbRT)
Density	LDL	36	250
Imaging: Resistivity	FMI	36	250
Neutron	CNL	36	250
Resistivity	DLL-MSFL	36	250
Resistivity	DLL-MSFL	36	250
Sonic	DSI	36	250
Spectral Gamma	NGS	36	250
Imaging: Acoustic	UBI-NGS	36	250
Sellafield 13B: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
Dipmeter	FMI	40	288
DSI Sonic Waveform	DSI	36	287
ELAN Petrophysical	Multiple Logs	35	299
FMI Static / Dynamic Images	FMI	40	288
Mechanical Properties	Multiple Logs	36	287

Table 26: Logging tools used in Sellafield 14A

Sellafield 13A: Logging Run 1	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Casing	USI	250	1101
Cement Bond	CBL	250	1101
Density	LDL	251	1101
Geochemical	GLT	251	1101
Imaging: Acoustic	UBI-NGS	251	1101
Imaging: Resistivity	FMI	251	1101
Neutron	CNL	251	1101
Resistivity	DLL-MSFL	251	1101
Sonic	DSI	251	1101
Spectral Gamma	NGS	251	1101
Sellafield 13A: Logging Run 2	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Casing	USI	10	1101
Cement Bond	CBL	10	1101
Density	LDL	1081	1741
Geochemical	GLT	1081	1741
Imaging: Acoustic	UBI-NGS	1081	1741
Imaging: Resistivity	FMI	1081	1741
Neutron	CNL	1081	1741
Resistivity	DLL-MSFL	1081	1741
Sonic	DSI	1081	1741
Spectral Gamma	NGS	1081	1741
Sellafield 13A: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
Dipmeter	FMI	248	1089
Dipmeter	FMI	1085	1640
DSI Sonic Waveform	DSI	250	1090
DSI Sonic Waveform	DSI	1080	1733
ELAN Petrophysical	Multiple Logs	250	1082
ELAN Petrophysical	Multiple Logs	1080	1723
FMI Static / Dynamic Images	FMI	248	1089
FMI Static / Dynamic Images	FMI	670	1741
Mechanical Properties	Multiple Logs	254	1082
Mechanical Properties	Multiple Logs	1081	1723

Table 27: Logging tools used in Sellafield 16

Sellafield 16: Logging Run 2	Tool Used	Top (mbST)	Base (mbST)
Density	LDL	319	597
Imaging: Resistivity	FMI	353	596
Neutron	CNL	319	597
Resistivity	DLL-MSFL	286	600
Resistivity	PI-MSFL	309	597
Sonic	DSI	330	597
Spectral Gamma	NGS	319	597
Sellafield 16: Post Processed Logs	**Derivation**	**Top (mbST)**	**Base (mbST)**
FMI Static / Dynamic Images	FMI	353	594

Table 28: Logging tools used in Sellafield RCF1

Sellafield RCF1: Logging Run 1	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	79	374
Imaging: Acoustic	UBI-NGS	79	370
Imaging: Resistivity	FMI	79	375
Neutron	CNL	79	374
Resistivity	DLL-MSFL	79	374
Sonic	DSI	79	374
Spectral Gamma	NGS	79	374
Sellafield RCF1: Logging Run 2	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	378	775
Imaging: Acoustic	UBI-NGS	378	765
Imaging: Resistivity	FMI	379	774
Neutron	CNL	378	775
Resistivity	DLL-MSFL	378	771
Sonic	DSI	378	771
Spectral Gamma	NGS	378	775
Sellafield RCF1: Logging Run 3	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Casing	USI	10	370
Cement Bond	CBL	7	367
Density	LDL	745	1150
Imaging: Acoustic	UBI-NGS	700	1140
Imaging: Resistivity	FMI	745	1144
Neutron	CNL	745	1150
Resistivity	DLL-MSFL	738	1146
Sonic	DSI	758	1145
Spectral Gamma	NGS	745	1150
Sellafield RCF1: Logging Run 4	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Geochemical	GLT	378	1148
Sellafield RCF1: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
Dipmeter	FMI	381	539
DSI Sonic Waveform	DSI	38	373
DSI Sonic Waveform	DSI	375	1142
ELAN Petrophysical	Multiple Logs	378	1130
FMI Static / Dynamic Images	FMI	83	375
FMI Static / Dynamic Images	FMI	379	1144
Mechanical Properties	Multiple Logs	82	370
Mechanical Properties	Multiple Logs	378	1130

Table 29: Logging tools used in Sellafield RCF2

Sellafield RCF2: Logging Run 1	Tool Used	Top (mbRT)	Base (mbRT)
Density	LDL	79	424
Imaging: Acoustic	BHTV	79	415
Imaging: Resistivity	FMI	79	420
Neutron	CNL	79	424
Resistivity	DLL-MSFL	79	421
Sonic	DSI	79	419
Spectral Gamma	NGS	79	424
Sellafield RCF2: Logging Run 2	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Imaging: Resistivity	HFMS	425	718
Sellafield RCF2: Logging Run 3	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Casing	USI	5	420
Cement Bond	CBL	10	418
Density	LDL	423	1148
Imaging: Acoustic	UBI-NGS	423	1145
Imaging: Resistivity	HFMS	670	1148
Neutron	CNL	423	1148
Resistivity	DLL-MSFL	423	1147
Sonic	DSI	423	1144
Spectral Gamma	NGS	423	1148
Sellafield RCF2: Logging Run 4	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Geochemical	GLT	423	1135
Sellafield RCF2: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
Dipmeter	FMI	83	419
DSI Sonic Waveform	DSI	79	419
DSI Sonic Waveform	DSI	422	1145
ELAN Petrophysical	Multiple Logs	70	380
ELAN Petrophysical	Multiple Logs	426	1121
FMI Static / Dynamic Images	FMI	83	420
FMS Static / Dynamic Images	FMS	428	716
FMS Static / Dynamic Images	FMS	706	1147
Mechanical Properties	Multiple Logs	80	416
Mechanical Properties	Multiple Logs	426	1121

Table 30: Logging tools used in Sellafield RCF3

Sellafield RCF3: Logging Run 1	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	9	218
Neutron	CNL	9	218
Resistivity	DLL-MSFL	9	214
Sonic	DSI	9	214
Spectral Gamma	NGS	9	218
Sellafield RCF3: Logging Run 2	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Imaging: Acoustic	UBI-NGS	205	505
Imaging: Resistivity	FMI	205	511
Imaging: Acoustic	UBI-NGS	440	745
Sellafield RCF3: Logging Run 3	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Imaging: Resistivity	FMI	440	752
Sellafield RCF3: Logging Run 4	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	205	986
Imaging: Acoustic	UBI-NGS	724	980
Imaging: Resistivity	FMI	740	990
Neutron	CNL	205	986
Resistivity	DLL-MSFL	205	986
Sonic	DSI	205	986
Spectral Gamma	NGS	205	986
Geochemical	GLT	205	982
Sellafield RCF3: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
Dipmeter	FMI	211	459
DSI Sonic Waveform	DSI	9	208
DSI Sonic Waveform	DSI	202	990
ELAN Petrophysical	Multiple Logs	9	208
ELAN Petrophysical	Multiple Logs	204	980
FMI Static / Dynamic Images	FMI	208	1080
Mechanical Properties	Multiple Logs	9	208
Mechanical Properties	Multiple Logs	204	970

Table 31: Logging tools used in Sellafield RCM1

Sellafield RCM1: Logging Run 1	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	50	989
Imaging: Acoustic	UBI-NGS	50	980
Imaging: Resistivity	FMI	50	989
Neutron	CNL	50	989
Resistivity	DLL-MSFL	50	985
Sonic	DSI	50	985
Spectral Gamma	NGS	50	989
Sellafield RCM1: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
Dipmeter	FMI	51	455
DSI Sonic Waveform	DSI	48	990
ELAN Petrophysical	Multiple Logs	51	979
FMI Static / Dynamic Images	FMI	51	989
Mechanical Properties	Multiple Logs	51	977

Table 32: Logging tools used in Sellafield RCM2

Sellafield RCM2: Logging Run 1	Tool Used	Top (mbRT)	Base (mbRT)
Density	LDL	49	249
Imaging: Acoustic	UBI-NGS	49	245
Imaging: Resistivity	FMI	49	249
Neutron	CNL	49	249
Resistivity	DLL-MSFL	49	245
Sonic	DSI	49	245
Spectral Gamma	NGS	49	249
Sellafield RCM2: Logging Run 2	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	212	989
Imaging: Acoustic	UBI-NGS	230	970
Imaging: Resistivity	FMI	197	987
Neutron	CNL	212	989
Resistivity	DLL-MSFL	54	986
Sonic	DSI	210	989
Spectral Gamma	NGS	212	989
Sellafield RCM2: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
DSI Sonic Waveform	DSI	43	985
ELAN Petrophysical	Multiple Logs	52	454
Mechanical Properties	Multiple Logs	53	454

Table 33: Logging tools used in Sellafield RCM3

Sellafield RCM3: Logging Run 1	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Density	LDL	78	403
Imaging: Acoustic	UBI-NGS	78	400
Imaging: Resistivity	FMI	78	402
Neutron	CNL	78	403
Resistivity	DLL-MSFL	78	399
Sonic	DSI	78	399
Spectral Gamma	NGS	78	403
Sellafield RCM3: Logging Run 2	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Casing	USI	6	398
Cement Bond	CBL	6	397
Density	LDL	401	1035
Imaging: Acoustic	UBI-NGS	401	1025
Imaging: Resistivity	FMI	401	1035
Neutron	CNL	401	1035
Resistivity	DLL-MSFL	401	1031
Sonic	DSI	210	1031
Spectral Gamma	NGS	401	1035
Sellafield RCM3: Logging Run 3	**Tool Used**	**Top (mbRT)**	**Base (mbRT)**
Geochemical	GLT	401	1033
Sellafield RCM3: Post Processed Logs	**Derivation**	**Top (mbRT)**	**Base (mbRT)**
Dipmeter	FMI	82	403
Dipmeter	FMI	405	470
DSI Sonic Waveform	DSI	75	404
DSI Sonic Waveform	DSI	397	1030
ELAN Petrophysical	Multiple Logs	82	370
ELAN Petrophysical	Multiple Logs	401	1022
FMI Static / Dynamic Images	FMI	74	405
FMI Static / Dynamic Images	FMI	405	1035
Mechanical Properties	Multiple Logs	75	405
Mechanical Properties	Multiple Logs	401	1022

Table 34: Logging tools used in Sellafield PRZ1

Sellafield PRZ1: Logging Run 1	**Tool Used**	**Top (mbST)**	**Base (mbST)**
Density	LDL	11	234
Imaging: Acoustic	UBI	11	234
Imaging: Resistivity	FMI	11	234
Neutron	CNL	11	234
Resistivity	ARI-MSFL	15	231
Sonic	DSI	18	230
Spectral Gamma	NGS	11	234
Sellafield PRZ1: Logging Run 2	**Tool Used**	**Top (mbST)**	**Base (mbST)**
Casing	USI		
Cement	CBL		
Density	LDL		
Imaging: Acoustic	UBI		
Imaging: Resistivity	HFMS		
Neutron	CNL		
Resistivity	ARI-MSFL		
Sonic	DSI		
Spectral Gamma	NGS		
Sellafield PRZ1: Post Processed Logs	**Derivation**	**Top (mbST)**	**Base (mbST)**
Dipmeter	FMI	15	235
Sonic Waveform	DSI	17	231
Sonic Waveform	DSI	222	770
FMS Static / Dynamic Images	HFMS	216	777
ELAN Petrophysical	Multiple Logs	11	226
ELAN Petrophysical	Multiple Logs	217	760
Mechanical Properties	Multiple Logs	11	226
Mechanical Properties	Multiple Logs	217	760

Table 35: Logging tools used in Sellafield PRZ2

Sellafield PRZ2: Logging Run 1	Tool Used	Top (mbST)	Base (mbST)
Density	LDL	28	235
Imaging: Acoustic	UBI	10	235
Imaging: Resistivity	FMI	10	235
Neutron	CNL	28	235
Resistivity	DLL-MSFL	28	235
Resistivity	ARI-MSFL	28	235
Sonic	DSI	31	220
Spectral Gamma	NGS	28	235
Sellafield PRZ2: Logging Run 2	**Tool Used**	**Top (mbST)**	**Base (mbST)**
Casing	USI	30	210
Cement	CBL	12	212
Density	LDL	215	535
Imaging: Acoustic	UBI	215	560
Imaging: Resistivity	HFMS	215	560
Neutron	CNL	215	535
Resistivity	ARI-MSFL	215	556
Sonic	DSI	215	535
Spectral Gamma	NGS	215	535
Sellafield PRZ2: Post Processed Logs	**Derivation**	**Top (mbST)**	**Base (mbST)**
Dipmeter	FMI	11	233
Dipmeter	HFMS	219	440
Sonic Waveform	DSI	10	228
Sonic Waveform	DSI	215	535
ELAN Petrophysical	Multiple Logs	11	224
ELAN Petrophysical	Multiple Logs	216	546
Mechanical Properties	Multiple Logs	29	224
Mechanical Properties	Multiple Logs	216	535

Table 36: Logging tools used in Sellafield PRZ3

Sellafield PRZ3: Logging Run 1	**Tool Used**	**Top (mbST)**	**Base (mbST)**
Density	LDL	13	234
Imaging: Acoustic	UBI	21	225
Imaging: Resistivity	FMI	12	230
Neutron	CNL	13	234
Resistivity	ARI-MSFL	42	230
Sonic	DSI	31	220
Spectral Gamma	NGS	13	234
Sellafield PRZ3: Logging Run 2	**Tool Used**	**Top (mbST)**	**Base (mbST)**
Cement	CBL-VDL-CCL	10	210
Density	LDL	216	776
Imaging: Acoustic	UBI-NGS	216	776
Imaging: Resistivity	FMI	216	776
Neutron	CNL	216	776
Resistivity	ARI-MSFL	216	776
Sonic	DSI	216	776
Spectral Gamma	NGS	216	776
Sellafield PRZ3: Post Processed Logs	**Derivation**	**Top (mbST)**	**Base (mbST)**
Dipmeter	FMI	14	234
Sonic Waveform	DSI	30	262
Sonic Waveform	DSI	216	767
ELAN Petrophysical	Multiple Logs	44	200
ELAN Petrophysical	Multiple Logs	216	759
FMI Dynamic Images	FMI	216	759
FMI Static Images	FMI	216	759
Inclinometry	FMI	216	759
Mechanical Properties	Multiple Logs	57	221
Mechanical Properties	Multiple Logs	216	759