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Äspö Hard Rock Laboratory

Prototype Repository

Tracer dilution tests during operation phase, test campaign 1

Sofia Gröhn
Peter Andersson
Eva Wass

GEOSIGMA AB

March 2005

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

Äspö Hard Rock Laboratory

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Author	Date
Sofia Gröhn	2005-01-21
Peter Andersson	
Eva Wass	
Checked by	Date
Erik Gustafsson	2005-03-04
Ingvar Rhén	2005-03-16
Approved	Date
Anders Sjöland	2005-04-05

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Abstract

The Prototype Repository project is focused on testing and demonstrating the function of the SKB deep repository system. Activities aimed at contributing to development and testing of the practical, engineering measures required to rationally perform the steps of a deposition sequence are also included in the project but are also part of other projects.

This report describes the first tracer dilution test campaign during the operation period of the Prototype Repository. The purpose is to estimate groundwater flow and will function as a full scale reference to comparisons with results of modelling and assumptions. The test campaign consisted of tracer dilution tests in 17 different borehole sections. Each test consisted of approximately 10-50 min tracer injection time and about 24-72 hours dilution test time depending on the transmissivity of the test section. The data interpretation also included estimates of the local hydraulic gradients in the vicinity of the borehole sections.

Sammanfattning

Huvudsyftet med Prototypförvaret är att testa och demonstrera funktionen av en del av SKB:s djupförvarssystem. Aktiviteter som syftar till utveckling och försök till praktiska och ingenjörsmässiga lösningar som krävs för att på ett rationellt sätt kunna stegvis utföra deponeringen av kapslar med kärnbränsle, är inkluderade i projektet för Prototypförvaret men även i andra projekt.

Rapporten beskriver den första utspädningskampanjen med spårämnen under Prototypförvarets driftperiod innan dräneringen av tunneln stängs. Syftet är att mäta grundvattenflöden som kommer att fungera som fullskaliga referenser vid modellering och antaganden om flödesfördelningen i berget.

I testkampanjen mättes 17 testsektioner med utspädningsmetoden. Varje test genomfördes så att ett spårämne injicerades under en period av 10-50 minuter med en påföljande provtagningsperiod av sektionsvatten på 24-72 timmar. Utvärderingen inkluderade också en uppskattning av den lokala hydrauliska gradienten intill borrhålet.

Executive summary

The Prototype Repository project is focused on testing and demonstrating the function of the SKB deep repository system. Activities aimed at contributing to development and testing of the practical, engineering measures required to rationally perform the steps of a deposition sequence are also included in the project but are also part of other projects.

This report describes the first tracer dilution campaign during the operation period of the Prototype Repository. The purpose is the estimate the groundwater flows and will function as a full scale reference to comparisons with results of modelling and assumptions.

The test campaign consisted of tracer dilution tests in 17 different sections. Each test consisted of approximately 10-50 min tracer injection time, depending of the volume in the section, followed by 24–72 hours dilution time with water sampling from the section.

The dilution method is based on a tracer injected in the section with constant rate during simultaneous circulation/mixing until a homogeneous tracer concentration is reached in the system. When the groundwater flows through the section the tracer will be diluted. The groundwater flow is calculated as a function of the decreasing tracer concentration with time as shown in the equation below and in Figure 1:

$$\ln (c/c_0) = -(Q_{bh}/V) \cdot \Delta t$$

By plotting ln (c/c_0) versus t, and by knowing the borehole volume V, Q_{bh} may then be obtained from the slope of the straight line. If c_0 is constant it is sufficient to use ln c in the plot (Figure 1).

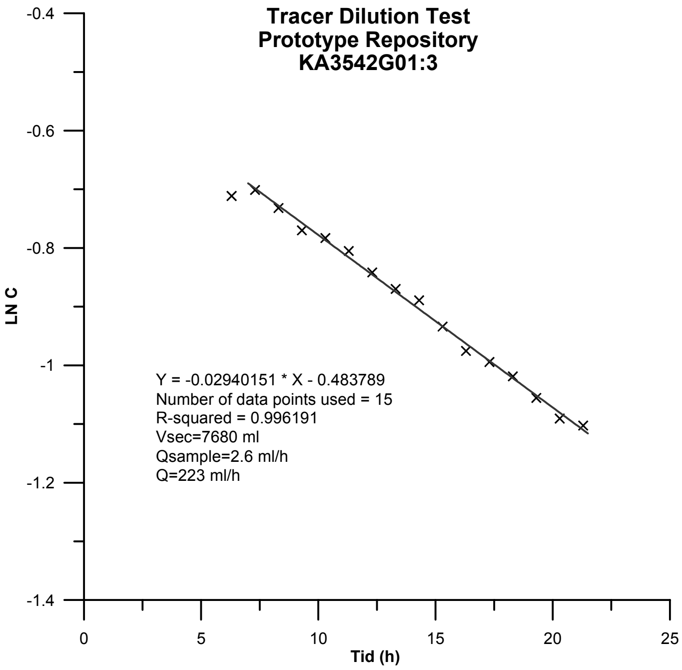

Figure 1. *Example of a tracer dilution test graph*

During the test campaign, the Prototype Repository tunnel was drained and the groundwater flow in each of the 17 sections therefore represents the situation with an enhanced hydraulic gradient. After closing the drainage the groundwater flow will most probably gradually decrease. There were no other major pressure disturbances during the tests and no interference between the sections was observed.

The magnitude of flow is governed by the local transmissivity of the borehole section and the hydraulic gradient. Ambient flow rates in Prototype Repository vary between 3-223 ml/h. Two sections with suspected packer leakage could also be identified and the leakage was confirmed.

Estimated local gradients vary between 0.2 and 31 m/m.

Contents

1 Background

1.1 Äspö Hard Rock Laboratory

In order to prepare for siting and licensing of a spent fuel repository SKB has constructed an underground research laboratory. In autumn of 1990, SKB began the construction of Äspö Hard Rock Laboratory (Äspö HRL), near Oskarshamn in the south-eastern part of Sweden. A 3.6 km long tunnel was excavated in crystalline rock down to a depth of approximately 460 m. The laboratory was completed in 1995 and research concerning the disposal of nuclear waste in crystalline rock has since then been carried out.

1.2 Prototype repository

The Äspö Hard Rock Laboratory is an essential part of the research, development and demonstration work performed by SKB in preparation for construction and operation of the deep repository for spent fuel. Within the scope of the SKB program for RD&D 1995, SKB has decided to carry out a project with the designation “Prototype Repository Test”. The aim of the project is to test important components in the SKB deep repository system in full scale and in a realistic environment.

The Prototype Repository Test is focused on testing and demonstrating the function of the SKB deep repository system. Activities aimed at contributing to development and testing of the practical, engineering measures required to rationally perform the steps of a deposition sequence are also included. However, efforts in this direction are limited, since these matters are addressed in the Demonstration of Repository Technology project and to some extent in the Backfill and Plug Test.

1.2.1 General objectives

The Prototype Repository should simulate as many aspects as possible a real repository, for example regarding geometry, materials and rock environment. The Prototype Repository is a demonstration of the integrated function of the repository components. Results will be compared with models and assumptions to their validity.

The major objectives for the Prototype Repository are

- To test and demonstrate the integrated function of the repository components under realistic conditions in full scale and to compare results with models and assumptions.
- To develop, test and demonstrate appropriate engineering standards and quality assurance methods.
- To simulate appropriate parts of the repository design and construction process.

The objective for the operation phase program is to monitor processes and properties in the canister, buffer material, backfill and near-field rock mass.

2 Objective

The objective of the tracer dilution tests during test campaign 1 is to measure the groundwater flow through 17 borehole sections in the Prototype Repository during drained conditions. The measurements will function as a full scale reference to comparisons with results of modelling and assumptions.

3 Scope

Tracer dilution tests were done using 17 borehole sections in Prototype Repository tunnel. The tested intervals and basic test data are listed in Table 3-1.

Table 3-1. List of borehole test sections during the tracer dilution test campaign in October – November 2004.

Borehole	Section	Start of test	Test stop
KA3539G:2	15.85 – 17.6	2004-10-12 10:40	2004-11-13 09:40
KA3548A01:3	8.8 – 10.75	2004-10-13 09:50	2004-10-14 09:00
KA3542G01:3	18.6 – 20.3	2004-10-14 09:05	2004-10-15 08:55
KA3574G01:3	1.8 – 4.1	2004-10-15 09:00	2004-10-18 12:45
KA3554G01:2	22.6 – 24.15	2004-10-18 12:50	2004-10-19 08:50
KA3566G02:2	16 – 18	2004-10-19 08:55	2004-10-20 13:20
KA3552G01:2	4.35 - 6.05	2004-10-20 13:30	2004-10-21 10:35
KA3544G01:2	8.9 – 10.65	2004-10-21 10:40	2004-10-22 07:50
KA3572G01:2	2.7 – 5.3	2004-10-22 07:55	2004-10-25 13:15
KG0021A01:3	35 – 36	2004-10-25 13:25	2004-10-26 08:55
KA3566G01:2	20- 21.5	2004-10-26 09:05	2004-10-27 08:45
KA3554G02:4	10.5 – 12.2	2004-10-27 08:50	2004-10-28 09:00
KA3550G01:2	5.2 – 7.3	2004-10-28 09:10	2004-10-29 07:40
KA3563G:4	1.5 – 3	2004-10-29 07:50	2004-11-01 10:30
KG0048A01:3	32.8 – 33.8	2004-11-01 10:35	2004-11-02 08:10
KA3542G02:2	25.6 – 27.2	2004-11-02 08:15	2004-11-03 11:15
KA3546G01:2	6.75 – 8.3	2004-11-03 11:20	2004-11-04 11:20

The results of the tests are presented in Chapter 5.

4 Equipment

4.1 Description of equipment

The 17 characterisation boreholes in the Prototype Repository involved in the dilution tests are instrumented with 1-4 inflatable packers isolating 1-5 borehole sections each (Rhén et al., 2001). All isolated borehole sections are connected through polyamide tubes to pressure transducers placed in the G-tunnel. The transducers are connected to the HMS-system at Äspö HRL through data loggers (Datascan). The sections used for tracer dilution tests are equipped with two additional polyamide tubes with an inner diameter of 4 mm. These are used for injection, sampling and circulation of tracer solution in the borehole section. The borehole sections are also equipped with volume reducers (dummies) made of polyamide.

A schematic drawing of the dilution test equipment used in the Prototype Repository is shown in Figure 4-1. The basic idea is to have an internal circulation in the borehole section. The circulation makes it possible to obtain a homogeneous tracer concentration in the borehole section and to sample the tracer concentration outside the borehole in order to monitor the dilution rate with time.

Circulation is controlled by a pump with variable speed (A) and measured by a flow meter (B). Tracer injections are made with a HPLC plunger pumps (C) and sampling is made by continuously extracting a small volume of water from the system through a flow controller (constant leak) to a fractional sampler (D). The total injected mass of tracer was weighed with a balance. Pictures of the equipment are shown in Figure 4-2.

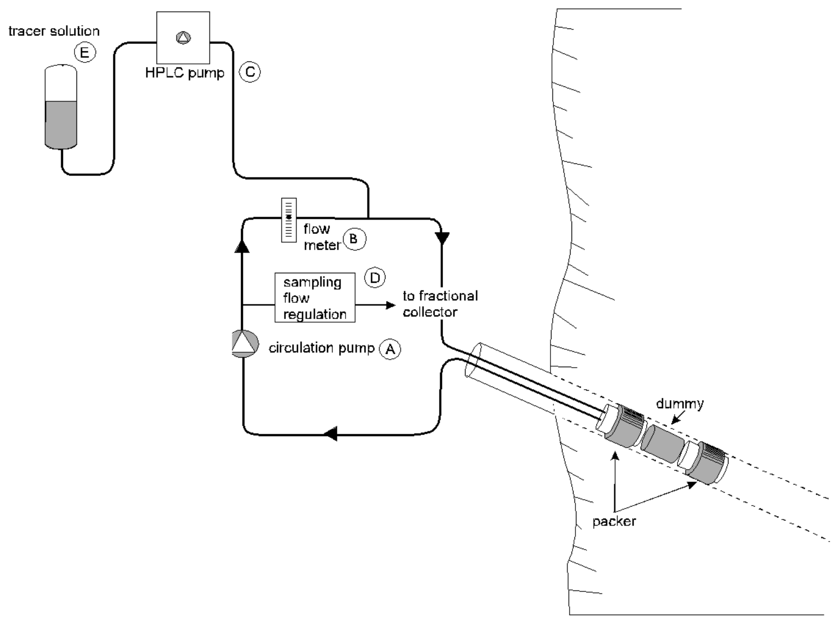

Figure 4-1. *Schematic drawing of the tracer injection/sampling system used in the Prototype Repository.*

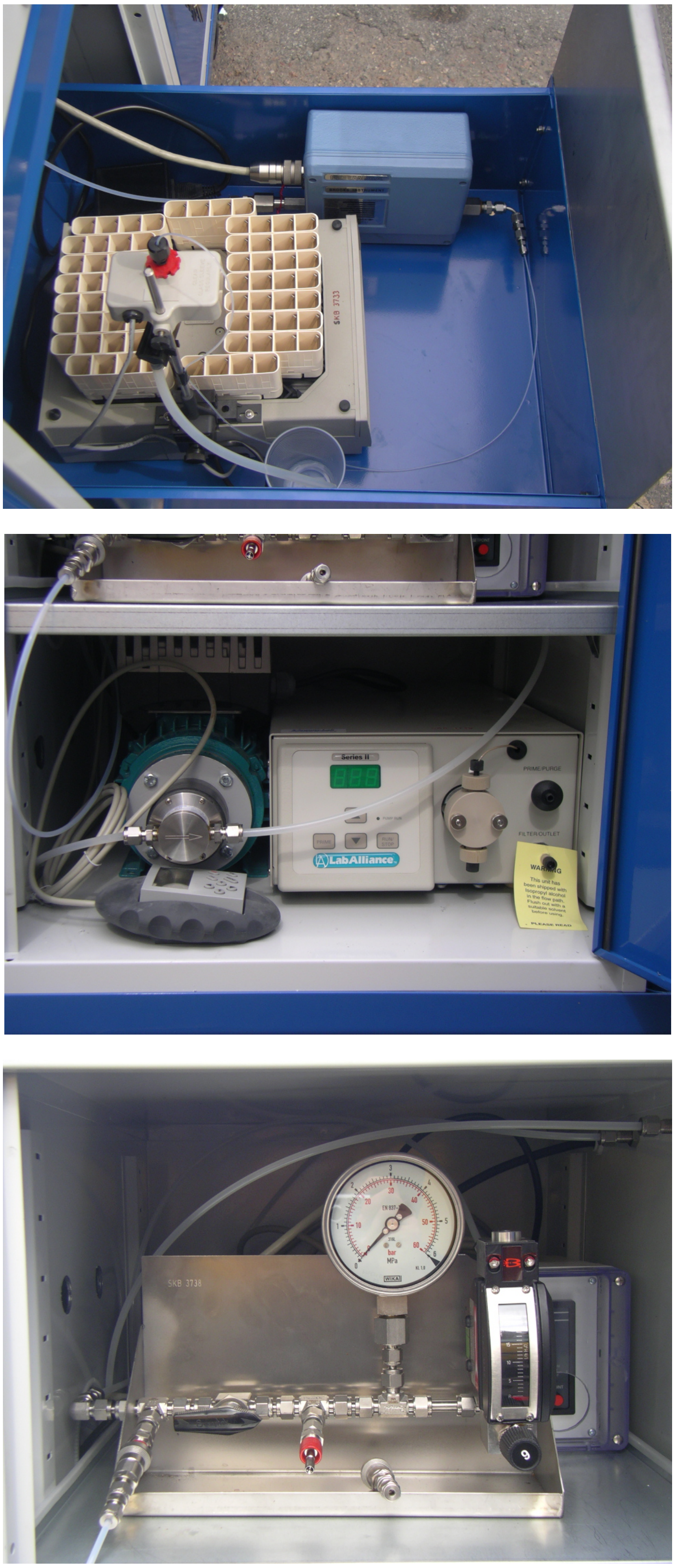

Figure 4-2. *Equipment from the dilution test: flow controller and fractional sampler (upper picture), circulation- and injection pump (middle) and the circulation board with flow meter and manometer (lower picture).*

4.2 Tracers used

The tracers used were two fluorescent dye tracers, Uranine (Sodium Fluorescein) from Merck (purum quality) and Amino G Acid from Aldrich (techn. quality). These tracers have been used extensively in the TRUE-1, TRUE Block Scale and TRUE Continuation tracer and dilution tests (Andersson et al., 2002, 2004). The tracers have been found to be conservative (non-reactive) in Äspö bedrock conditions.

5 Execution

5.1 Preparations

The preparations included functionality checks of the equipment, calibration of sampling flow regulator and tracer injection pump. It was also important to check that no other activities which may cause pressure disturbances occurred in the neighbourhood of the test area.

Protocols were prepared for tracer injection and sampling.

5.2 Performance of the dilution tests

The test campaign involved 17 different borehole sections, cf. Table 3.1. Based on values of transmissivity (Forsmark et al, 2004) and borehole volumes, listed in Appendix 3*,* the test duration for one section was estimated to 24 hours except for the most low transmissive fractures where the test duration was increased to approximately 72 hours. For exact dates and times of each test, see Table 3-1.

The dilution method is based on a tracer injected in the section with constant rate during simultaneous circulation/mixing until a homogeneous tracer concentration is reached in the system. This was achieved by injecting a 50 ppm tracer solution during a time period equivalent to the time it takes to circulate one section volume. The mixing rate to circulation rate was set to 1/100 implying that the start concentration in the borehole should be about 0.5 ppm.

When the groundwater flows through the section the tracer will be diluted. The groundwater flow is calculated as a function of the decreasing tracer concentration with time.

Additional parameters monitored were pressure and hydraulic head (Äspö Hydro Monitoring System)

Table 5-1 summarises the test set-ups including calculated transmissivities and volumes. Locations of the boreholes in the Prototype Repository are shown in Figure 5-1 in both vertical and plan view.

Table 5-1. Data on test sections used in the Prototype Repository tracer dilution tests. T (= transmissivity) values are evaluated from interference tests performed in May 2003 (Forsmark et al., 2004).

Bh section	Secup	Seclow	T (m^2/s)	$V_{section\ +tubing}$ (dm^3)	Comments
KA3539G:2	15.85	17.6	5.40E-07	7.66	Interference test performed IPR04-16
KA3542G01:3	18.6	20.3	6.40E-08	7.68	
KA3542G02:2	25.6	27.2	5.30E-10	7.49	
KA3544G01:2	8.9	10.65	1.30E-08	7.69	Packer system leakage
KA3546G01:2	6.75	8.3	7.80E-11	6.83	
KA3548A01:3	8.8	10.75	8.20E-08	8.29	
KA3550G01:2	5.2	7.3	4.40E-09	9.05	Packer system leakage
KA3552G01:2	4.35	6.05	2.20E-09	7.36	
KA3554G01:2	22.6	24.15	4.70E-07	7.19	Interference test performed IPR04-16
KA3554G02:4	10.5	12.2	2.50E-08	7.60	
KA3563G:4	1.5	3	9.40E-10	3.78	
KA3566G01:2	20	21.5	4.60E-09	4.08	
KA3566G02:2	16	18	8.70E-09	4.15	
KA3572G01:2	2.7	5.3	6.60E-10	3.99	
KA3574G01:3	1.8	4.1	3.70E-10	4.09	
KG0021A01:3	35	36	1.20E-07	2.52	Interference test performed IPR04-16
KG0048A01:3	32.8	33.8	3.80E-08	2.47	Interference test performed IPR04-16

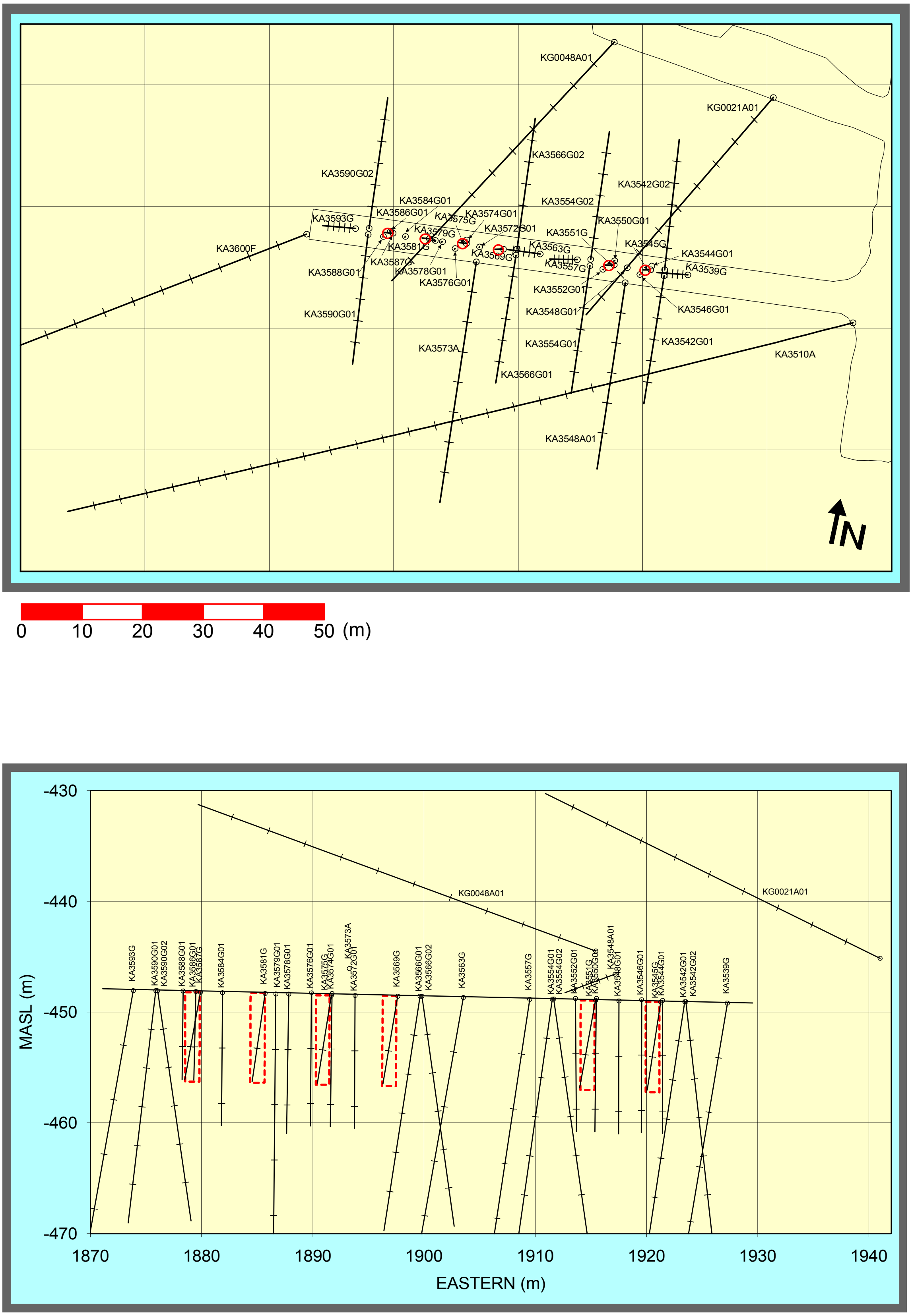

Figure 5-1. *Plan view (upper) and vertical view (below) of the location of the boreholes in the Prototype Repository. In the plan view the G-tunnel, where the equipment was set up, is shown in the upper part of the picture.*

5.3 Laboratory analyses

Samples were analysed for dye tracer content at the Geosigma Laboratory using a Jasco FP 777 Spectrofluorometer.

5.4 Evaluation and interpretation

5.4.1 Tracer dilution tests

Flow rates were calculated from the decay of tracer concentration versus time through dilution with natural unlabelled groundwater, c.f. Gustafsson (2002). The so-called "dilution curves" were plotted as the natural logarithm of concentration versus time. Theoretically, a straight-line relationship exists between the natural logarithm of the relative tracer concentration (c/c_0) and time (t):

$$\ln (c/c_0) = -(Q_{bh}/V) \cdot \Delta t \qquad (5\text{-}1)$$

where Q_{bh} (m^3/s) is the groundwater flow rate through the borehole section and V (m^3) is the volume of the borehole section. By plotting ln (c/c_0) versus t, and by knowing the borehole volume V, Q_{bh} may then be obtained from the slope of the straight line. If c_0 is constant it is sufficient to use ln c in the plot.

The sampling procedure with a constant flow of 2-4 ml/h also creates a dilution of tracer. This flow rate is therefore subtracted from the value obtained from eq. 5-1.

5.4.2 Hydraulic gradient

Hydraulic gradients are roughly estimated from Darcy´s law where the gradient *(I)* is calculated as the function of the Darcy velocity *(v)* with the conductivity *(K):*

$$I = \frac{v}{K} = \frac{Q_{bh} \cdot L_{bh}}{\alpha \cdot A \cdot T_{bh}} = \frac{Q_{bh} \cdot L_{bh}}{2 \cdot d_{bh} \cdot L_{bh} \cdot T_{bh}} \qquad (5\text{-}2)$$

where Q_{bh} is the groundwater flow rate through the borehole section , L_{bh} is the length of the borehole section, T_{bh} the transmissivity of the section, A the cross section area between the packers and d_{bh} the borehole diameter which for the boreholes in the Prototype Repository is 76 mm.

The contraction factor α depends on the interference of the flow field in the fracture plane locally surrounding the borehole. For a homogeneous rock with the fracture cutting the borehole axis in 90° the contraction factor α is equal 2 according to Gustafsson (2002). Since the rock mostly is heterogeneous and the angles in the sections not always 90° the calculation of the hydraulic gradient is a rough estimate.

6 Results and interpretation

6.1 Hydraulic conditions

During the test campaign, the Prototype Repository tunnel was drained and the groundwater flow in each of the 17 sections therefore represents the situation with an enhanced hydraulic gradient. After closing the drainage the groundwater flow will most probably gradually decrease. There were no other major pressure disturbances during the tests and no interference between the sections was observed.

6.2 Dilution tests

The evaluated flow rates in the sections together with the hydraulic gradients are presented in Table 6-1. Tracer injection data are listed in Table 6-2. The test generally yields results that are consistent with the expectations and the data quality is good. There are some uncertainties in calculation of the groundwater flow that need to be commented:

The exact length of the tubing from each section is not known. This will introduce some uncertainty in the volume calculations. Calculated volumes of the section between packers are however very accurate. A good check of the accuracy of the volume determination is to compare the theoretical concentration of tracer in the borehole section at the start of the test to the actually measured one. The data presented in Table 6.2 shows good agreement in 14 of the sections.

One of the three sections having much lower concentration than the theoretical one has a packer leakage (*KA3550G01:2*) which explains the discrepancy. Section *KG0021A01:3* has very small volume which makes it important to have the correct tubing length thus, the volume, and consequently also the flow may be somewhat underestimated. Finally, section *KA3546G01:2* shows a large discrepancy which cannot be explained by volume differences alone. The section also has an anomalous hydraulic gradient (352) and an extremely low transmissivity (8E-11 m^2/s). The pressure measurements (Appendix 2) show that the section pressure both in the section itself and in surrounding sections is largely affected by the opening of the section necessary for attachment of the equipment due to the low transmissivity. In fact, a valve was turned in the wrong direction creating a leakage throughout the entire measurement. Thus, the borehole is not at steady state and an anomalous gradient was created.

The uncertainty of the analyses of the tracers is ± 2% based on replication measurement made by Geosigma Laboratory. This affects the fits of the dilution graphs (logarithm of concentration versus time) in sections having very small dilution (low flow). Dilution graphs from all 17 sections are presented in Appendix 1 with uncertainty presented as R-squared, see also Table 6-1. The fits are generally good (14 of the 17 tests) but in sections having low flow rates (<10 ml/h) the uncertainty increases, especially in *KA3542G02:2.* This is possibly due to a short test period (26 h) compared to the low transmissivity, 5.3E-10 m^2/s. A longer test period for *KA3552G01:2* and *KA3554G02:4* would presumably also result in a higher regression coefficient.

The measurement limit of the groundwater flow is set to 2 ml/h since the sampling of the water during the test is approximately 2-3 ml/h. This also increases the uncertainty for the determination of low flow rates (<10 ml/h). Sections *KA3544G01:2* and *KA3550G01:2* were expected to have a packer system leakage and this was confirmed during performed tracer dilution tests. The groundwater flows are much higher than the others, and what could be expected for natural conditions, which indicate leakage of water to neighboring sections. Consequently the calculated gradients of these sections are extremely high.

6.3 Hydraulic gradient

The hydraulic gradients of the test sections are presented in Table 6-1. Note that these are rough estimated based on several assumptions and not should be used as exact data. The gradients vary between 0.2 and 30 m/m except for the three leaking sections discussed above.

Table 6-1. Results of tracer dilution tests during natural conditions in the Prototype Repository. The volume includes the section with tubing.

Test section	V (dm^3)	$Q_{natural}$ (ml/h)	Regression coefficient	I Gradient	Comments
KA3539G:2	7.66	56	0.990	0.2	
KA3542G01:3	7.68	223	0.996	6.4	
KA3542G02:2	7.49	9.0	0.478	31	
KA3544G01:2	7.69	*(384)*	*1.000*	(54)	*Packer system leakage*
KA3546G01:2	*6.83*	*(15)*	*0.935*	*(352)*	*Valve leakage*
KA3548A01:3	8.29	90	0.982	2.0	
KA3550G01:2	9.05	*(255)*	*0.977*	(106)	*Packer system leakage*
KA3552G01:2	7.36	12	0.787	9.9	
KA3554G01:2	7.19	66	0.975	0.3	
KA3554G02:4	7.60	8.4	0.672	0.6	
KA3563G:4	3.78	14	0.977	26	
KA3566G01:2	4.08	19	0.989	7.4	
KA3566G02:2	4.15	3.1	0.872	0.6	
KA3572G01:2	3.99	6.0	0.990	17	
KA3574G01:3	4.09	3.8	0.813	19	
KG0021A01:3	2.52	56	0.999	0.9	
KG0048A01:3	2.47	7.8	0.945	0.4	

Table 6-2. Comparison of calculated injection concentration (based on known volumes) and analysed tracer concentration from dilution tests in Prototype Repository.

Test section	Tracer	Calculated C_0 in test section (mg/l)	Analysed C_0 in test section (mg/l)	Comments
KA3539G:2	Uranine	0.39	0.4	
KA3542G01:3	Uranine	0.49	0.5	
KA3542G02:2	Uranine	0.51	0.53	
KA3544G01:2	Uranine	0.48	0.47	*Packer system leakage*
KA3546G01:2	Amino-G acid	0.50	0.32	*Valve leakage*
KA3548A01:3	Uranine	0.49	0.52	
KA3550G01:2	Amino-G acid	0.51	0.26	*Packer system leakage*
KA3552G01:2	Uranine	0.50	0.47	
KA3554G01:2	Uranine	0.50	0.47	
KA3554G02:4	Uranine	0.50	0.49	
KA3563G:4	Uranine	0.32	0.38	
KA3566G01:2	Uranine	0.34	0.35	
KA3566G02:2	Uranine	0.33	0.35	
KA3572G01:2	Uranine	0.34	0.35	
KA3574G01:3	Uranine	0.34	0.36	
KG0021A01:3	Uranine	0.32	0.19	
KG0048A01:3	Uranine	0.31	0.25	

6.4 Supporting data

The pressure data from each section during the tests are showed in Appendix 2. These data are collected from the HMS. There are no major pressure disturbing activities observed during the period. However, a few of the sections show pressure changes related to the tracer dilution tests. The dip of pressure in *KA3546G01:2* depend on an incorrectly turned pressure valve as discussed above.

In section *KG0021A01:3* the pressure increases to the same level as in section 1 of the same borehole. This may be an indication of a cross-connection between the two sections that need to be checked.

A general observation is that in all low transmissive sections (T<E-8 m^2/s) there is a pressure lowering of between 10-60 kPa in the section. This is due to the constant sampling rate of 2-4 ml/h that affect the pressure in these low transmissive sections, but not notably in the high transmissive sections. The sampling flow rate has been subtracted from the results.

7 Discussion and conclusions

The determination of flow rates using the tracer dilution method was performed under ambient gradient and represents the groundwater flow through each of the 17 sections during tunnel drainage conditions. The drainage of the tunnel has been going on for a long period of time and the hydraulic conditions during the test may therefore be considered to be stable. There was no other major pressure disturbance during the tests and no interference between the sections was observed with the exception of borehole *KG0021A01:3* where an indication of a cross-connection to section 1 in the same borehole was indicated.

The magnitude of flow is governed by the local transmissivity of the borehole section and the hydraulic gradient. Under ambient gradient conditions flow rates in the Prototype Repository vary by between 3 and 223 ml/h (c.f. Table 6-1) and there is a fairly good correlation between transmissivity and flow rate, as shown in Figure 7-1.

No groundwater flow could be calculated for *KA3550G01:2, KA3546G01:2* and *KA3544G01:2* since the values determined represent leakage rather than flow through fractures intersecting the section.

One may expect that the largest hydraulic gradient would occur close to the tunnel. High gradients are also found in *KA3572G01:2, KA3574G01:3* and *KA3563G:4* located close to the tunnel. However, high gradients were also found in *KA3542G02:2, KA3542G01:3* and *KA3566G01:2* located 16-25 m from the tunnel. This is not surprising since the rock is fractured the flow rate and gradients could be expected to vary quite a lot depending on the connectivity to the tunnel.

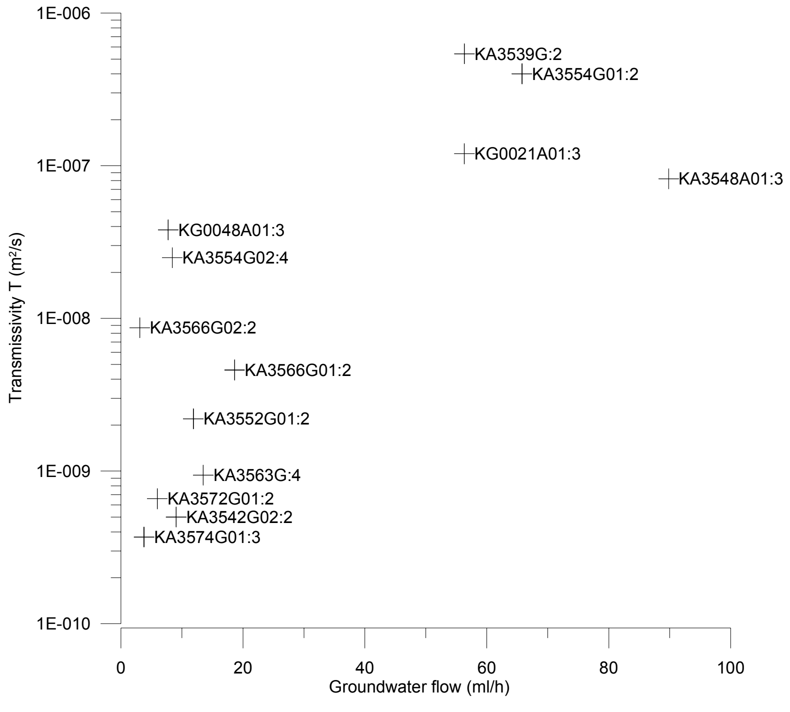

Figure 7-1*. Logarithm of transmissivity versus groundwater flow rate for the sections measured in the tracer dilution test campaign (leaking sections excluded).*

8 References

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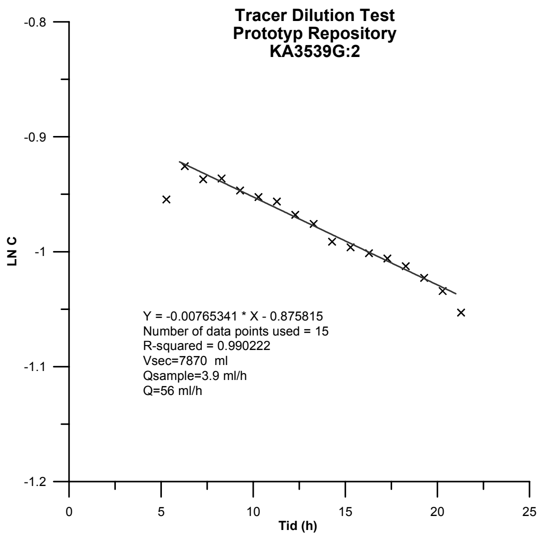
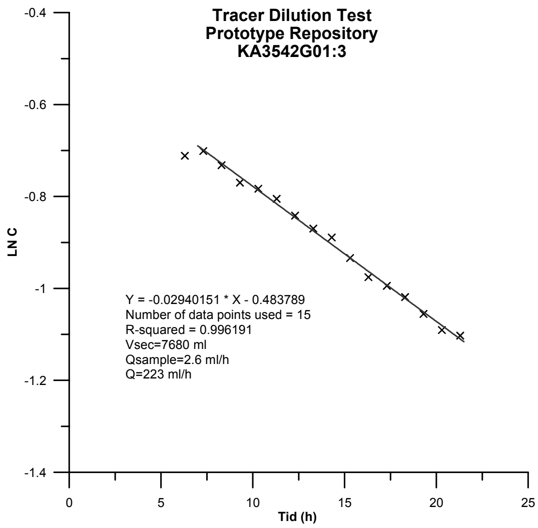
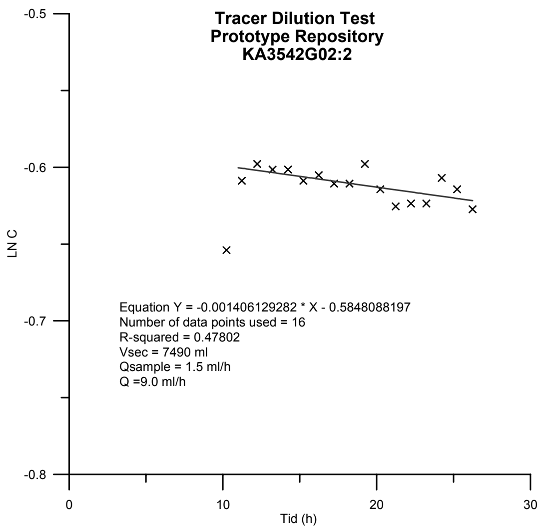
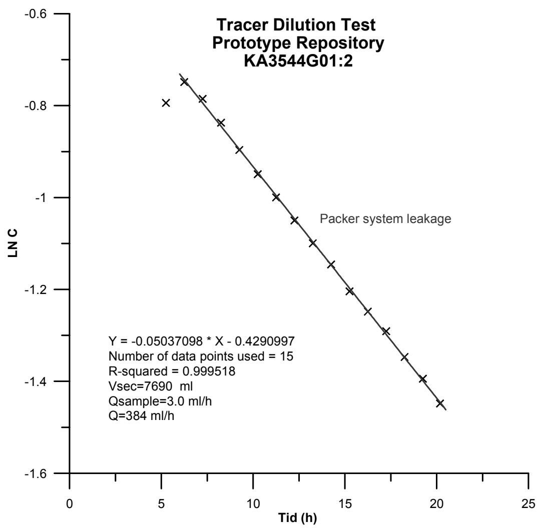
Appendix 1

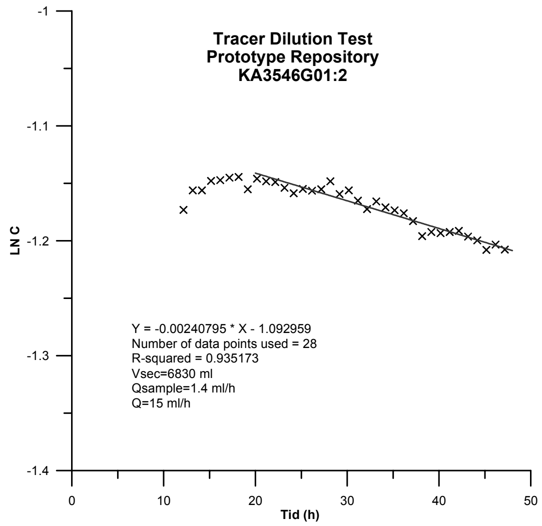
Tracer Dilution graphs from tests in 17 borehole sections in Prototype Repository campaign 1.

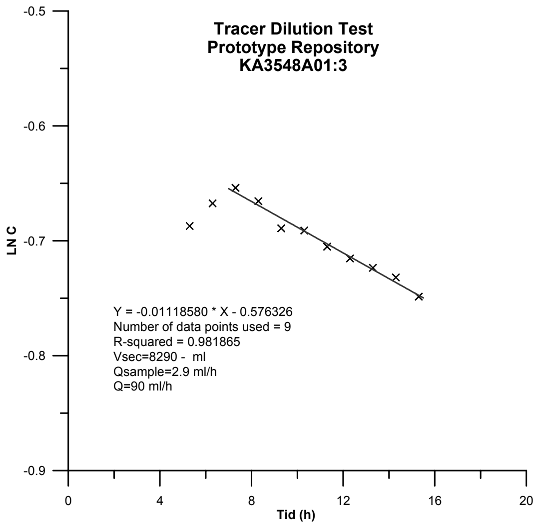


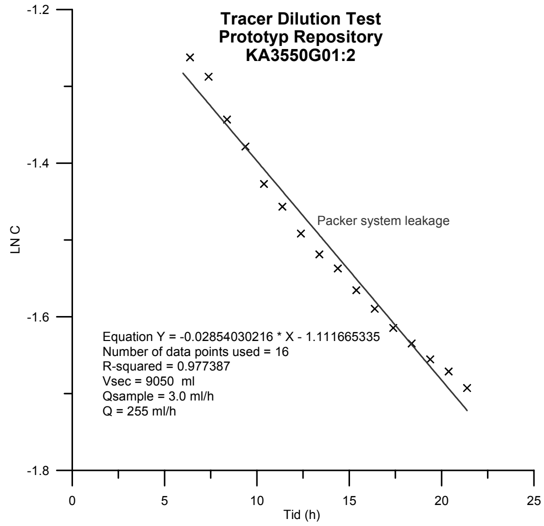


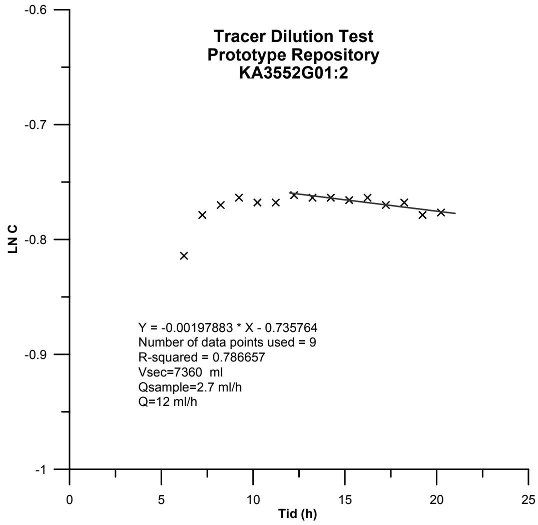


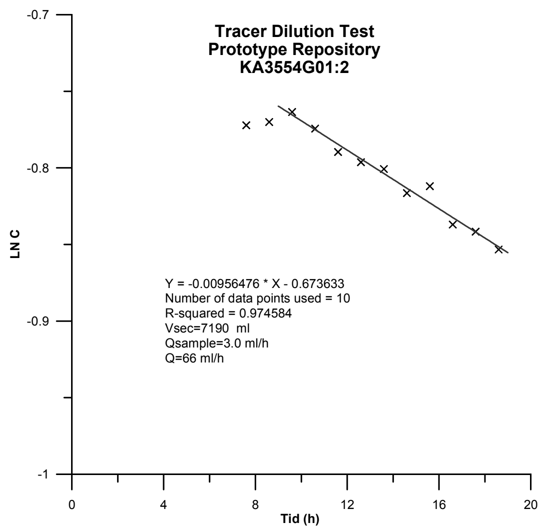


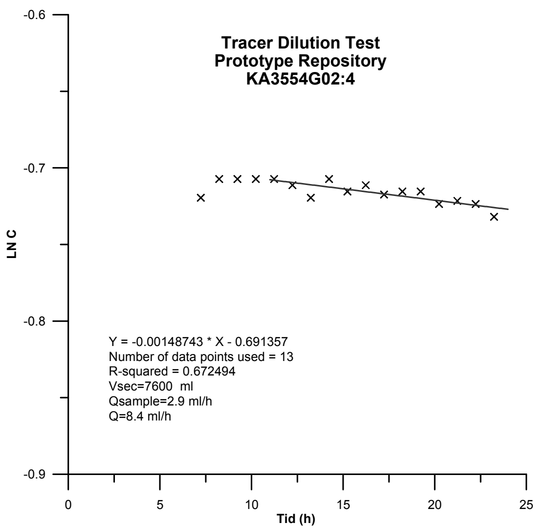

Tracer Dilution Test
Prototype Repository
KA3546G01:2
Y = -0.00240795 * X - 1.092959
Number of data points used = 28
R-squared = 0.935173
Vsec=6830 ml
Qsample=1.4 ml/h
Q=15 ml/h
LN C
Tid (h)

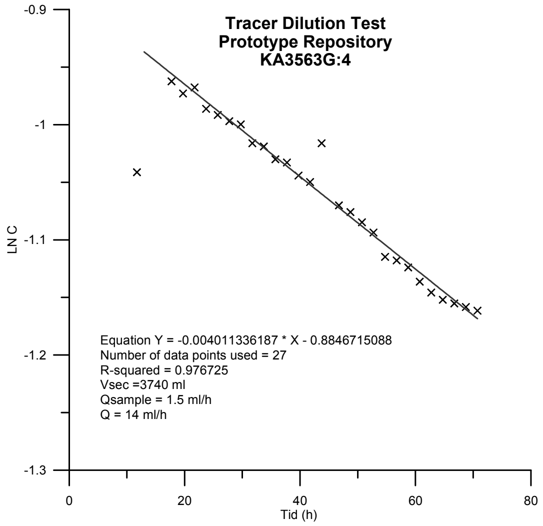

Tracer Dilution Test
Prototype Repository
KA3548A01:3
Y = -0.01118580 * X - 0.576326
Number of data points used = 9
R-squared = 0.981865
Vsec=8290 - ml
Qsample=2.9 ml/h
Q=90 ml/h
LN C
Tid (h)

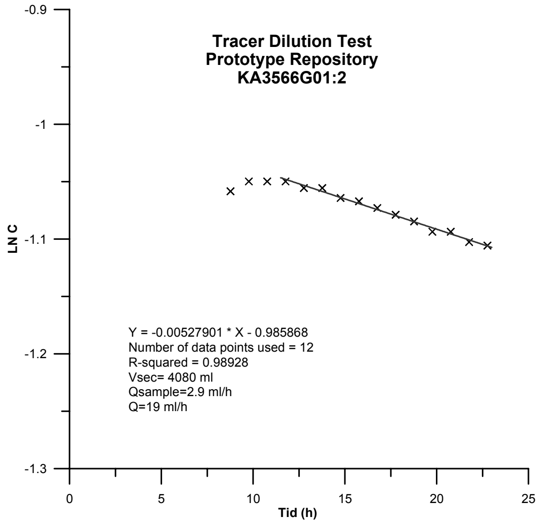

Tracer Dilution Test
Prototyp Repository
KA3550G01:2
Packer system leakage
Equation Y = -0.02854030216 * X - 1.111665335
Number of data points used = 16
R-squared = 0.977387
Vsec = 9050 ml
Qsample = 3.0 ml/h
Q = 255 ml/h
LN C
Tid (h)

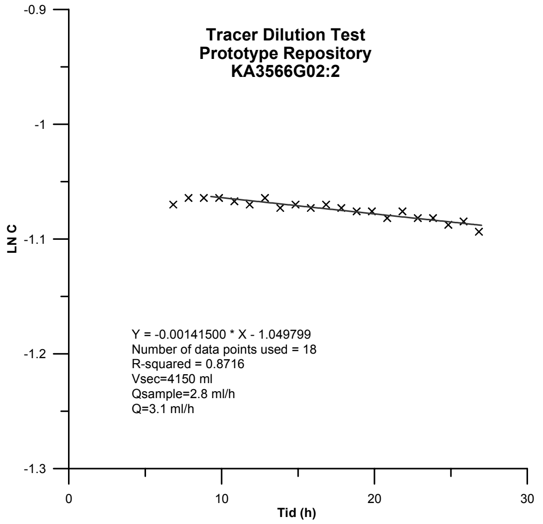

Tracer Dilution Test
Prototype Repository
KA3552G01:2
Y = -0.00197883 * X - 0.735764
Number of data points used = 9
R-squared = 0.786657
Vsec=7360 ml
Qsample=2.7 ml/h
Q=12 ml/h
LN C
Tid (h)

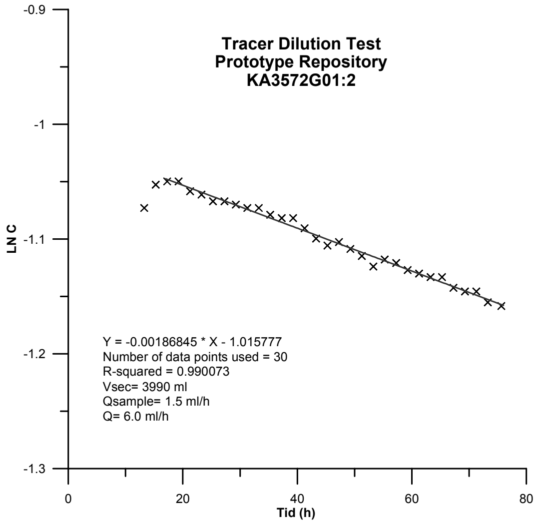

Tracer Dilution Test
Prototype Repository
KA3554G01:2
Y = -0.00956476 * X - 0.673633
Number of data points used = 10
R-squared = 0.974584
Vsec=7190 ml
Qsample=3.0 ml/h
Q=66 ml/h
LN C
Tid (h)

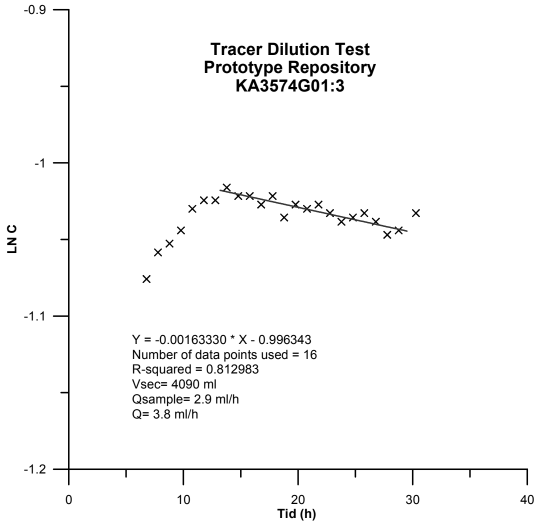

Tracer Dilution Test
Prototype Repository
KA3554G02:4
Y = -0.00148743 * X - 0.691357
Number of data points used = 13
R-squared = 0.672494
Vsec=7600 ml
Qsample=2.9 ml/h
Q=8.4 ml/h
LN C
Tid (h)

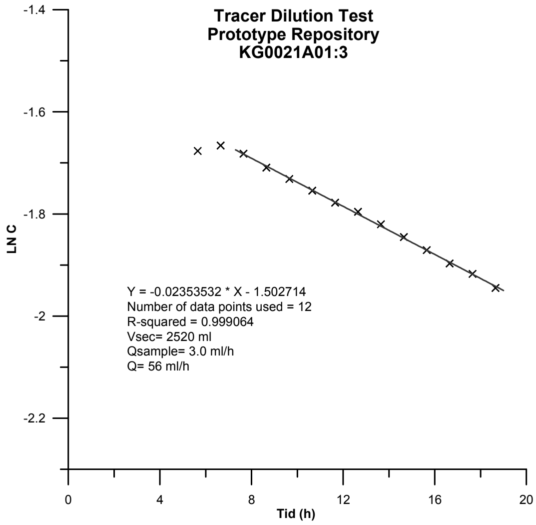

Tracer Dilution Test
Prototype Repository
KA3563G:4
Equation Y = -0.004011336187 * X - 0.8846715088
Number of data points used = 27
R-squared = 0.976725
Vsec =3740 ml
Qsample = 1.5 ml/h
Q = 14 ml/h
LN C
Tid (h)

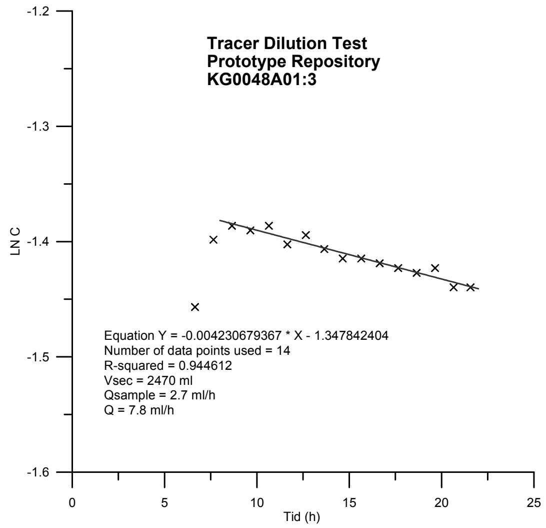

Tracer Dilution Test
Prototype Repository
KA3566G01:2
Y = -0.00527901 * X - 0.985868
Number of data points used = 12
R-squared = 0.98928
Vsec= 4080 ml
Qsample=2.9 ml/h
Q=19 ml/h
LN C
Tid (h)


Tracer Dilution Test
Prototype Repository
KA3566G02:2
Y = -0.00141500 * X - 1.049799
Number of data points used = 18
R-squared = 0.8716
Vsec=4150 ml
Qsample=2.8 ml/h
Q=3.1 ml/h
LN C
Tid (h)


Tracer Dilution Test
Prototype Repository
KA3572G01:2
Y = -0.00186845 * X - 1.015777
Number of data points used = 30
R-squared = 0.990073
Vsec= 3990 ml
Qsample= 1.5 ml/h
Q= 6.0 ml/h
LN C
Tid (h)


Tracer Dilution Test
Prototype Repository
KA3574G01:3
Y = -0.00163330 * X - 0.996343
Number of data points used = 16
R-squared = 0.812983
Vsec= 4090 ml
Qsample= 2.9 ml/h
Q= 3.8 ml/h
LN C
Tid (h)


Tracer Dilution Test
Prototype Repository
KG0021A01:3
Y = -0.02353532 * X - 1.502714
Number of data points used = 12
R-squared = 0.999064
Vsec= 2520 ml
Qsample= 3.0 ml/h
Q= 56 ml/h
LN C
Tid (h)

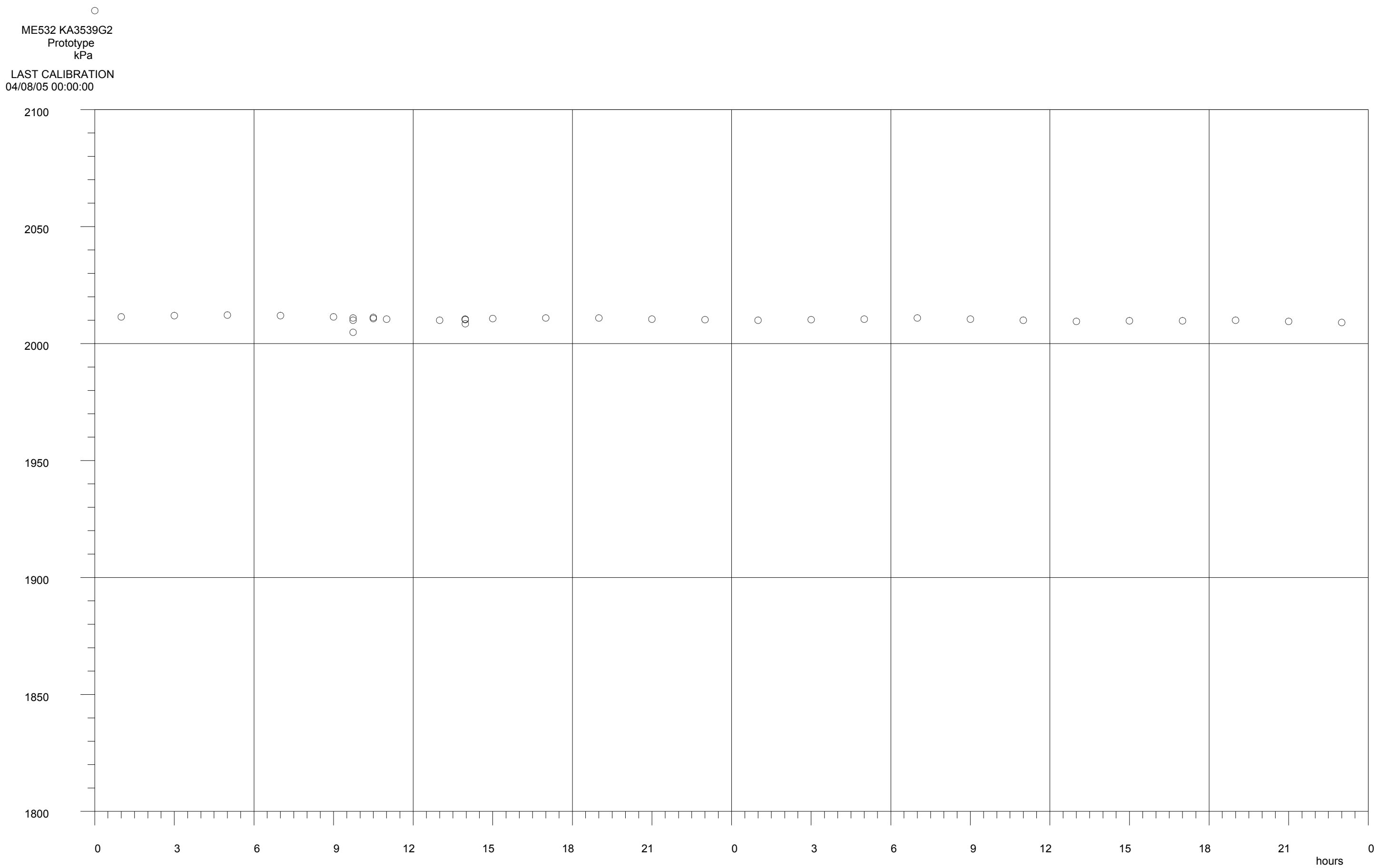

Tracer Dilution Test
Prototype Repository
KG0048A01:3
Equation Y = -0.004230679367 * X - 1.347842404
Number of data points used = 14
R-squared = 0.944612
Vsec = 2470 ml
Qsample = 2.7 ml/h
Q = 7.8 ml/h
LN C
Tid (h)
-1.2
-1.3
-1.4
-1.5
-1.6
0
5
10
15
20
25

Appendix 2

Pressure data from tracer dilution tests in 17 borehole sections during Prototype Repository test campaign 1.

PLOT TIME :04/11/10 16:39:38
PLOT FILE :Aatest_ew
Adjusted for DST

DSPV HRL

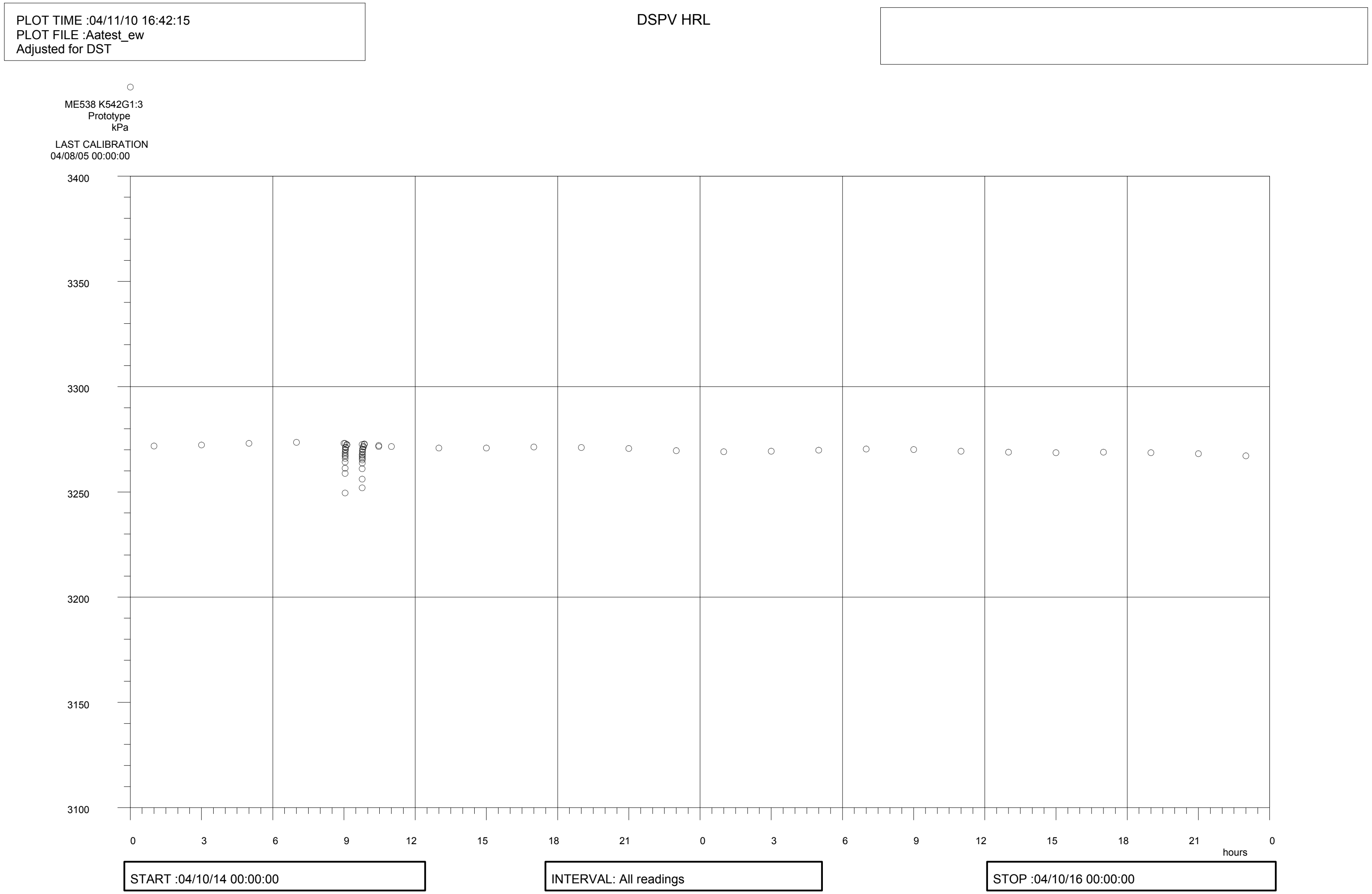


START :04/10/12 00:00:00

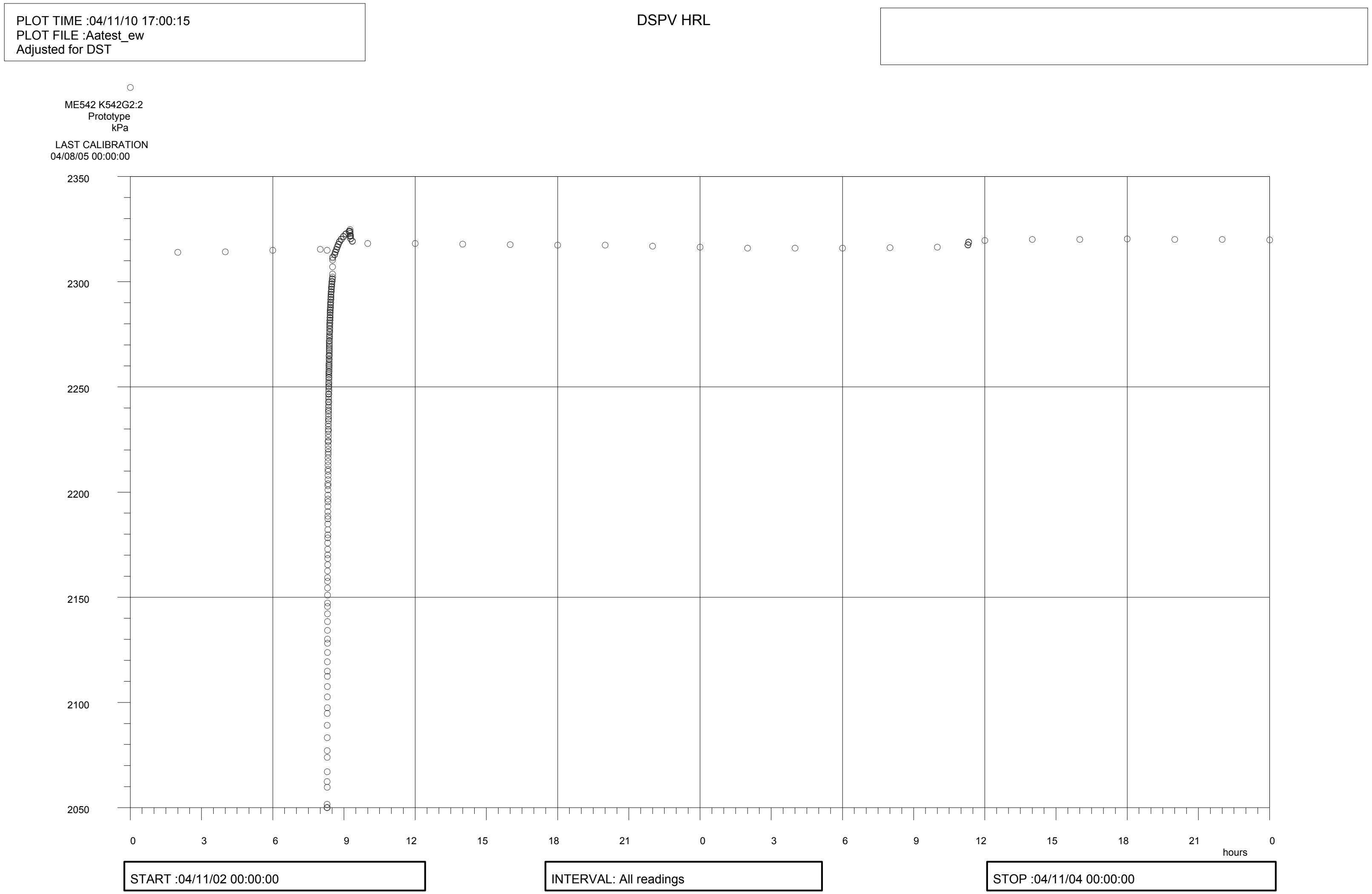
INTERVAL: All readings

STOP :04/10/14 00:00:00

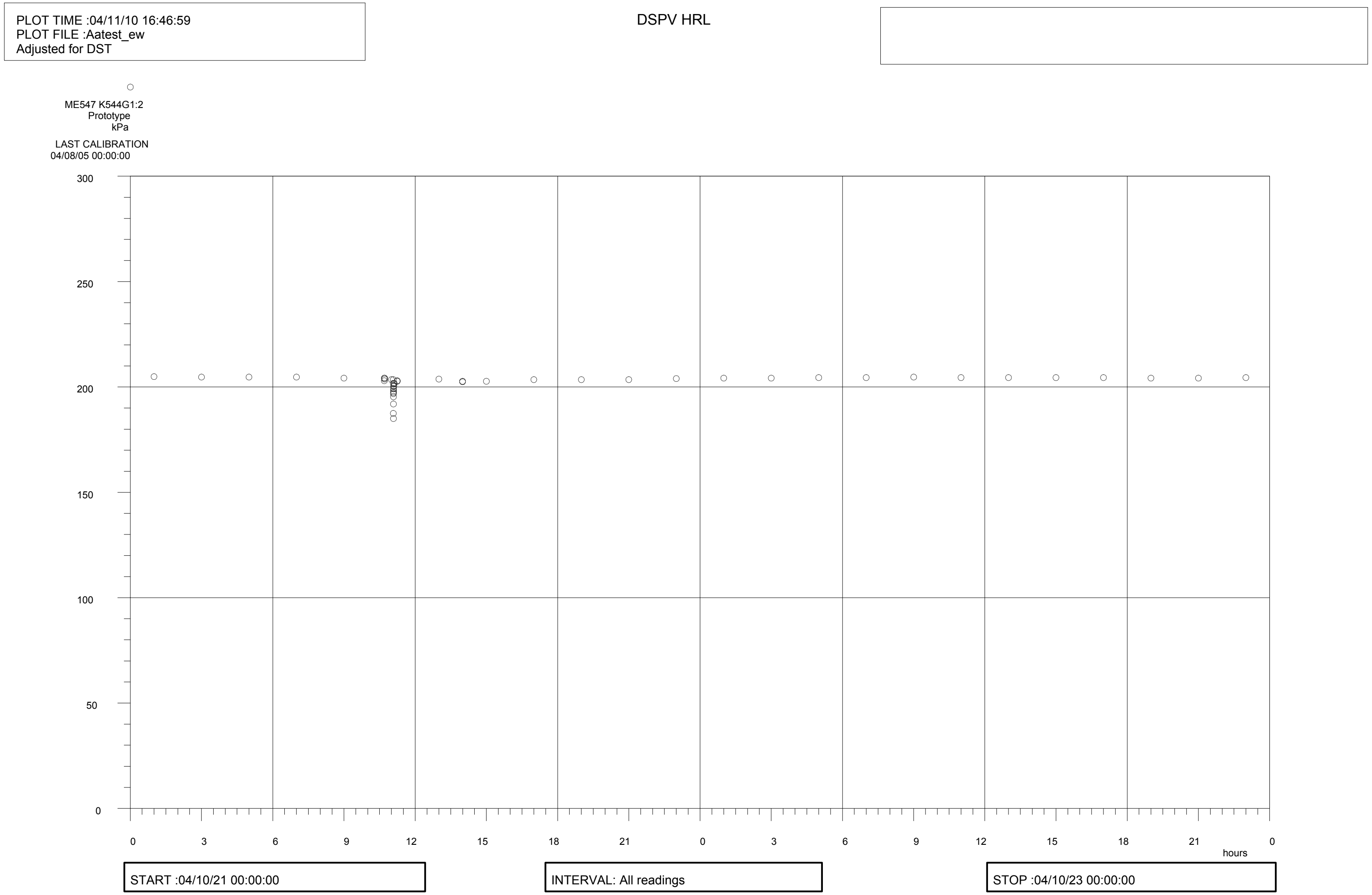
KA3539G:2


PLOT TIME :04/11/10 16:42:15
PLOT FILE :Aatest_ew
Adjusted for DST
DSPV HRL
ME538 K542G1:3
Prototype
kPa
LAST CALIBRATION
04/08/05 00:00:00
3400
3350
3300
3250
3200
3150
3100
0 3 6 9 12 15 18 21 0 3 6 9 12 15 18 21 0
hours
START :04/10/14 00:00:00
INTERVAL: All readings
STOP :04/10/16 00:00:00

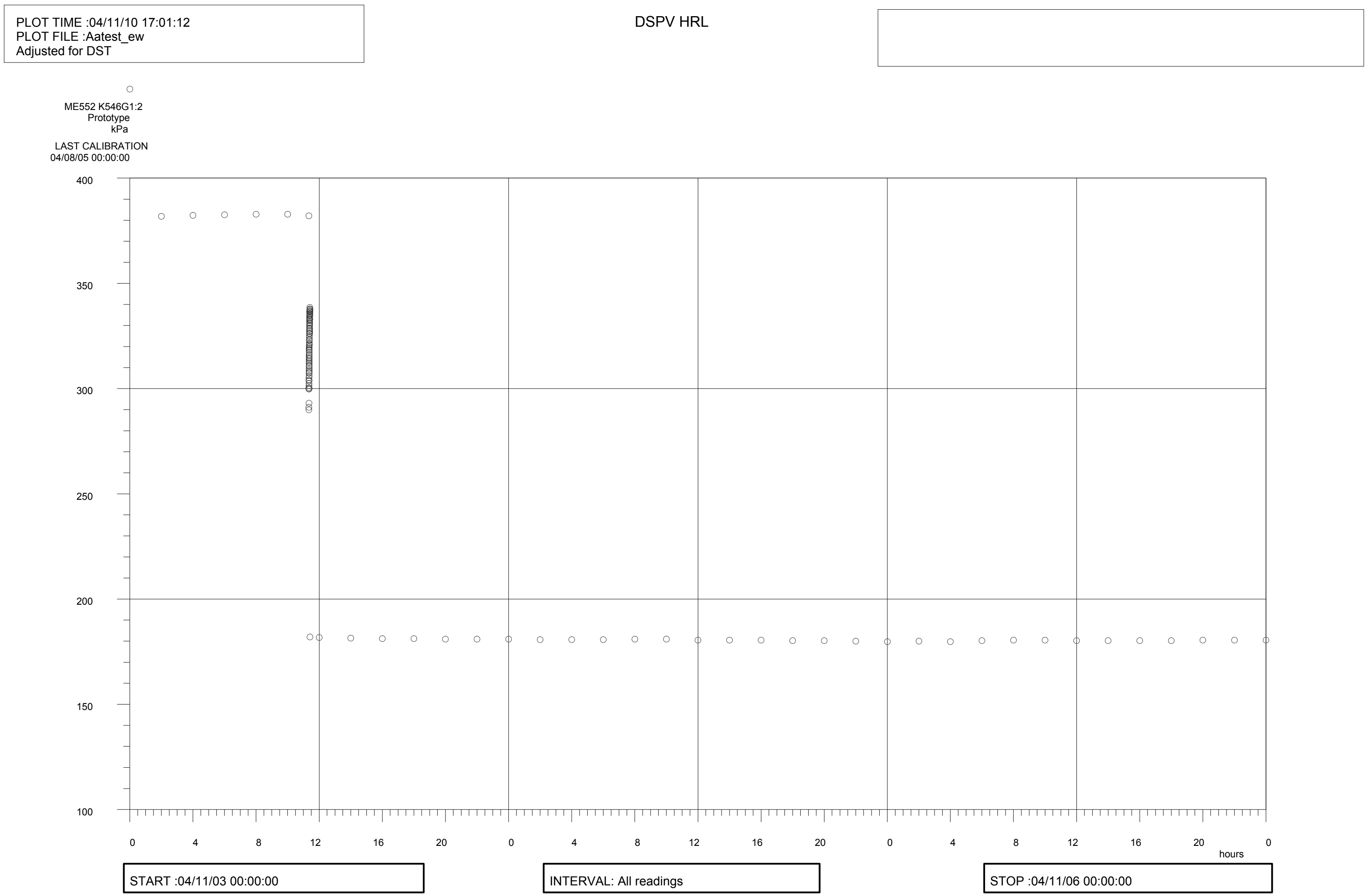
KA3542G01:3


PLOT TIME :04/11/10 17:00:15
PLOT FILE :Aatest_ew
Adjusted for DST
DSPV HRL
ME542 K542G2:2
Prototype
kPa
LAST CALIBRATION
04/08/05 00:00:00
2350
2300
2250
2200
2150
2100
2050
0 3 6 9 12 15 18 21 0 3 6 9 12 15 18 21 0
hours
START :04/11/02 00:00:00
INTERVAL: All readings
STOP :04/11/04 00:00:00

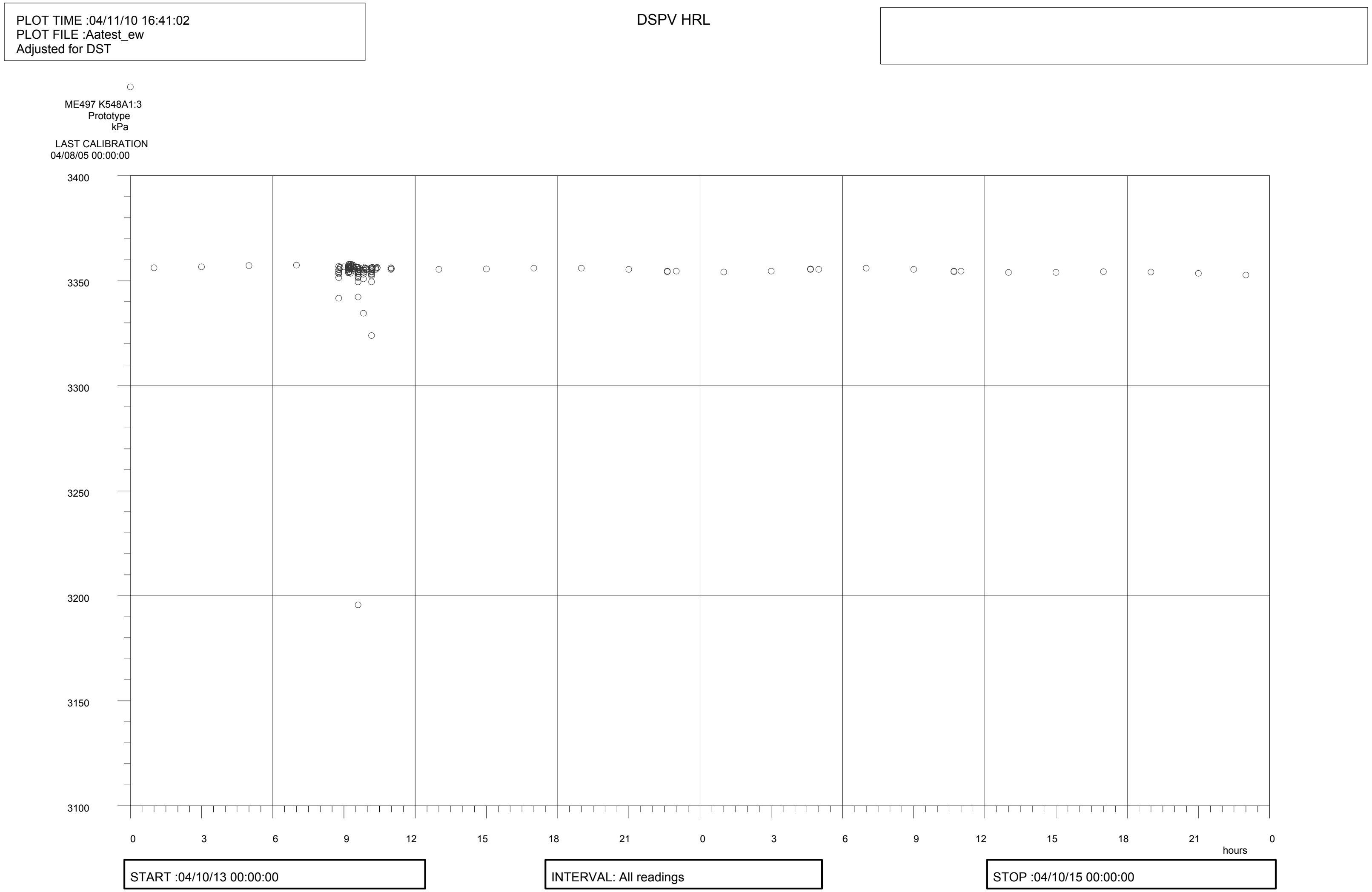
KA3542G02:2


PLOT TIME :04/11/10 16:46:59
PLOT FILE :Aatest_ew
Adjusted for DST
DSPV HRL
ME547 K544G1:2
Prototype
kPa
LAST CALIBRATION
04/08/05 00:00:00
300
250
200
150
100
50
0
0
3
6
9
12
15
18
21
0
3
6
9
12
15
18
21
0
hours
START :04/10/21 00:00:00
INTERVAL: All readings
STOP :04/10/23 00:00:00

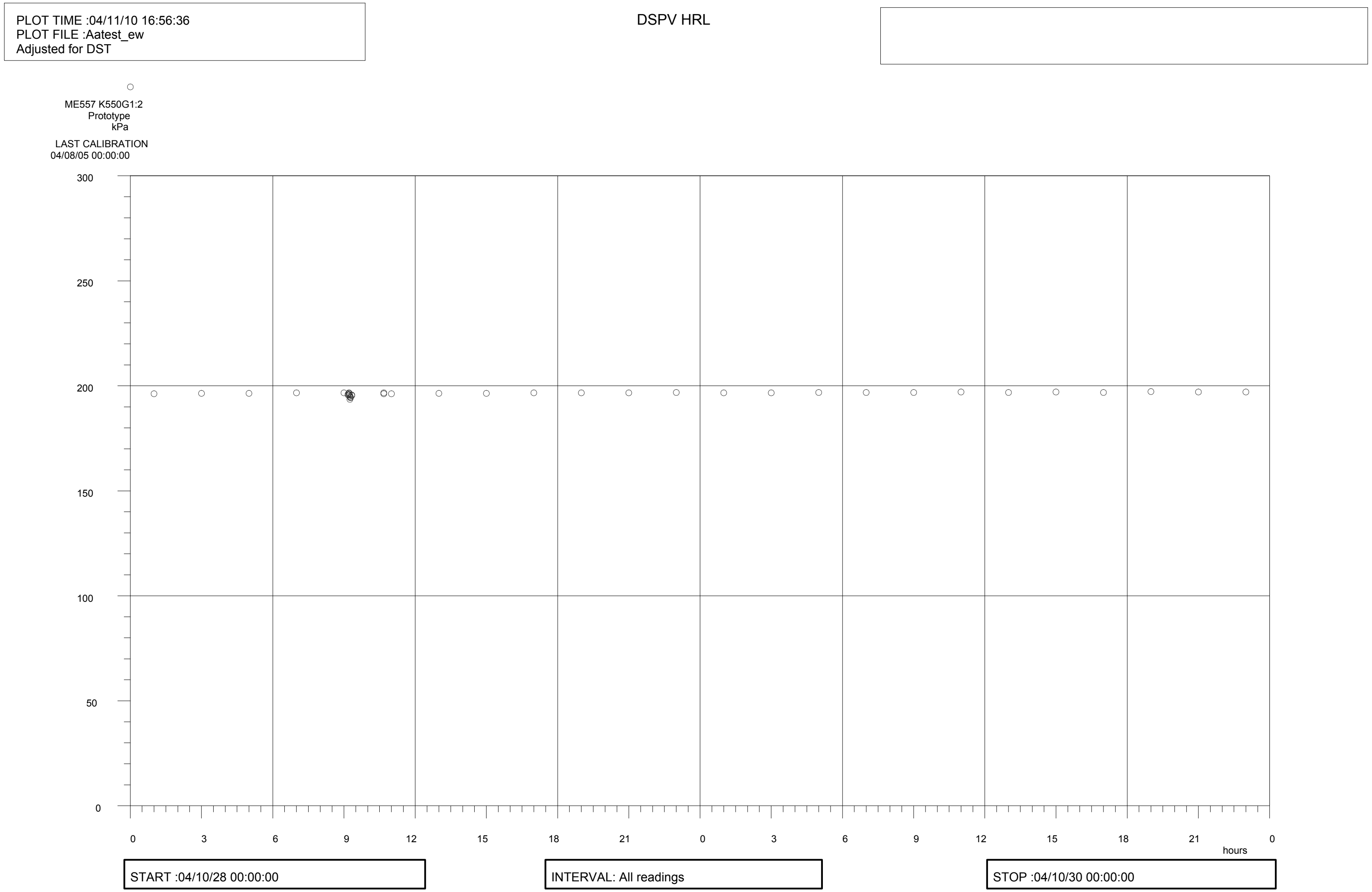
KA3544G01:2


PLOT TIME :04/11/10 17:01:12
PLOT FILE :Aatest_ew
Adjusted for DST
DSPV HRL
ME552 K546G1:2
Prototype
kPa
LAST CALIBRATION
04/08/05 00:00:00
400
350
300
250
200
150
100
0
4
8
12
16
20
hours
START :04/11/03 00:00:00
INTERVAL: All readings
STOP :04/11/06 00:00:00

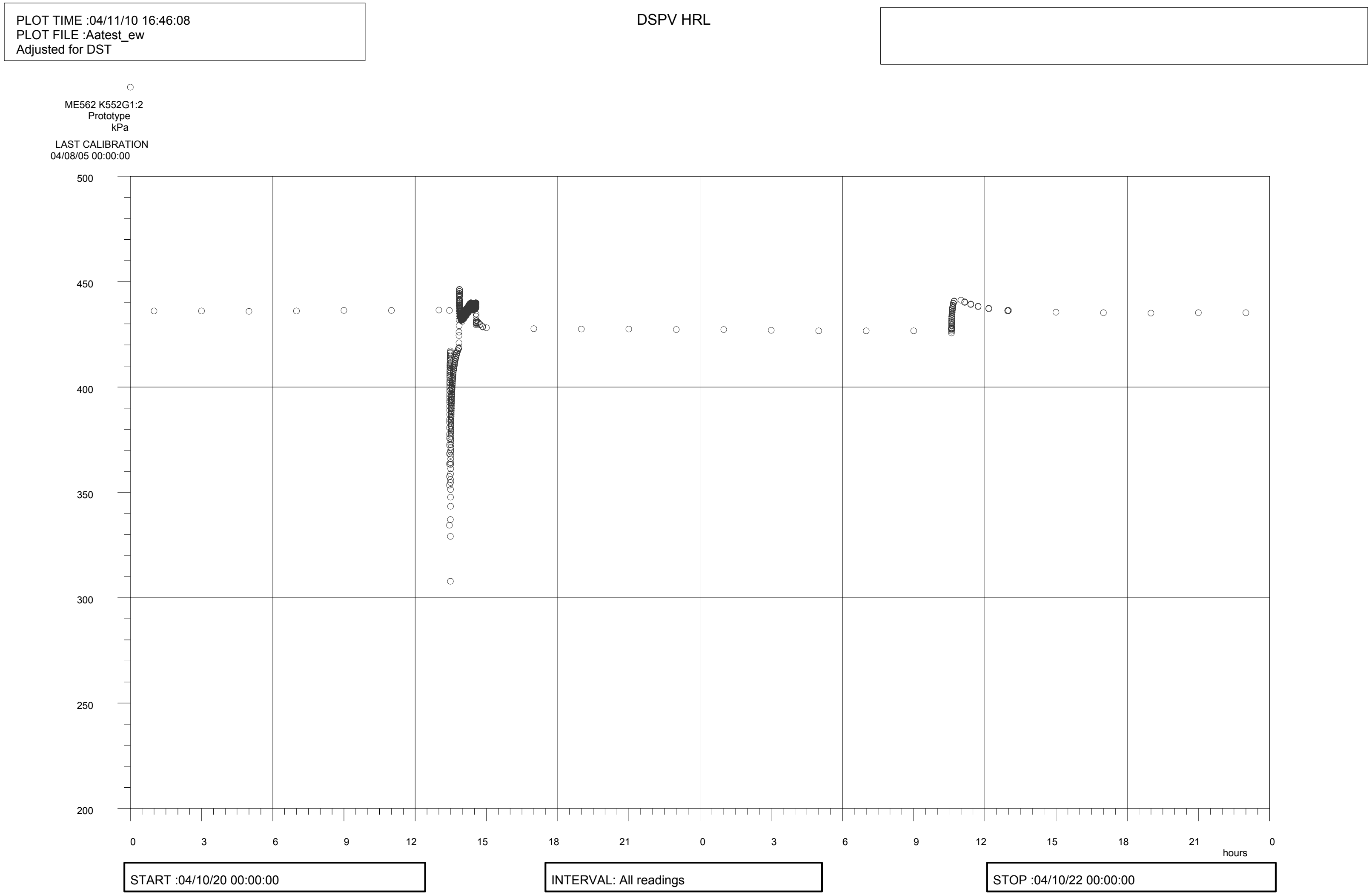
KA3546G01:2


PLOT TIME :04/11/10 16:41:02
PLOT FILE :Aatest_ew
Adjusted for DST
DSPV HRL
ME497 K548A1:3
Prototype
kPa
LAST CALIBRATION
04/08/05 00:00:00
3400
3350
3300
3250
3200
3150
3100
0 3 6 9 12 15 18 21 0 3 6 9 12 15 18 21 0
hours
START :04/10/13 00:00:00
INTERVAL: All readings
STOP :04/10/15 00:00:00

KA3548A01:3


PLOT TIME :04/11/10 16:56:36
PLOT FILE :Aatest_ew
Adjusted for DST
DSPV HRL
ME557 K550G1:2
Prototype
kPa
LAST CALIBRATION
04/08/05 00:00:00
300
250
200
150
100
50
0
0 3 6 9 12 15 18 21 0 3 6 9 12 15 18 21 0
hours
START :04/10/28 00:00:00
INTERVAL: All readings
STOP :04/10/30 00:00:00

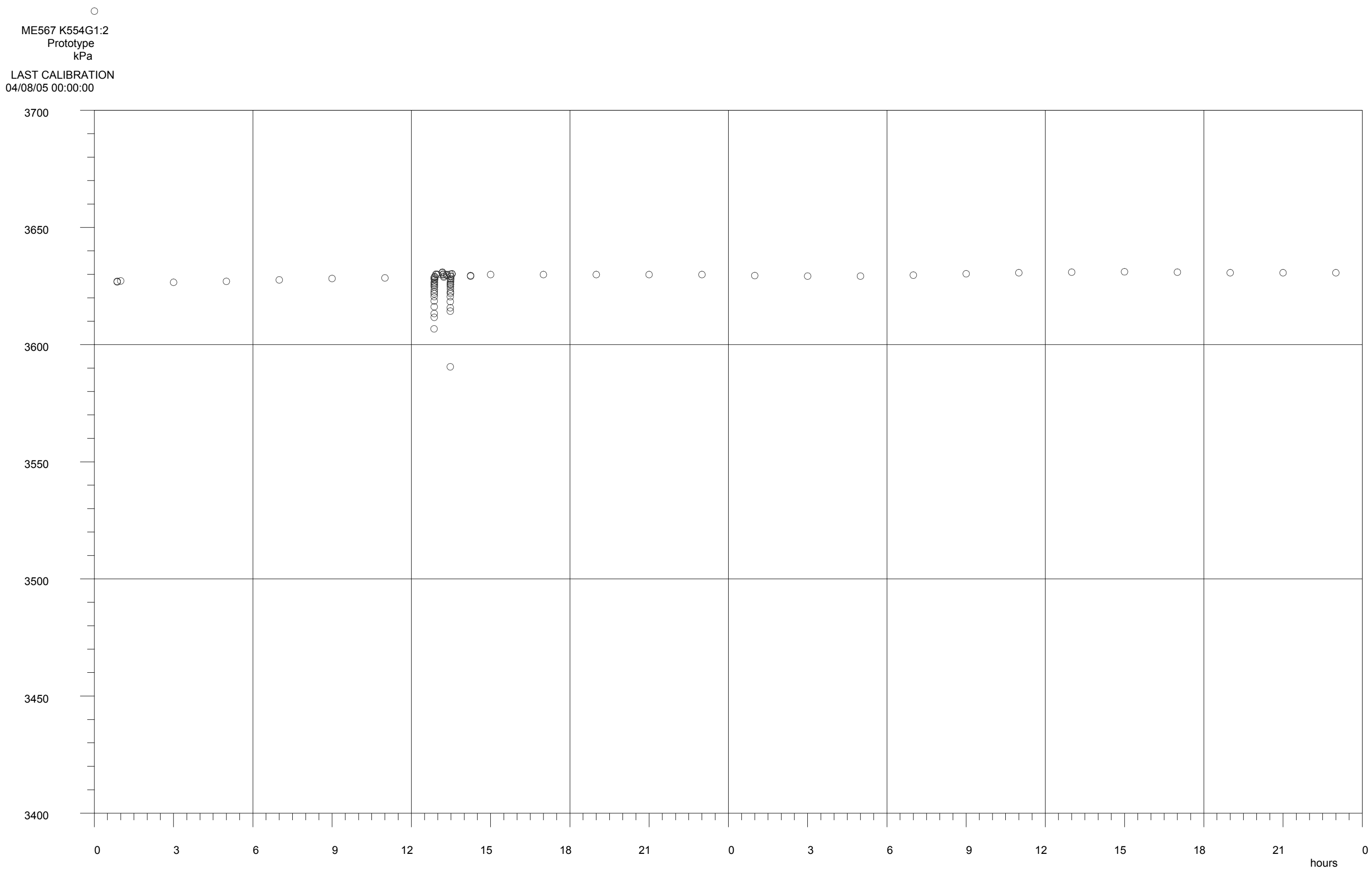
KA3550G01:2


PLOT TIME :04/11/10 16:46:08
PLOT FILE :Aatest_ew
Adjusted for DST
DSPV HRL
ME562 K552G1:2
Prototype
kPa
LAST CALIBRATION
04/08/05 00:00:00
500
450
400
350
300
250
200
0
3
6
9
12
15
18
21
0
3
6
9
12
15
18
21
0
hours
START :04/10/20 00:00:00
INTERVAL: All readings
STOP :04/10/22 00:00:00

KA3552G01:2

PLOT TIME :04/11/10 16:44:17
PLOT FILE :Aatest_ew
Adjusted for DST

DSPV HRL

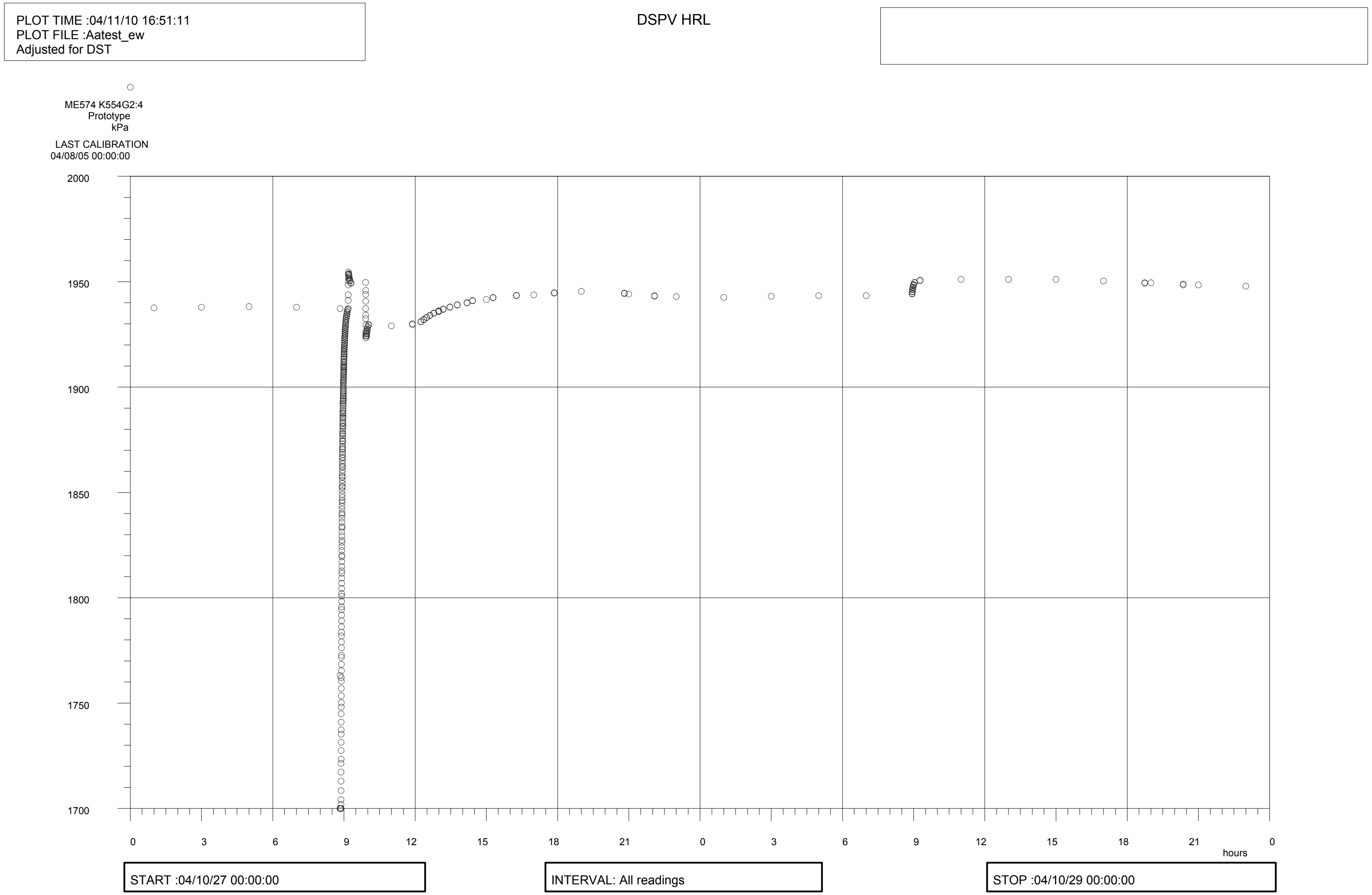


START :04/10/18 00:00:00

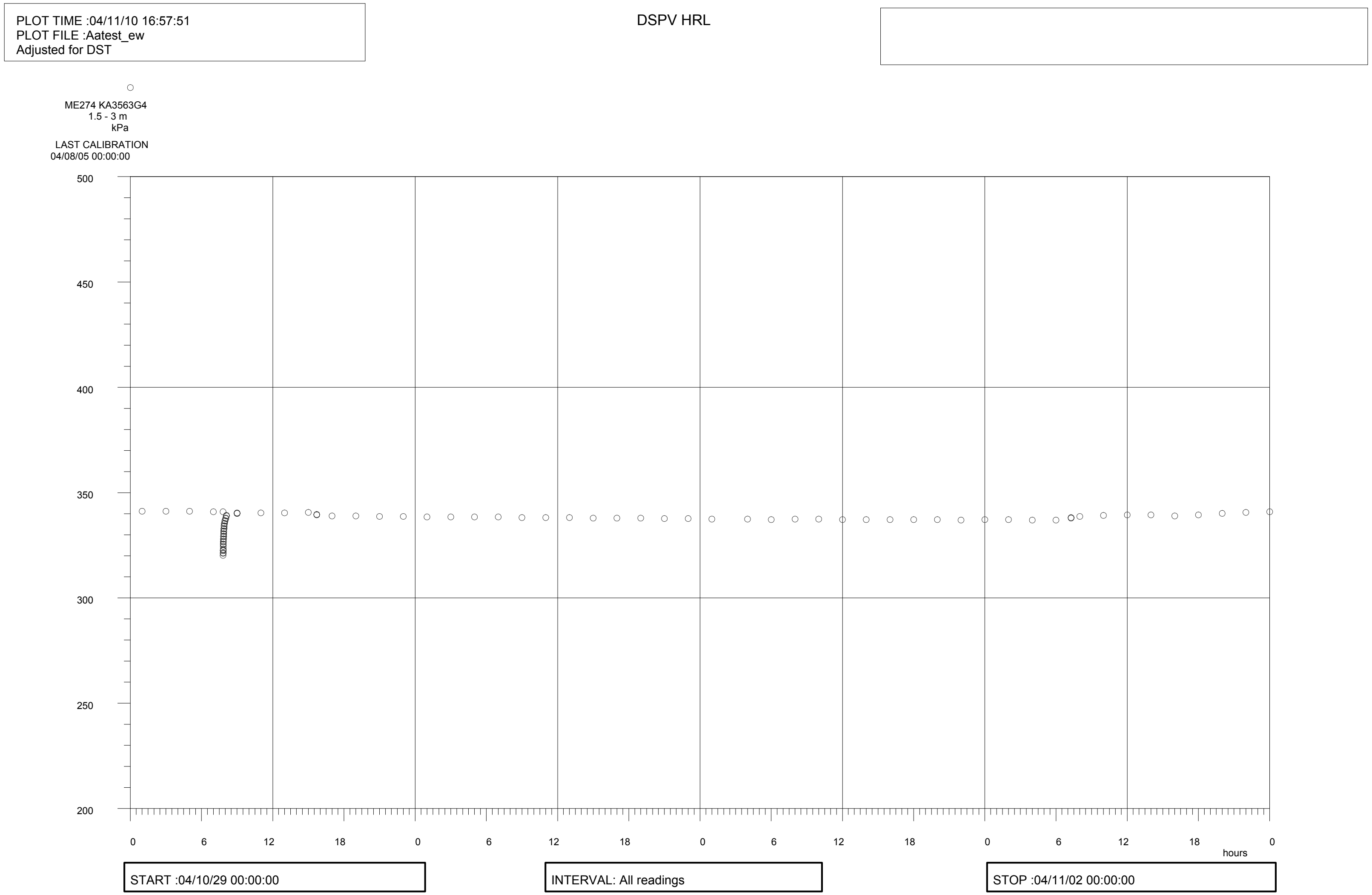
INTERVAL: All readings

STOP :04/10/20 00:00:00

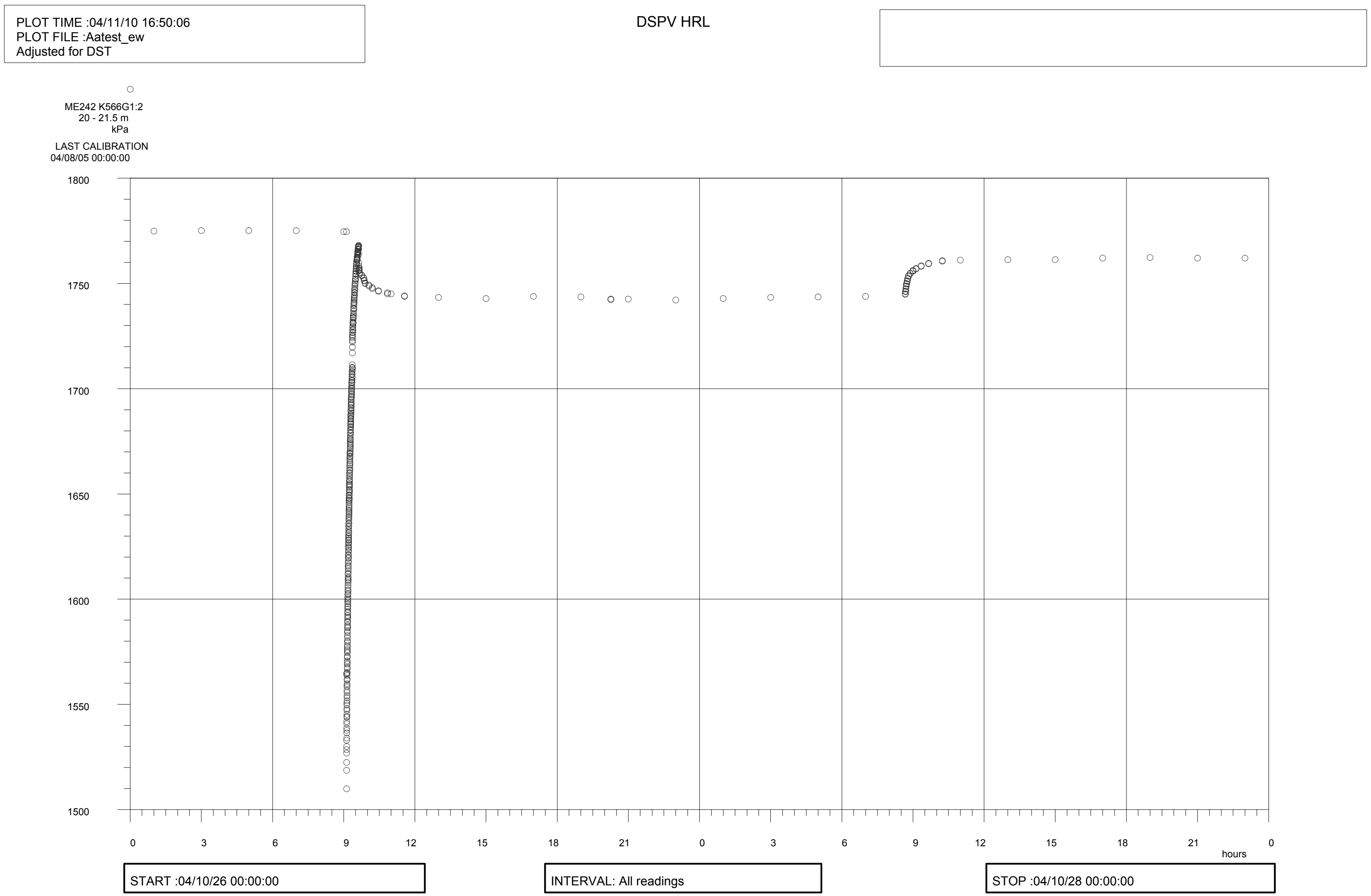
KA3554G01:2


PLOT TIME :04/11/10 16:51:11
PLOT FILE :Aatest_ew
Adjusted for DST
DSPV HRL
ME574 K554G2:4
Prototype
kPa
LAST CALIBRATION
04/08/05 00:00:00
2000
1950
1900
1850
1800
1750
1700
0 3 6 9 12 15 18 21 0 3 6 9 12 15 18 21 0
hours
START :04/10/27 00:00:00
INTERVAL: All readings
STOP :04/10/29 00:00:00

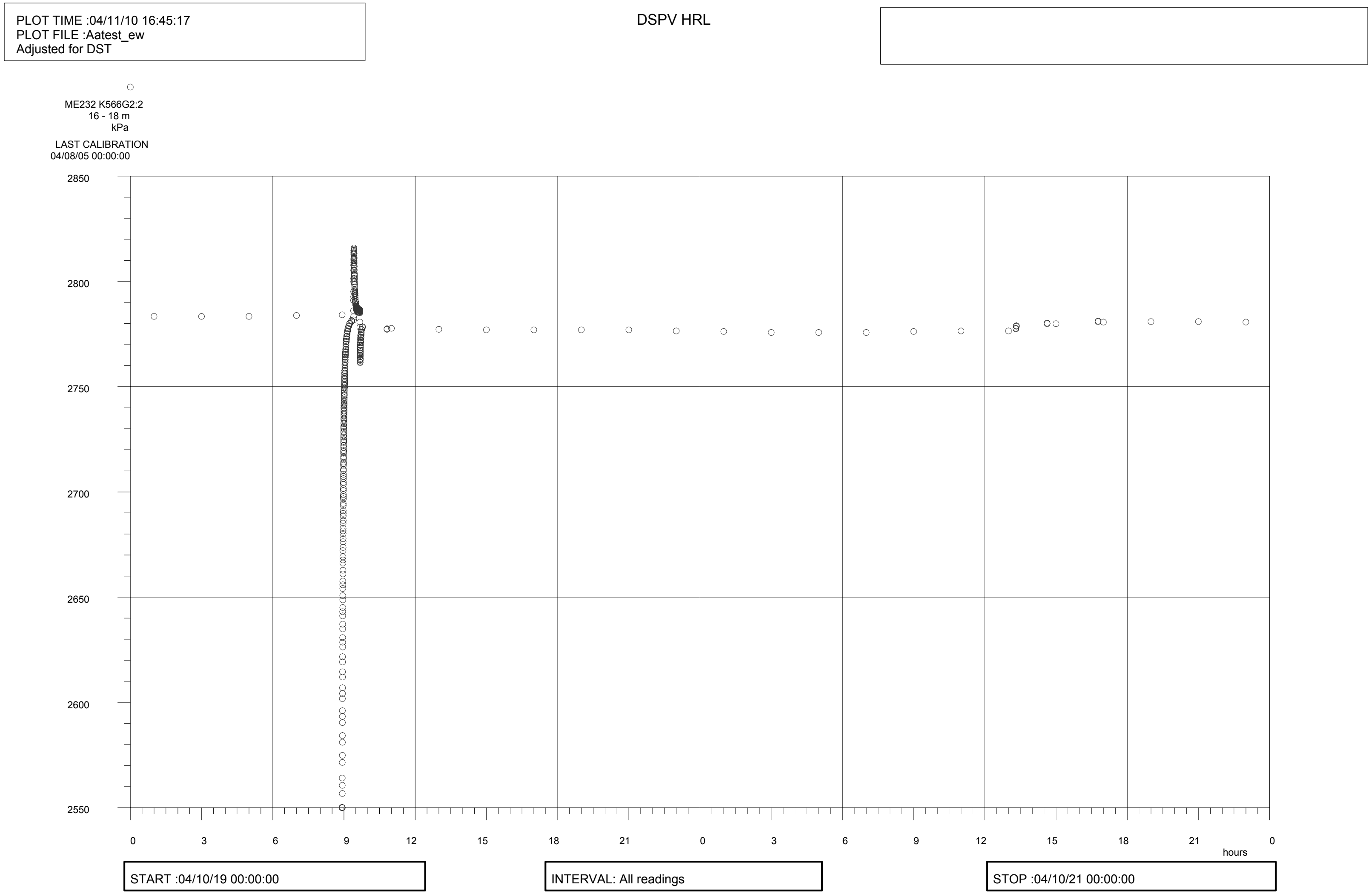
KA3554G02:4


PLOT TIME :04/11/10 16:57:51
PLOT FILE :Aatest_ew
Adjusted for DST
DSPV HRL
ME274 KA3563G4
1.5 - 3 m
kPa
LAST CALIBRATION
04/08/05 00:00:00
500
450
400
350
300
250
200
0
6
12
18
0
6
12
18
0
6
12
18
0
6
12
18
0
hours
START :04/10/29 00:00:00
INTERVAL: All readings
STOP :04/11/02 00:00:00

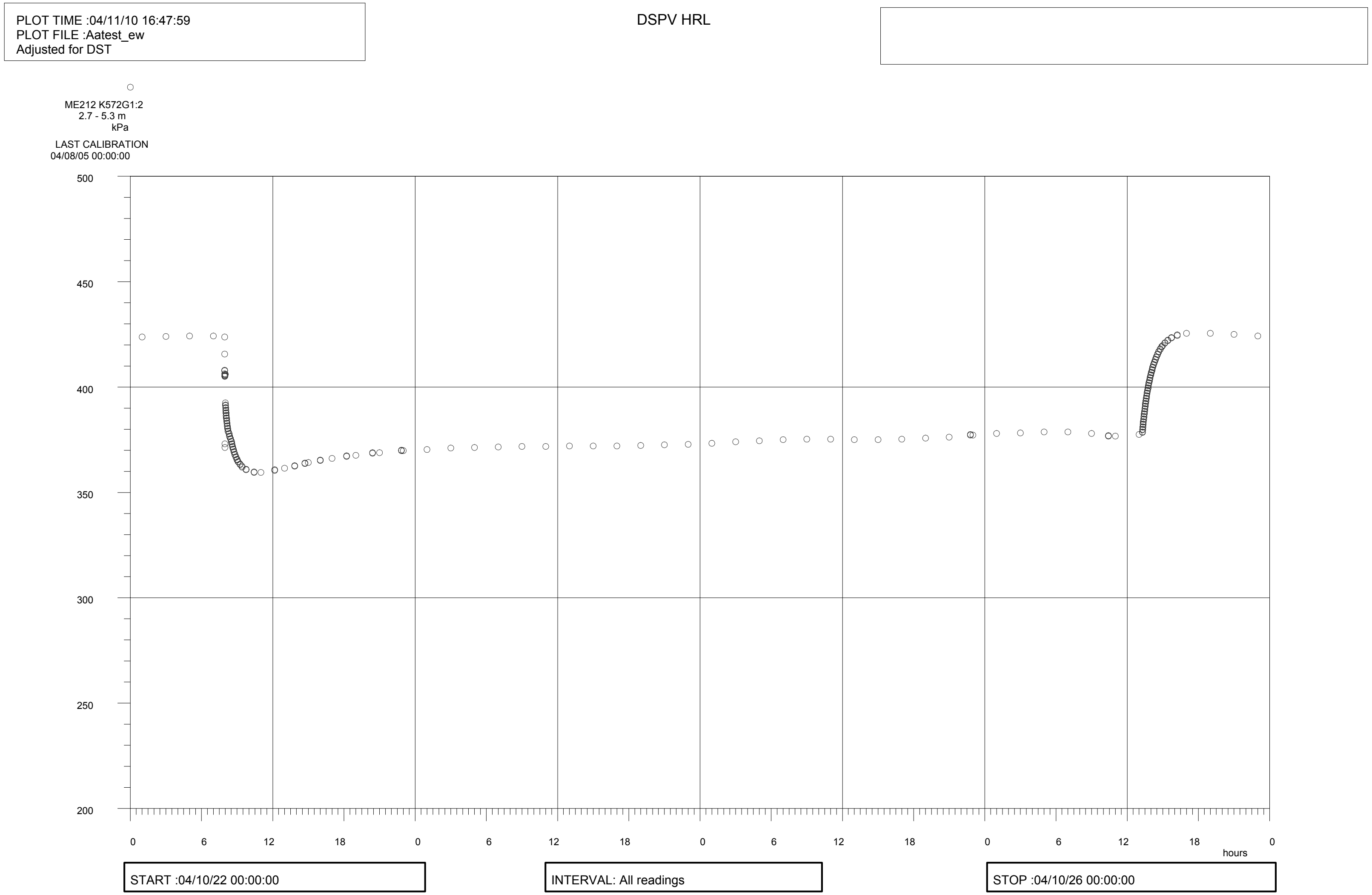
KA3563G:4


PLOT TIME :04/11/10 16:50:06
PLOT FILE :Aatest_ew
Adjusted for DST
DSPV HRL
ME242 K566G1:2
20 - 21.5 m
kPa
LAST CALIBRATION
04/08/05 00:00:00
1800
1750
1700
1650
1600
1550
1500
0 3 6 9 12 15 18 21 0 3 6 9 12 15 18 21 0
hours
START :04/10/26 00:00:00
INTERVAL: All readings
STOP :04/10/28 00:00:00

KA3566G01:1

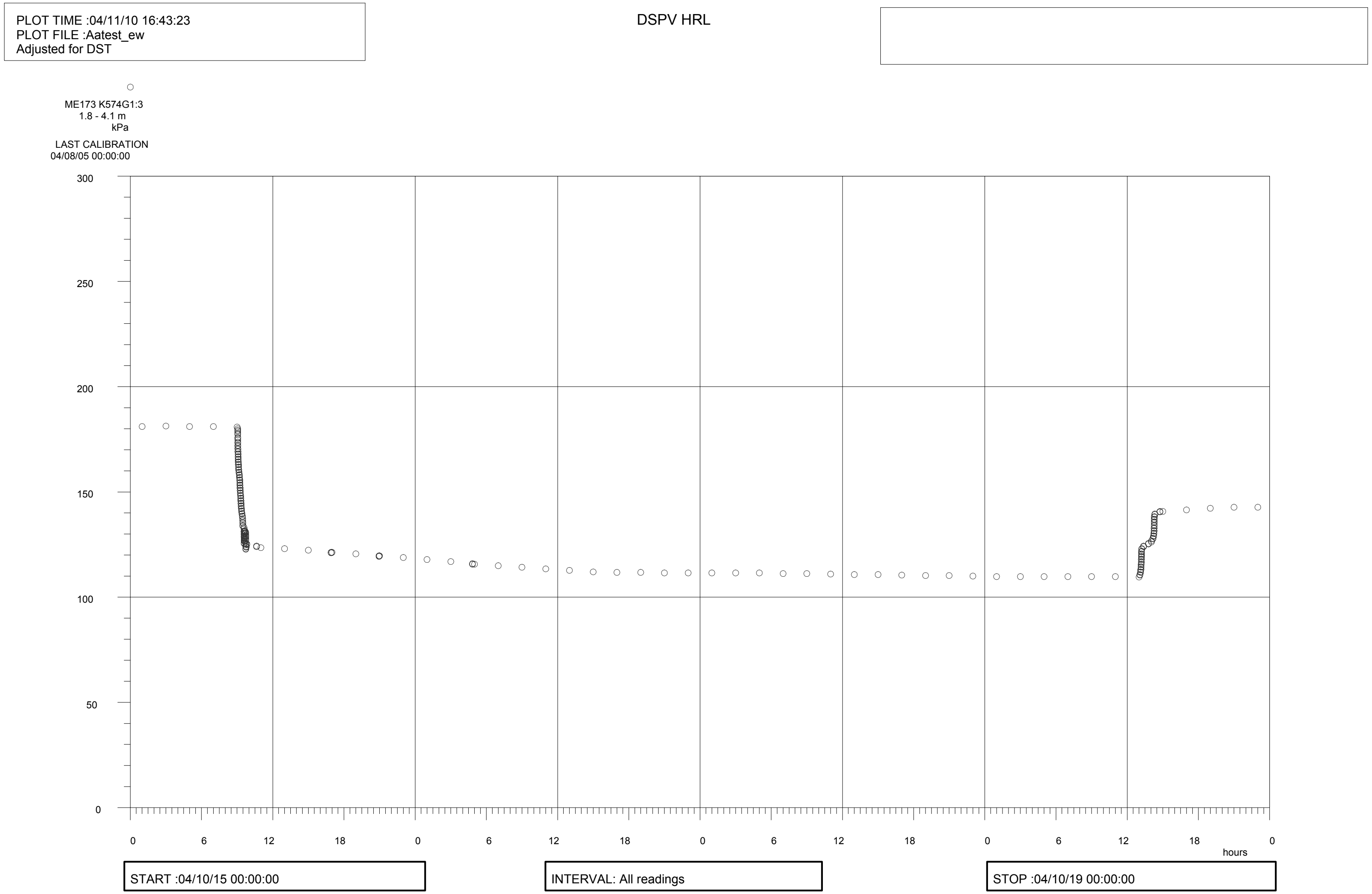

PLOT TIME :04/11/10 16:45:17
PLOT FILE :Aatest_ew
Adjusted for DST
DSPV HRL
ME232 K566G2:2
16 - 18 m
kPa
LAST CALIBRATION
04/08/05 00:00:00
2850
2800
2750
2700
2650
2600
2550
0
3
6
9
12
15
18
21
0
3
6
9
12
15
18
21
0
hours
START :04/10/19 00:00:00
INTERVAL: All readings
STOP :04/10/21 00:00:00

KA3566G02:2

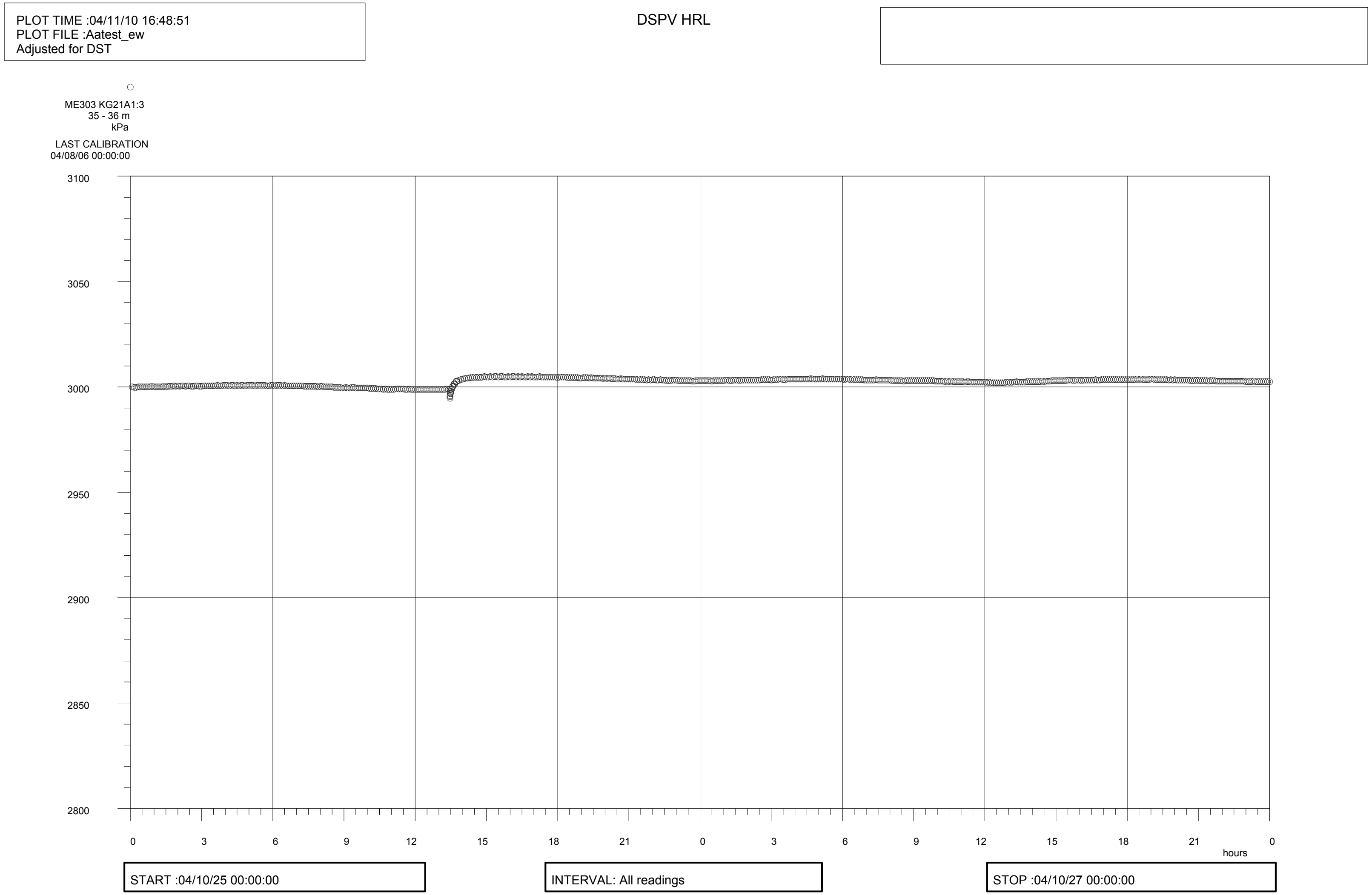


PLOT TIME :04/11/10 16:47:59
PLOT FILE :Aatest_ew
Adjusted for DST
DSPV HRL
ME212 K572G1:2
2.7 - 5.3 m
kPa
LAST CALIBRATION
04/08/05 00:00:00
500
450
400
350
300
250
200
0
6
12
18
0
6
12
18
0
6
12
18
0
6
12
18
0
hours
START :04/10/22 00:00:00
INTERVAL: All readings
STOP :04/10/26 00:00:00

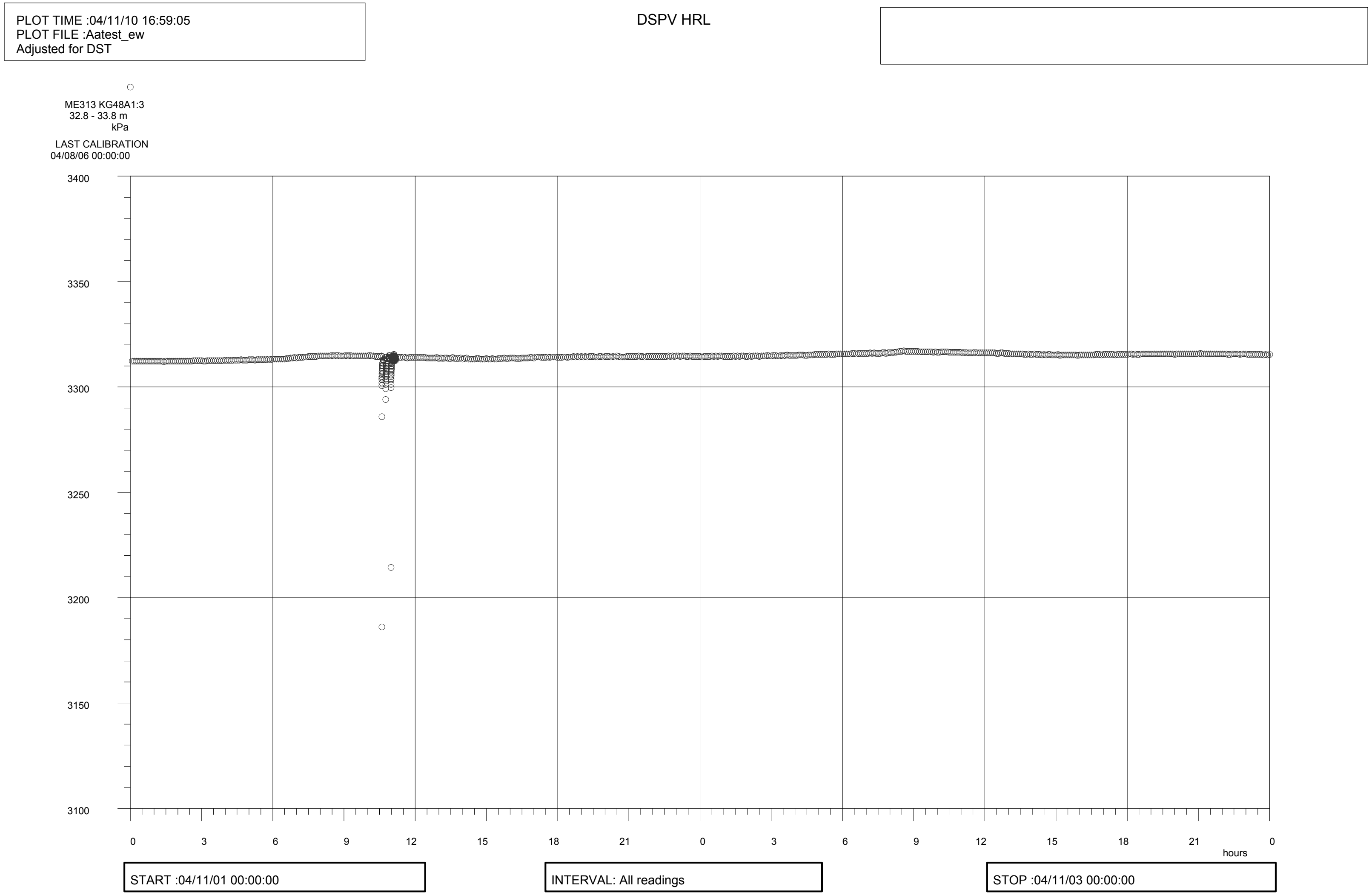
KA3574G01:3


PLOT TIME :04/11/10 16:43:23
PLOT FILE :Aatest_ew
Adjusted for DST
DSPV HRL
ME173 K574G1:3
1.8 - 4.1 m
kPa
LAST CALIBRATION
04/08/05 00:00:00
300
250
200
150
100
50
0
0
6
12
18
0
6
12
18
0
6
12
18
0
6
12
18
0
hours
START :04/10/15 00:00:00
INTERVAL: All readings
STOP :04/10/19 00:00:00

KA3574G01:3


PLOT TIME :04/11/10 16:48:51
PLOT FILE :Aatest_ew
Adjusted for DST
DSPV HRL
ME303 KG21A1:3
35 - 36 m
kPa
LAST CALIBRATION
04/08/06 00:00:00
3100
3050
3000
2950
2900
2850
2800
0
3
6
9
12
15
18
21
0
3
6
9
12
15
18
21
0
hours
START :04/10/25 00:00:00
INTERVAL: All readings
STOP :04/10/27 00:00:00

KG0021A01:3


PLOT TIME :04/11/10 16:59:05
PLOT FILE :Aatest_ew
Adjusted for DST
DSPV HRL
ME313 KG48A1:3
32.8 - 33.8 m
kPa
LAST CALIBRATION
04/08/06 00:00:00
3400
3350
3300
3250
3200
3150
3100
0 3 6 9 12 15 18 21 0 3 6 9 12 15 18 21 0
hours
START :04/11/01 00:00:00
INTERVAL: All readings
STOP :04/11/03 00:00:00

KG0048A01:3

Appendix 3

Volumes in borehole sections- and tubing.

Borehole	$V_{section}$ (dm^3)	V_{tubing} (dm^3)	V_{total} (dm^3)
KA3539G:2	5.10	2.56	7.66
KA3542G01:3	4.84	2.84	7.68
KA3542G02:2	4.48	3.01	7.49
KA3544G01:2	5.10	2.59	7.69
KA3546G01:2	4.27	2.56	6.83
KA3548A01:3	5.80	2.49	8.29
KA3550G01:2	6.55	2.50	9.05
KA3552G01:2	4.88	2.48	7.36
KA3554G01:2	4.26	2.93	7.19
KA3554G02:4	4.97	2.63	7.60
KA3563G:4	1.29	2.49	3.78
KA3566G01:2	1.29	2.79	4.08
KA3566G02:2	1.46	2.69	4.15
KA3572G01:2	1.63	2.36	3.99
KA3574G01:3	1.54	2.55	4.09
KG0021A01:3	1.17	1.35	2.52
KG0048A01:3	1.17	1.30	2.47