PUBLIC POWER CORPORATION

ATHENS, GREECE

MILOS GEOTHERMAL DEVELOPMENT

Consultants review of trial operation and reinjection until March 1, 1988

OS-88024/JHD-14B

ORKUSTOFNUN
NATIONAL ENERGY AUTHORITY

VIRKIR CONSULTING GROUP LTD.

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Report No.: OS-88024/JHD-14-B

June 1988

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1. Introduction

The consultants Mr. Sverrir Thorhallsson and Mr. Omar Sigurdsson travelled to Milos at the request of PPC in the first week of March in accordance with a contract between the Public Power Corporation of Greece (PPC) on one hand, and the Joint Venture of the Virkir Consulting Group Ltd. and the National Energy Authority of Iceland (Virkir/NEA) on the other. The purpose of the visit was to witness a falloff test in the reinjection well M-1 and to review the operating experience and the data collected on the reinjection system and the steam collection system.

The latest developments in this project were discussed with PPC representatives at the power plant site, especially with Mr. Koutroupis and Mr. Koutinas from the Alternative Energy Department and Mr. Vernikos from the Thermal Production Department. Mr. Gelegenis from the Technical University took also part in the discussion. Data on the reinjection well was supplied by Mr. Koutinas and Mr. Chlamboutakis, and on the turbine operation by Mr. Vernikos.

The following report summarizes the response of well M-1 during the first four months of the second reinjection period. The report presents the main findings from our review of the operating data for both the reinjection and the steam gathering systems.

The field report and letters written during our stay in Milos were handed to PPC representatives in the field and in Athens. A copy of the report and the letters is included in the appendix.

2. Reinjection into well M-1

The first reinjection period, was from November 23, 1986 to January 14, 1987. Reinjection into well M-1 was started for the second time on October 26, 1987 and is still in progress. During the warming-up and stabilization of the reinjection system from October 10, to the time of injection, the brine was disposed to pond M-1. Since the start of the second reinjection period, injection has only been interupted for few short periods coinciding with the three falloff tests which have been measured. On December 11, 1987 the injection was stopped for five (5) hours for falloff test, for 80 hours on January 25-28, 1988 for falloff test and modifications on the surface installation at the power plant, and for 7 hours on March 1, 1988 for falloff test. The latest test was witnessed by the Virkir/NEA consultants.

The injection rate during this second reinjection period has been between 5.6-7.0 kg/s (20.3-25.2 ton/hr). On the average the injection rate has been fairly stable around 6.3 kg/s (22.7 ton/hr), but with some fluctuation mainly during the month of February. Some of the fluctuation could be attributed to dirt in the orifice flow meter, which requires dayly attention to stay operative.

3. Measurements in well M-1

Pressure and temperature has been measured regularly by PPC in the reinjection well during this period. The temperature profiles are shown on figures 1-3 and the pressure profiles on figures 4-8 with the measurement data given in tables 1-24. The temperature profile for the well, when static, follows the boiling point curve with depth. As injection is started, the well is cooled to the bottom. The temperature profiles measured during injection indicate the existence of three fracture zones which absorb the injected brine. These zones are between 900-950 m depth, 1050-1100 m depth and at the bottom of the well at 1150 m depth. At first the fracture between 1050-1100 m depth does not accept the injected brine, but opens during the first week of injection causing less fluid to reach to the bottom of the well, which in turn warms up by about 7°C. Similar behavior was observed in the well during the first reinjection period. The static bottom hole temperature is about 320°C, but during hot injection it is about 244°C. The injection therefore causes a temperature drop of more than 75°C in the well. This temperature drop can possibly enhance the permeability near the wellbore by contraction of the rock formation.

The pressure measurements reported in this report have been corrected for temperature effects in accordance with the temperature calibration given with each pressure gauge. Two KUSTER-pressure gauges have been used for the down hole pressure measurements. The gauge KPG-29271 was used for the measurements until February 25, 1988 and also for most of the pressure measurements made during the first reinjection period. After February 25, gauge KPG-16470 has been used. The calibration for each gauge is only upto temperatures 260°C and 250°C, respectively. This is sufficient to correct the pressure for measurements made in the M-1 well during injection, but during falloff tests and in a static well the temperature becomes much higher. In last two cases the measurements are outside the calibrated range for the gauges and can therefore not be corrected for temperature. This makes the last mentioned measurements questionable and hinders conventional interpretation of the falloff tests. Furthermore, the recalibration given with gauge KPG-16470 appears to be opposite to what is usually considered the normal behavior of such gauges. Could the recalibration book marked for 150°C be the calibration at 250°C and opposite? There is also some discrepancy between the two pressure gauges which could be due to inaccurate calibration. For future use these gauges should both be recalibrated and for a higher temperature range i. e. upto 300°C.

The pressure profiles indicate that the measurements are fairly consistent. The static bottom hole pressure can, however, not be determined, since the static temperature is far outside the calibrated range for the pressure gauges. It is, however, considered to be approximately 115 bar.

It has not been possible to interpret the falloff tests made during the second reinjection period in a conventional manner. The reason is that the thermal recovery in the well has a dominating effect on the recorded pressure change about 15 minuts after the well is shut in. Furthermore, the temperature in the well has by then become higher than the calibrated range for the pressure gauges so the pressure data can not be corrected for the temperature effect of the gauges. However, a qualitative interpretation of the falloff tests indicates a similar behavior as during the first reinjection period and that the permeability thickness product and the skin factor are quantitatively about the same as was obtained during that period. When the pressure gauges have been calibrated to higher temperatures, the falloff test data obtained so far can be corrected for temperature effects and a conventional interpretation on the data attemped.

4. Response of well M-1 to reinjection

The response of well M-1 to the reinjection as measured at three different depths is shown on figures 9-11. The different fluctuation observed in the measurements at different depths after reinjection is started on October 26, 1987 is indicative of the error involved in reading the charts from the pressure gauges. This error is of the order of 1 bar. The quenching period for the well ended about 3 weeks after reinjection started or around November 19, 1987. After that time the pressure has been increasing in the well. The pressure increase up to March 1, 1988 is in the range 2.0-2.5 bar. At the same time the injection rate has in general increased about 0.6 kg/s (2.2 ton/hr) from 6.0 kg/s (21.6 ton/hr) to 6.6 kg/s (23.8 ton/hr).

Overall the M-1 well has responded favorably to the injection. Indications are that near well transmissivity is improved during the quenching period, by opening of fractures. Opening of fractures and fracture growth due to pressure increase and cooling of the reservoir formation is advantageous for the reinjection. There is a limit to for how long this positive process overrides the eventual negative effects of scaling and particle plugging from suspended solids. To rectify the latter problem, the well has to be cleaned or replaced. With present day knowledge it is, however, impossible to predict the lifetime of the M-1 well or the time until it needs to be cleaned with any accuracy. The experience of continued reinjection into M-1 well will put certain limits on the longevity of the well, but to get an impression of how the future response could be we will look at three examples.

The pressure profiles measured in M-1 well indicate that the liquid level in the well is near the wellhead or approximately at 20-25 m depth. Furthermore, the high pressure reinjection pumps can deliver a pressure of about 30 bar at the wellhead, but the current wellhead pressure is about 16 bar. The allowable pressure increase in the well is thus 16 bar. First one can smooth the available pressure data from the well, regarding variance in injection rate and reading errors from the pressure gauge charts. Then for the first example the smoothed data can be fitted with a given model as has been done in figure 12. The model chosen here is an analytical one for propagating thermal front into a porous media. A good fit is obtained between the smoothed data and the model with the reservoir parameters given in the figure. The model implies that the cooled region around the well, due to the injection, extents 5.6 m into the formation. The inferred permeability thickness product is similar to that obtained during the first short term reinjection test in April 1985, but is about four times lower than has been inferred from later falloff tests. The skin factor is slightly lower than earlier tests have indicated. One should not take the numerical values implied by the model too seriously, because they are highly model dependent and will change, if some given different model is used. This model develops a straight line on semi-log graph and when extrapolated gives an additional pressure increase of about 3 bar over the next 5 years (figure 13). If the weight on the last measured data point around March 1, 1988 is lowered, the model gives pressure increase of about 5 bar over the next 5 years. This can be considered as the most optimistic future development of the well.

For the second example one can assume a more realistic situation. The same analytical model is used as in the earlier example, but the skin factor is increased in steps which would account for scaling and particle plugging in the near well formation. The actual time and magnitude of those changes will, however, be different from what is assumed here. Here the skin factor is increased from -5.1 to -4 after half year of injection, to -3.0 after 1 year, to -2.0 after 2 years and to -1.0 after 3 years. This gives a pressure increase of 10 bar or more over the next 5 years.

Finally for the third example one can take the conservative view and assume a linear pressure increase in the well during the first 127 days of the present injection period. Assuming a similar behavior of the well in the future, a pressure increase of 16 bar will occur in about 2.5 years.

From these examples and on the premise that the quality of the reinjected brine will not get worse in the future one can expect that the lifetime for M-1 reinjection well will be be in the range 2 to 5 years. A longer injection history well reveal more information regarding this and narrow down this estimate.

5. Operating Experience

The second objective of the mission was to review the operating experience of the power plant at Milos. The last mission of a Virkir/NEA expert to Milos took place one and a half years ago, at the time of the first reinjection falloff test in November 1986. During the three days spent on Milos, we heard Mr. Koutroupis, and the plant manager Mr. Vernikos describe the experience to date. We focused on items covered by our contract, namely the reinjection system, and also the steam gathering system which was added in the last supplement to our contract. We also had for the first time the opportunity to witness the plant in full operation.

The wells and plant have been in intermittent operation since the construction was completed late 1986. The following list shows the dates of operation and of cleaning the 2 MW unit on Milos:

6/12 - 18/12 1986	Preliminary tests of turbine. Protective devices tests etc.
18/12 - 9/1 1987	Semi-commercial operation for 22 days. Operation was stopped due to turbine scaling.
12/1 - 15/1	Cleaning of turbine. Photographs were taken by PPC. They show white scaling products in the inlet nozzles, and black corrosion products in other parts of the turbine.

10/1 - 16/9	Turbine not in use.
16/9 - 12/10	Turbine operated for 26 days.
12/10 - 19/10	Turbine cleaned for the second time. Photographs taken by PPC show severe pitting of the first three stages and scaling build-up, the same as before.
20/10 - 21/11	Turbine operated for 32 days.
21/11 - 24/11	Turbine cleaned for the third time. Turbine performance tests were scheduled at this time, but cancelled after it was found that the steam chest pressure was greater than 7.3 bar g.
24/11 - 9/12	Turbine operated for 15 days.
9/12 - 11/12	Turbine washed for the first time, for 30 minutes and 20 minutes at a time by injecting water directly into the steam pipeline leading to the turbine.
11/12 - 19/1 1988	The turbine continued to operate, 56 days in all.
19/1 - 7/2	The turbine was stopped for modifications. Modifications were made by installing a wire mesh mist eliminator in the H.P. steam separator, and spray nozzles in the moisture separator. The turbine was not cleaned at this time.
7/2 - 11/2	Turbine balance, alignment, vibration ajustment and washing of turbine.
12/2 - 1/3	Turbine operated with spraying water admitted to the moisture separator.

The reason for these stoppages were described as well as the improvements and modifications that Mitsubishi has made. The subjects of scaling, cleaning of scales, and maintenance of the reinjection system, separators and turbine were discussed and excellent photographs taken by Mr. Vernikos vand PPC operator Mr. Zanetis proved of great help in describing these problems. After our return to Iceland Virkir/NEA received a letter from PPC outlining the main problems, as they had been described to us. We had, however, during our stay no first hand opportunities to collect data or to make inspections of our own.

In the opinion of Virkir/NEA two main problems still remain:

1. Scaling is a serious problem in the pipes, separators and pumps all the way from the wellhead of the production well M-2 through to the reinjection pipeline approximately half-way to the reinjection well M-1. This scaling has caused serious problems during the short periods the plant has operated to date, such as:

   - The pipes from the M-2 wellhead to the HP separator plug.
   - The level sensor in the hot water collecting tank sticks.
   - The high pressure reinjection pumps have to be opened for cleaning every 20-30 days.
   - The control valve on the reinjection pipeline has to be cleaned at approx 20 day intervals.
   - The taps of the orifice flow meter on the reinjection pipeline have to be reamed out every day.
   - The gate valves are not tight, difficult to operate and stick at times.
   - Scaling is accumulating inside the pipes, and they will in time increase the pressure drop and finally plug the reinjection pipeline.

2. The second problem has to do with the steam purity and steam quality. Mitsubishi has made improvements in the steam system by installing mist eliminators as Virkir/NEA recommended a long time ago to improve the steam purity. Spraying has also been added to the mist eliminator in the LP separator and corrugated plates installed in the moisture separator. These modifications have improved the steam purity, but further operation of the turbine is required to confirm that the steam is clean enough, and that the quality of the steam is within the specified limits of 99.9%.

   The measurement of steam purity and quality is complicated and samples have to be taken from several locations to insure a representative sample. These measurements have now been made even more complicated because of the spraying with condensate and suspected carry-over of water to the turbine. The following example describes this.

   Mr. Koutroupis showed us a tap on the lower side of the steam pipe feeding the turbine. By partly opening this valve a constant stream of water was observed. The water flow was measured to be 30 l/hr, and a sample of it collected by Virkir/NEA showed the chloride concentration to be 12.60 ppm and sodium 6.15 ppm. This is in sharp contradiction to the reported steam purity and quality. This carry over will travel to the turbine and bypasses the isokinetic probes used for steam sampling. This may in part explain the relatively rapid scaling rate of the turbine in spite of the low chloride concentration reported (appr. 1 ppm) for the steam.

   Once spraying is started the chemical method (chloride, silica, TDS) can no longer be used to measure the steam quality, although it is still applicable for the steam purity measurements. For this reason Virkir/NEA has provided PPC with information on how to measure steam quality with a "flowing calorimeter" and the relevant standard method. It is safe to say that no one method can be used to determine whether the steam quality and purity is sufficient for long and trouble free operation of a turbine. Measurements of increases in steam chest pressures, and visual inspection of the turbine on two occasions has shown scaling in the inlet nozzle, and also considerable blade damage due to corrosion and erosion.

Virkir/NEA has received additional material from PPC, reports and recommendations of MHI after our return to Iceland. Direct replies to these reports either have been or will be given to PPC separately, as they are outside the scope of this report which is to present the final findings of observations made during the trip to Milos in early March and to support the recommendations given to PPC at that time in our field report (see appendix).

6. Summary and recommendations

The pressure gauges used for downhole pressure measurements in the reinjection well M-1 should be recalibrated for temperatures up to 300°C. This will give a check on the current calibration for the gauges and enable temperature correction for the falloff tests so they could possibly be interpreted.

The response of well M-1 to the brine reinjection indicates that the operating time for the well will be 2 to 5 years until major cleaning of the well is needed.

During the next months of continued reinjection, downhole temperature and pressure should be measured in M-1 well once a month.

As a part of regular monitoring program for the geothermal field, downhole temperature and pressure profiles should be measured in the production well M-2 twice a year. For other stand-by or observation wells in the field downhole temperature and pressure should be measured once a year.

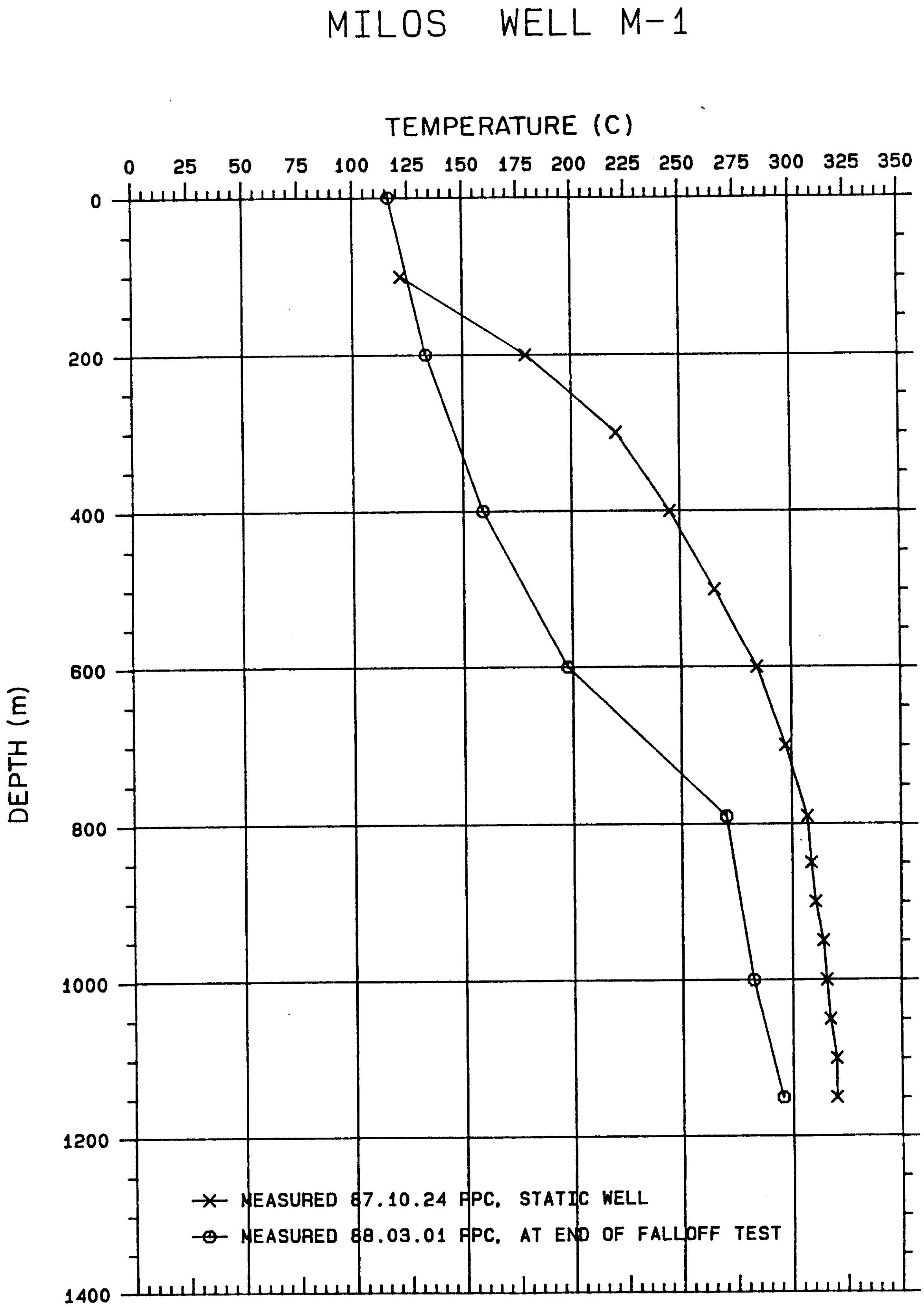
It is considered advantageous to relocate the brine flow metering at the orifice meter set-up close to the reinjection well and take up the use of a fluid sealed differential pressure indicator.

It is recommended that attention be further focused on ensuring better steam quality. Observations made by the Virkir/NEA Consultants in the field do not agree with the reported average values of less than 1 ppm chloride. The rapid scaling of the turbine experienced in operation throws further doubt on the reported steam quality. Turbine washing is not considered a viable alternative to good steam quality. It is further recommended that a sodium (Na) analysis be adopted in preference to the chloride technique currently used, for reasons of greater simplicity.

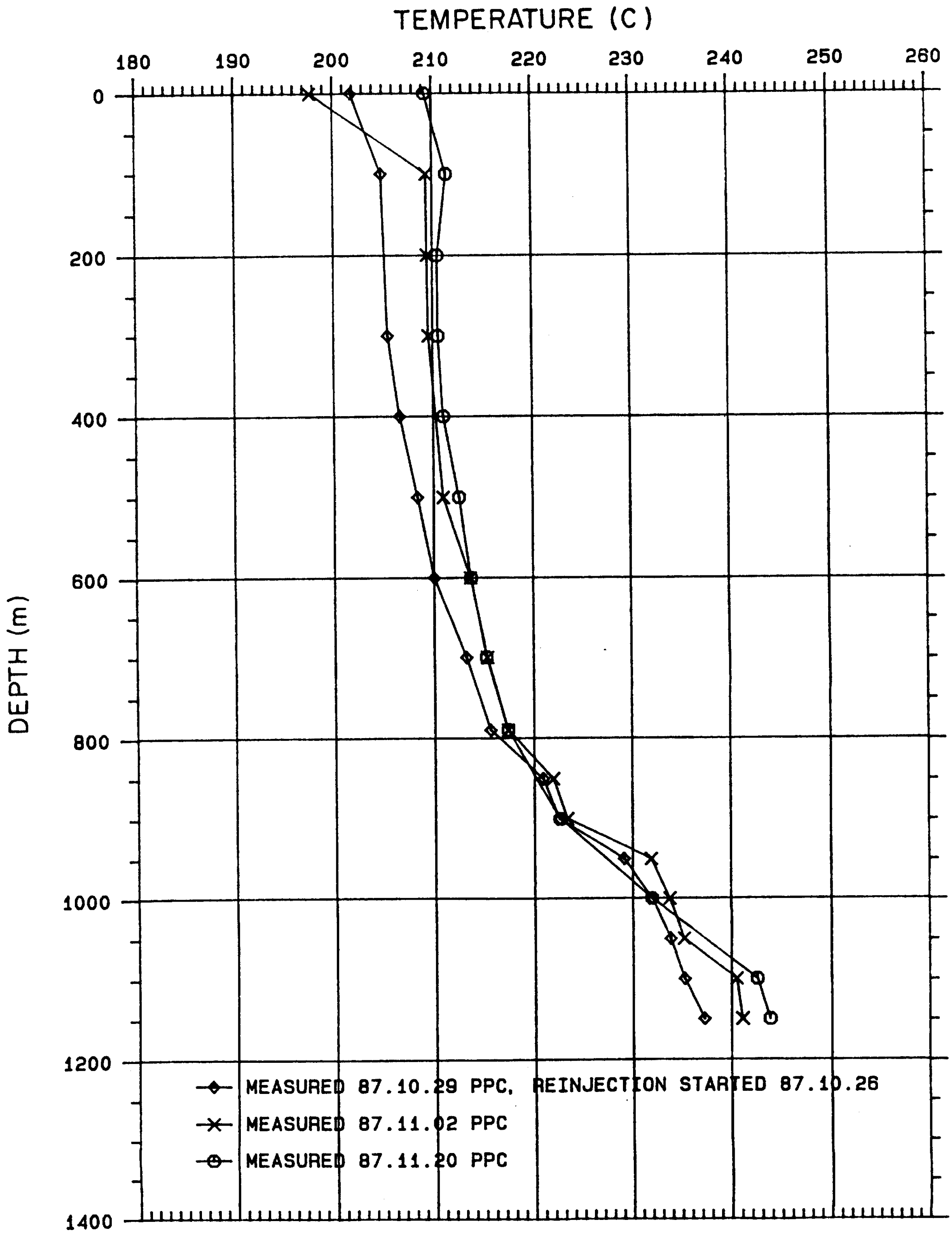
The recommendation to redisign the pipeline between the production well and the HP separator is reiterated.

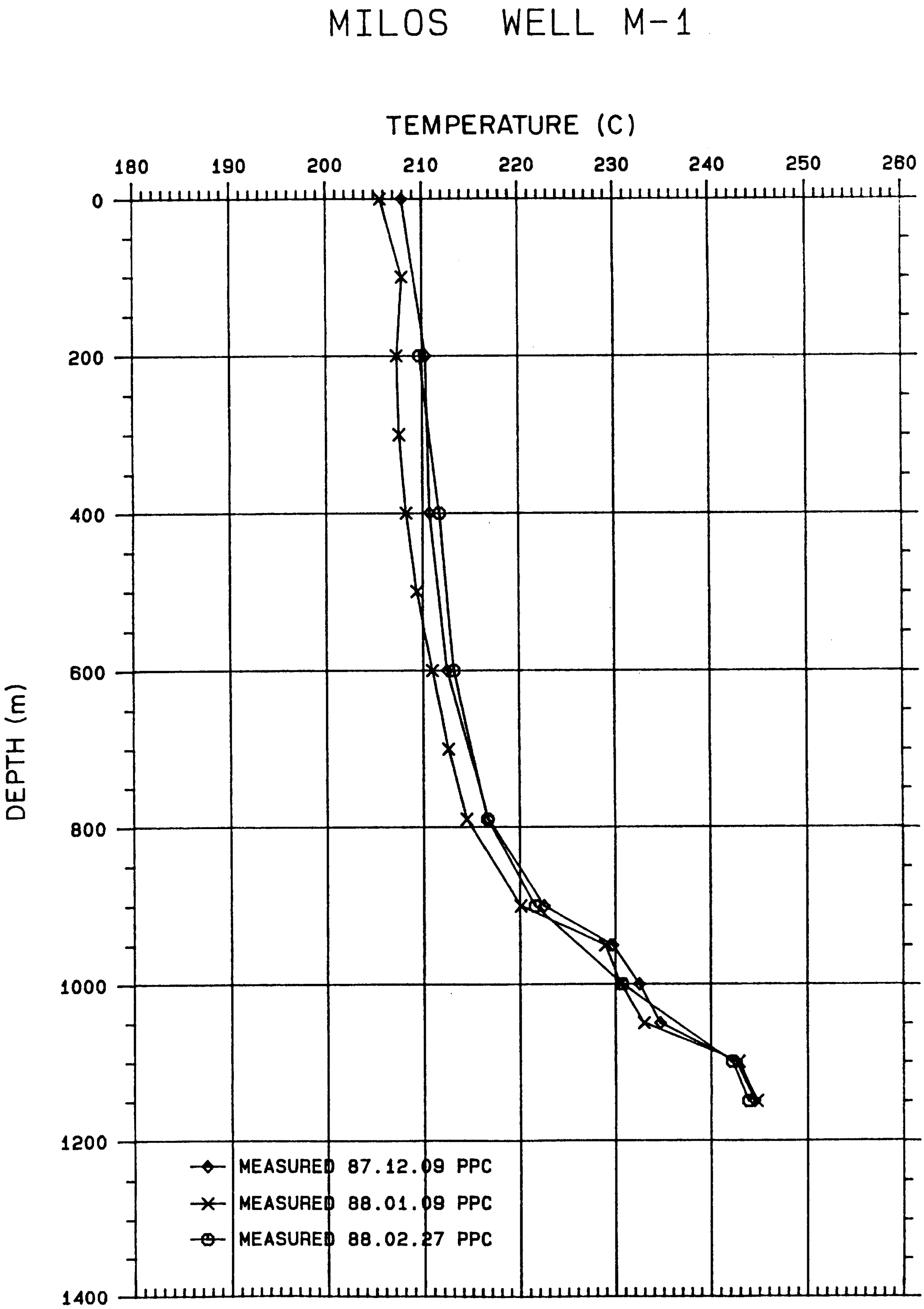
It is recommended that the PPC measure on a regular basis the scaling rate in the first 200 m of reinjection pipeline with a view to improving the situation, which currently does not satisfy normal criteria for a safe plant operation. Measures for improvement such as increased brine retention time, periodic acid washing merit investigation.

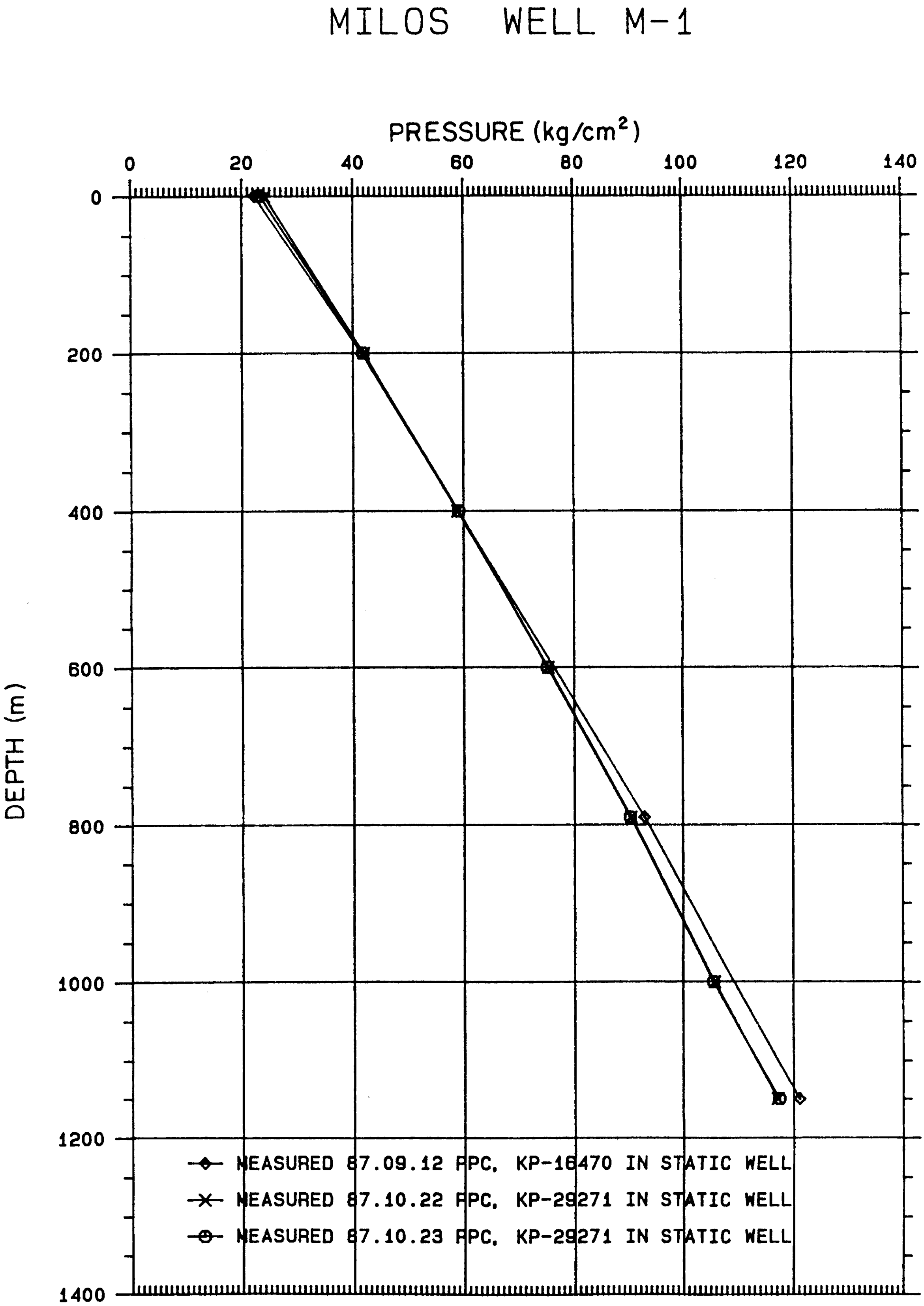
It is stressed here that Virkir/NEA does not consider the plant in an acceptable operational condition as matters currently stand and again recommends a review meeting to discuss status and likely measures.

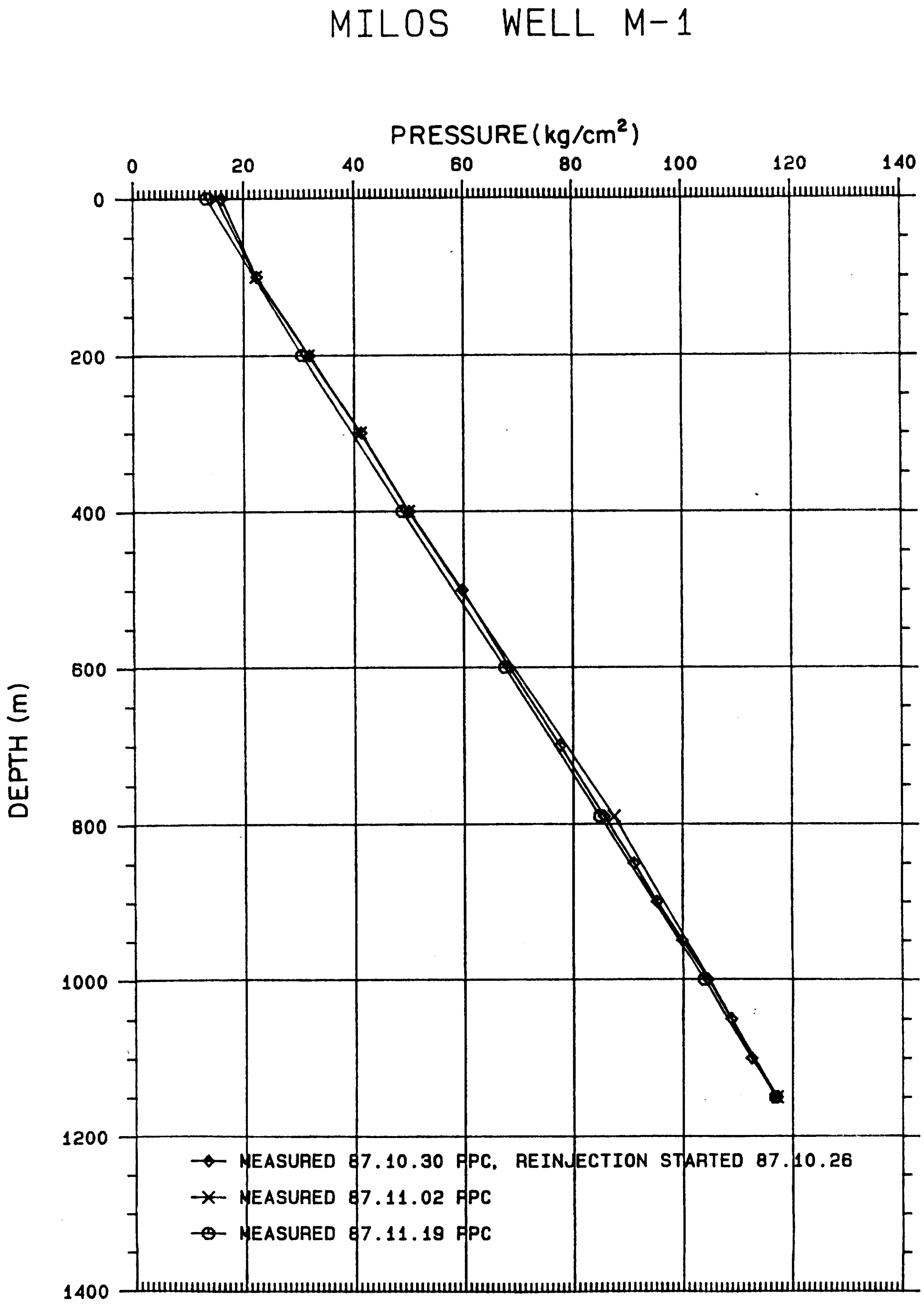

MILOS WELL M-1
TEMPERATURE (C)
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
DEPTH (m)
0
200
400
600
800
1000
1200
1400
MEASURED 87.10.24 PPC, STATIC WELL
MEASURED 88.03.01 PPC, AT END OF FALLOFF TEST

MILOS WELL M-1

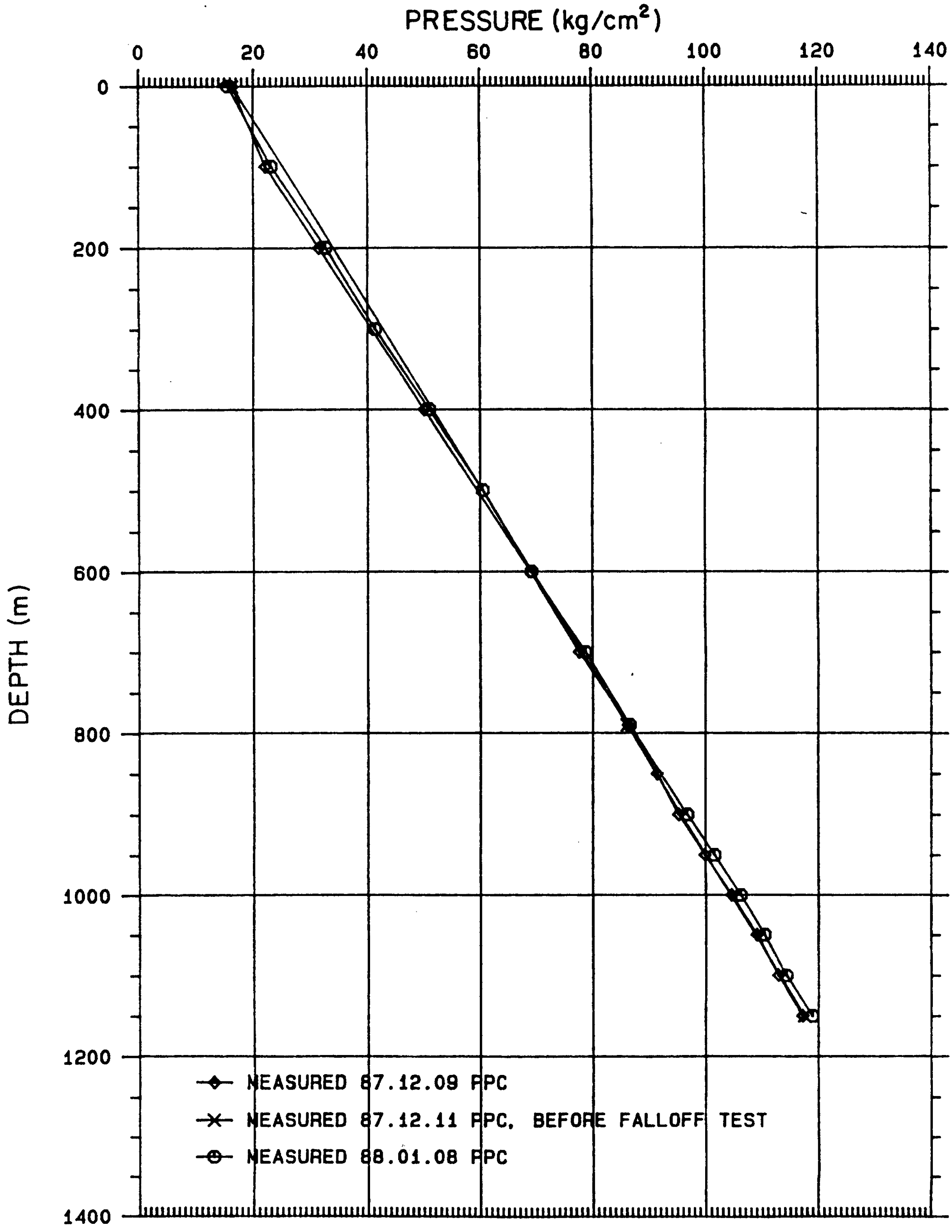


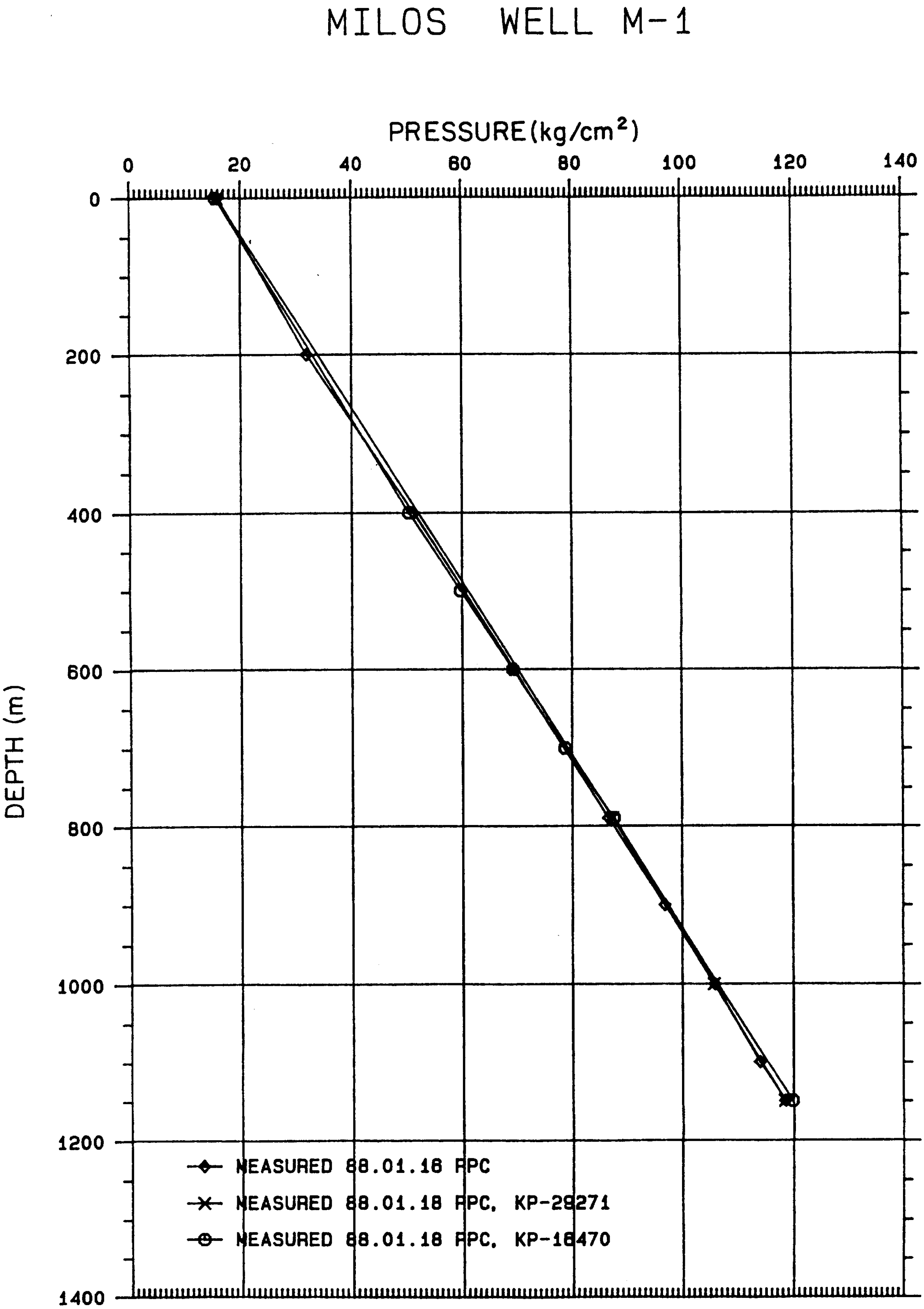

MILOS WELL M-1
TEMPERATURE (C)
180
190
200
210
220
230
240
250
260
DEPTH (m)
0
200
400
600
800
1000
1200
1400
MEASURED 87.12.09 PPC
MEASURED 88.01.09 PPC
MEASURED 88.02.27 PPC

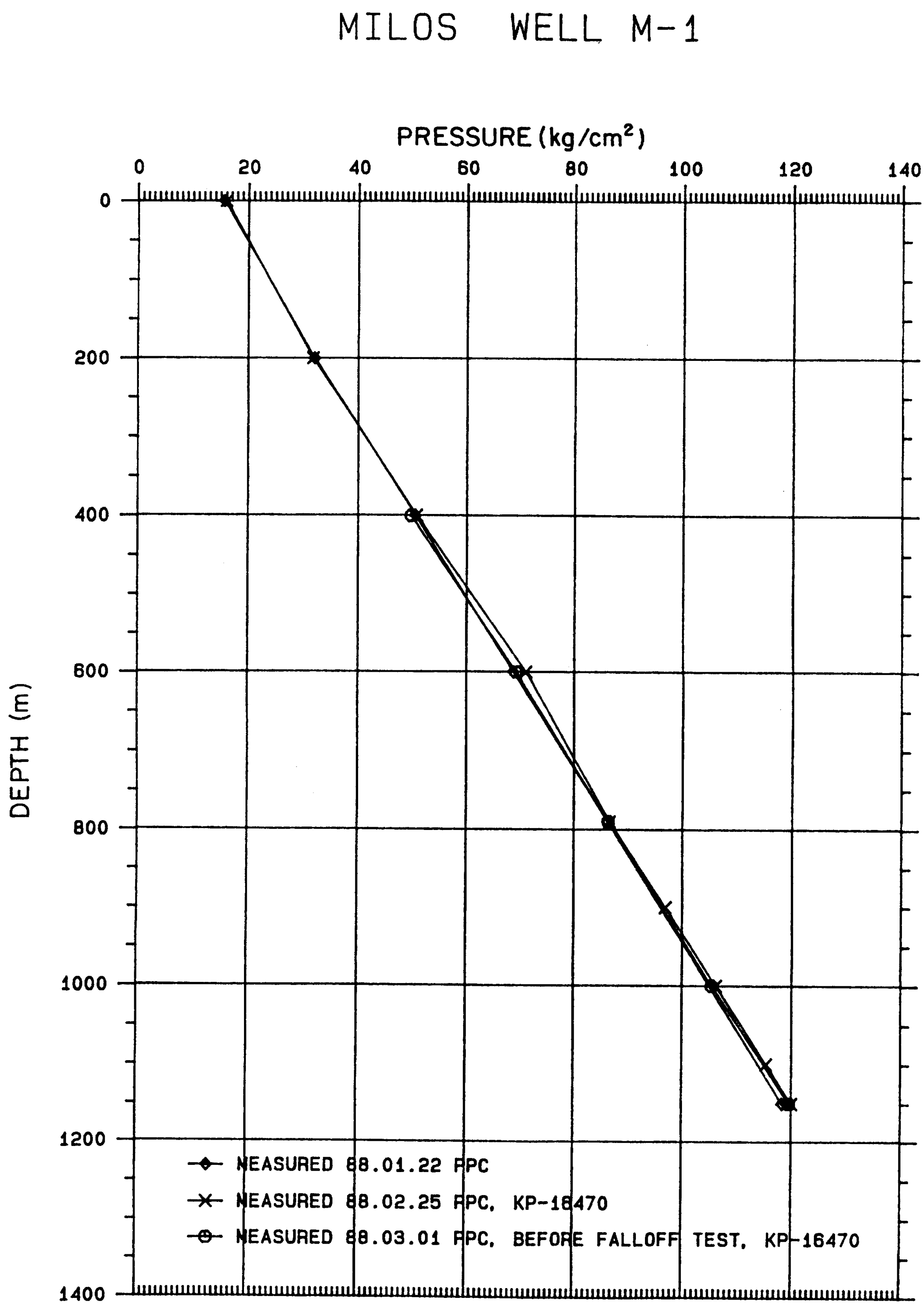

MILOS WELL M-1
PRESSURE (kg/cm²)
0
20
40
60
80
100
120
140
DEPTH (m)
0
200
400
600
800
1000
1200
1400
MEASURED 87.09.12 FPC, KP-16470 IN STATIC WELL
MEASURED 87.10.22 FPC, KP-29271 IN STATIC WELL
MEASURED 87.10.23 FPC, KP-29271 IN STATIC WELL


MILOS WELL M-1
PRESSURE(kg/cm²)
0
20
40
60
80
100
120
140
0
200
400
600
800
1000
1200
1400
DEPTH (m)
MEASURED 87.10.30 PPC, REINJECTION STARTED 87.10.26
MEASURED 87.11.02 PPC
MEASURED 87.11.19 PPC

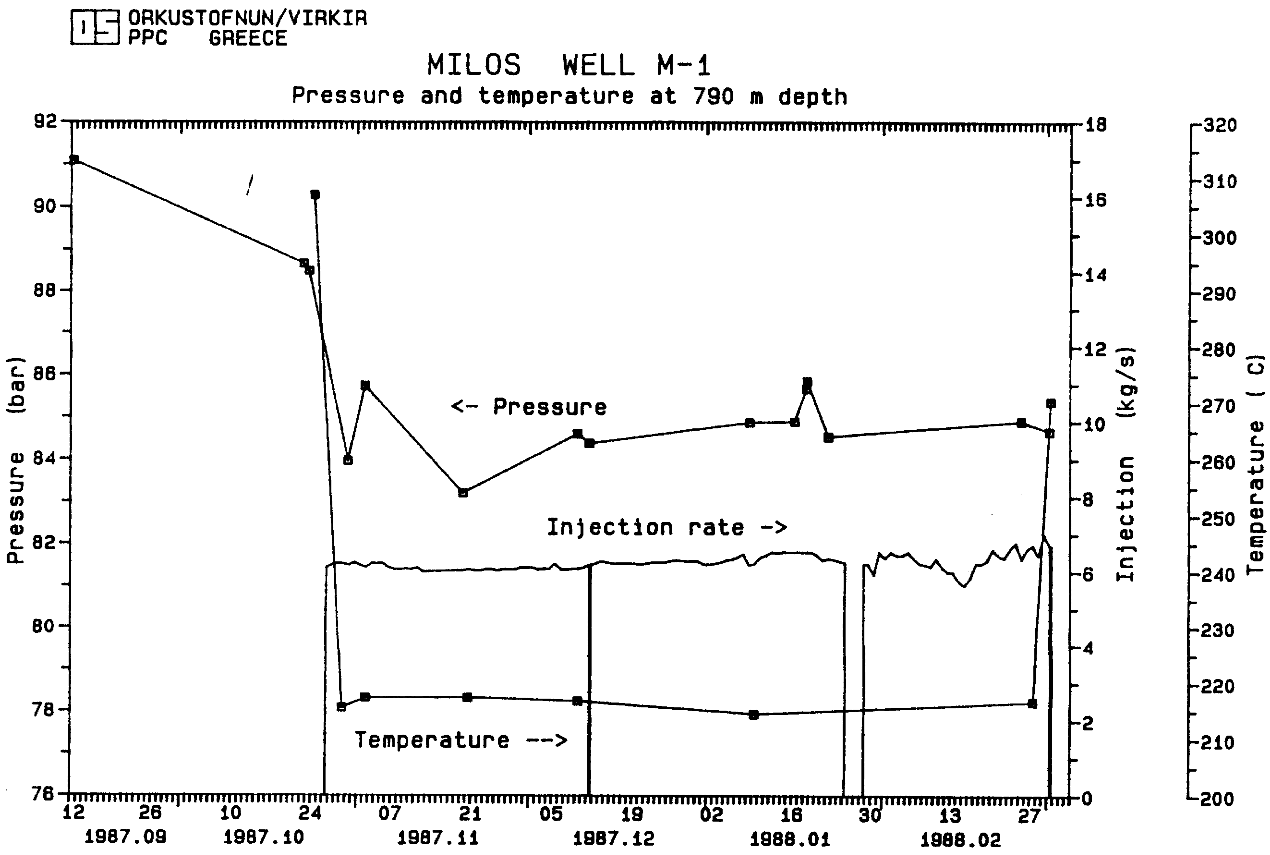
MILOS WELL M-1




MILOS WELL M-1
PRESSURE(kg/cm²)
0
20
40
60
80
100
120
140
DEPTH (m)
0
200
400
600
800
1000
1200
1400
MEASURED 88.01.18 PPC
MEASURED 88.01.18 PPC, KP-29271
MEASURED 88.01.18 PPC, KP-16470



MILOS WELL M-1
PRESSURE (kg/cm²)
0
20
40
60
80
100
120
140
DEPTH (m)
0
200
400
600
800
1000
1200
1400
MEASURED 88.01.22 FPC
MEASURED 88.02.25 FPC, KP-16470
MEASURED 88.03.01 FPC, BEFORE FALLOFF TEST, KP-16470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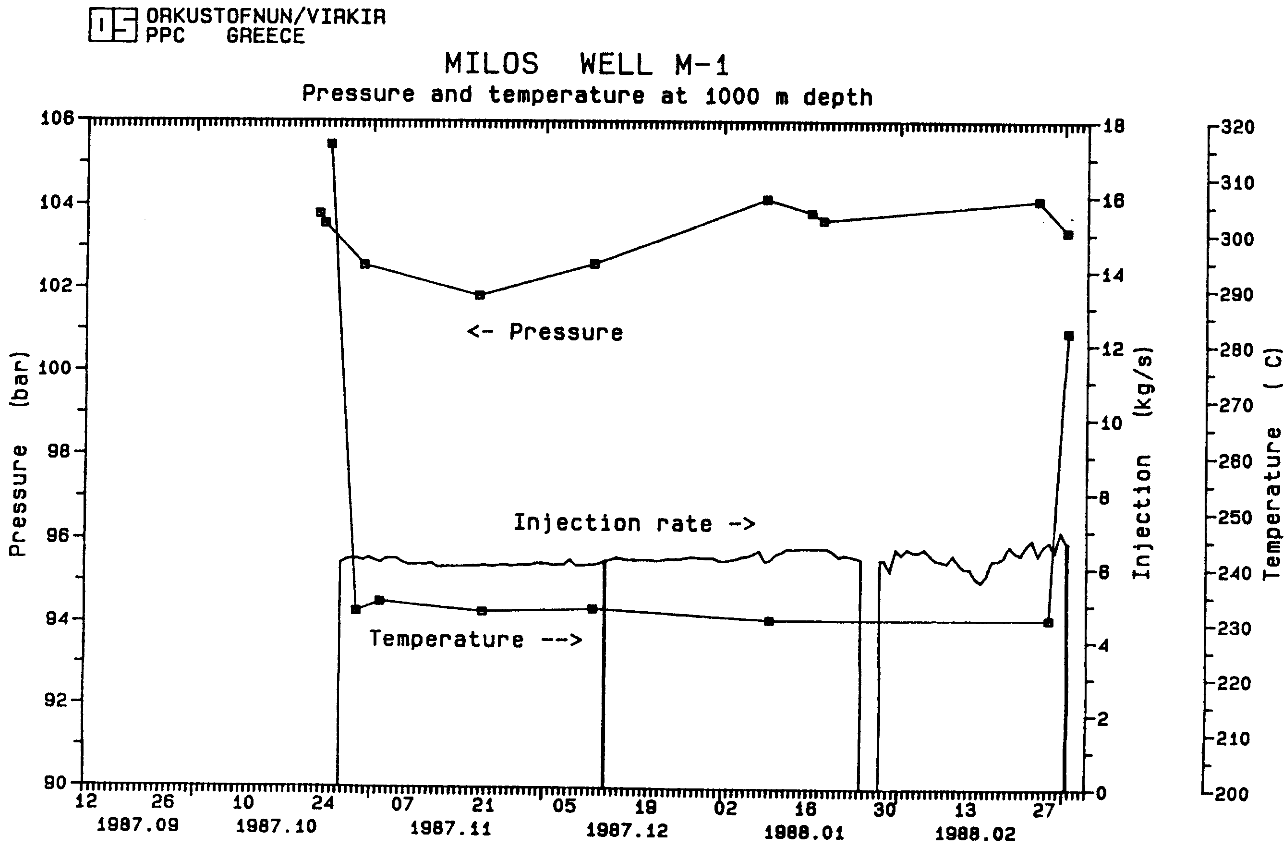
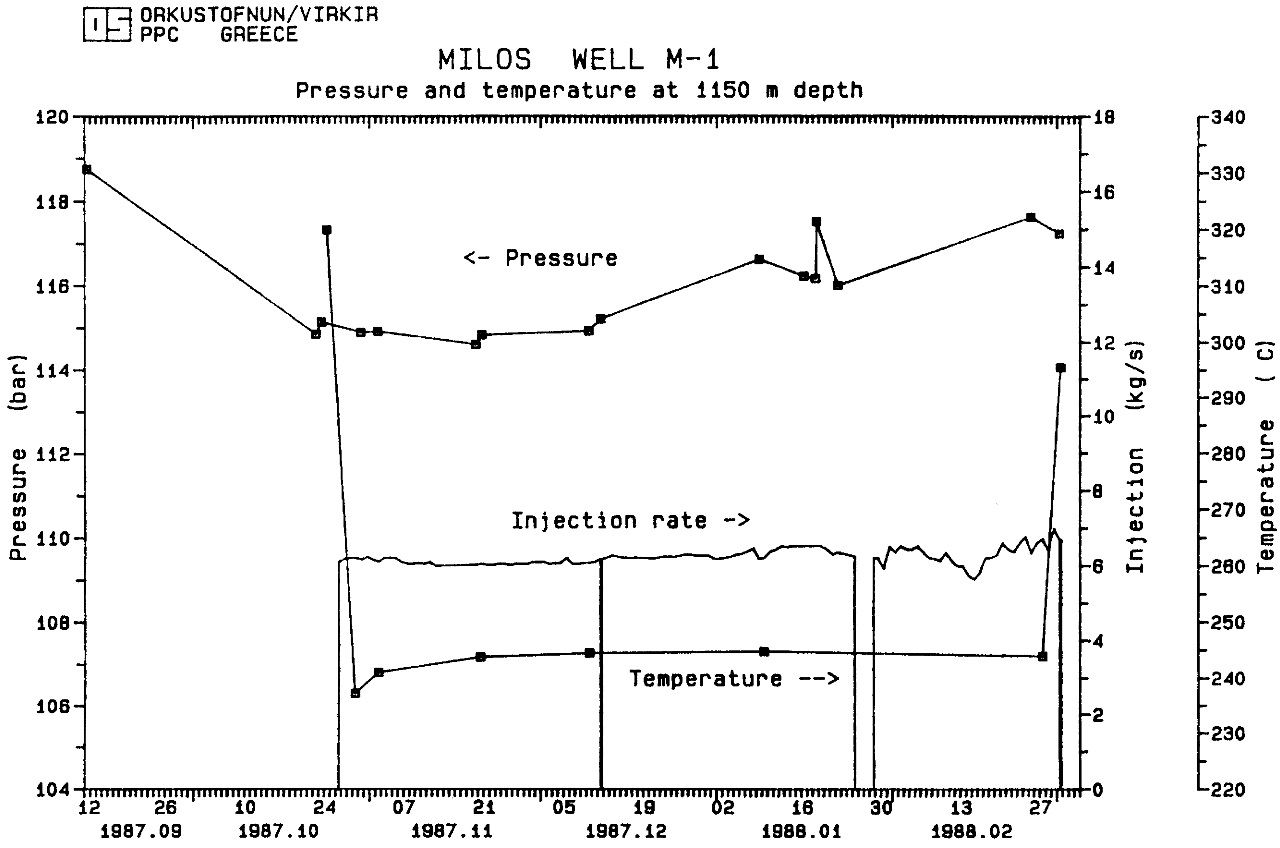
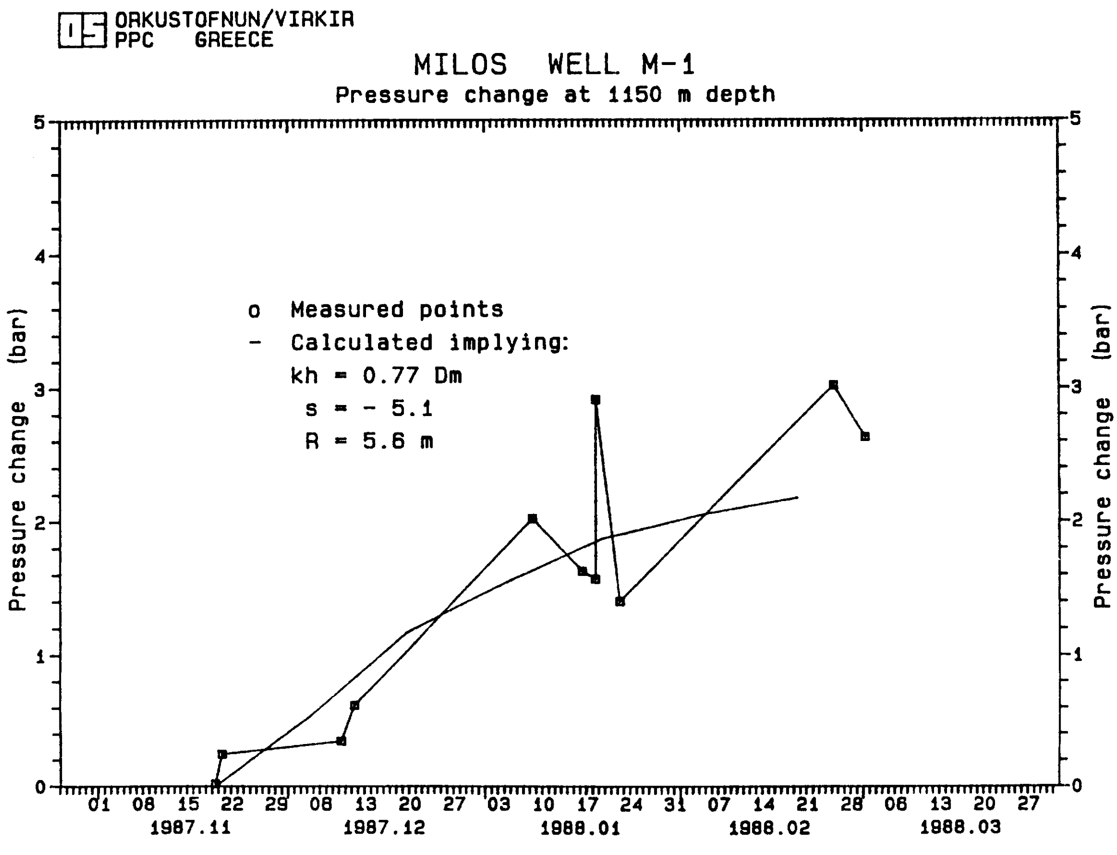
PPC GREECE
MILOS WELL M-1
Pressure and temperature at 790 m depth
Pressure (bar)
Injection (kg/s)
Temperature (C)
<- Pressure
Injection rate ->
Temperature -->
1987.09
1987.10
1987.11
1987.12
1988.01
1988.02


ORKUSTOFNUN/VIRKIR
PPC GREECE
MILOS WELL M-1
Pressure and temperature at 1000 m depth
Pressure (bar)
Injection (kg/s)
Temperature (C)
<- Pressure
Injection rate ->
Temperature -->
1987.09
1987.10
1987.11
1987.12
1988.01
1988.02


ORKUSTOFNUN/VIRKIR
PPC GREECE
MILOS WELL M-1
Pressure and temperature at 1150 m depth
<- Pressure
Injection rate ->
Temperature -->
Pressure (bar)
Injection (kg/s)
Temperature (C)
1987.09
1987.10
1987.11
1987.12
1988.01
1988.02


ORKUSTOFNUN/VIRKIR
PPC GREECE
MILOS WELL M-1
Pressure change at 1150 m depth
o Measured points
- Calculated implying:
kh = 0.77 Dm
s = - 5.1
R = 5.6 m
Pressure change (bar)
1987.11
1987.12
1988.01
1988.02
1988.03

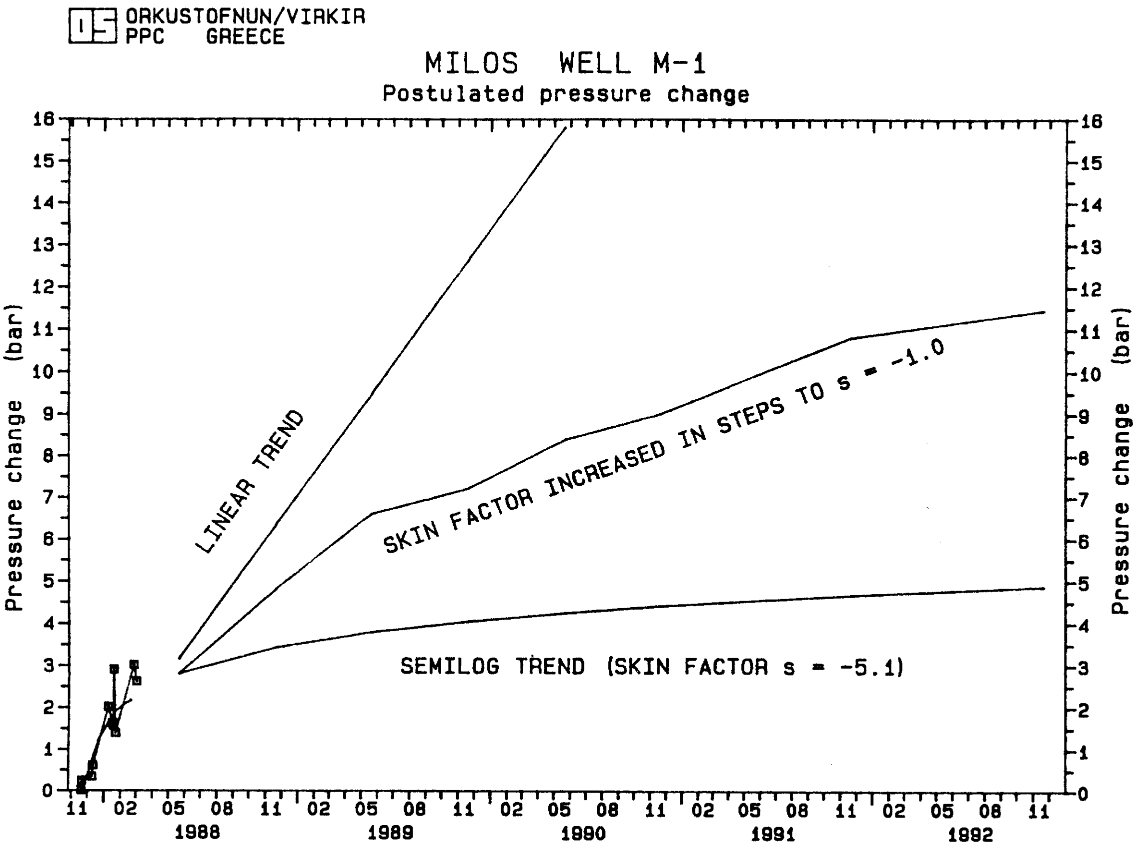

ORKUSTOFNUN/VIRKIR
PPC GREECE
MILOS WELL M-1
Postulated pressure change
Pressure change (bar)
LINEAR TREND
SKIN FACTOR INCREASED IN STEPS TO s = -1.0
SEMILOG TREND (SKIN FACTOR s = -5.1)
1988
1989
1990
1991
1992

TABLE 1: MILOS WELL M-1 PRESSURE MEASUREMENT

Date 870912 Time 1000 Gauge KP-16470 Measured by PPC
Wellhead pressure 21.82 bar Injection rate 0.00 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	21.82	STATIC CONDITION
200.00	40.77	BEFORE 2ND
790.00	91.08	REINJECTION
1150.00	118.75	

TABLE 2: MILOS WELL M-1 PRESSURE MEASUREMENT

Date 871022 Time 1231 Gauge KP-29271 Measured by PPC
Wellhead pressure 23.63 bar Injection rate 0.00 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	23.63	STATIC CONDITION
200.00	41.22	BEFORE 2ND
400.00	57.76	REINJECTION
600.00	73.83	
790.00	88.66	
1000.00	103.77	
1150.00	114.86	

TABLE 3: MILOS WELL M-1 PRESSURE MEASUREMENT

Date 871023 Time 1210 Gauge KP-29271 Measured by PPC
Wellhead pressure 22.81 bar Injection rate 0.00 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	22.81	STATIC CONDITION
200.00	41.06	BEFORE 2ND
400.00	57.99	REINJECTION
600.00	73.71	
790.00	88.49	
1000.00	103.55	
1150.00	115.15	

TABLE 4: MILOS WELL M-1 TEMPERATURE MEASUREMENT

Date 871024 Time 0910 Gauge KT-872426 Measured by PPC
Wellhead pressure 22.80 bar Injection rate 0.00 kg/s

DEPTH m	TEMPERATUR °C	REMARKS
100.00	121.80	STATIC CONDITION
200.00	178.94	BEFORE 2ND
300.00	220.71	REINJECTION
400.00	245.25	
500.00	265.58	
600.00	284.22	
700.00	297.17	
790.00	307.03	
850.00	308.76	
900.00	310.58	
950.00	314.10	
1000.00	315.64	
1050.00	317.16	
1100.00	319.85	
1150.00	319.85	

TABLE 5: MILOS WELL M-1 TEMPERATURE MEASUREMENT

Date 871029 Time 0925 Gauge KT-872426 Measured by PPC
Wellhead pressure 15.75 bar Injection rate 6.22 kg/s

DEPTH m	TEMPERATURE °C	REMARKS
0.00	201.85	SECOND REINJECTION
100.00	204.86	STARTED 87.10.26
300.00	205.47	
400.00	206.62	
500.00	208.35	
600.00	210.02	
700.00	213.20	
790.00	215.59	
850.00	220.90	
900.00	222.54	
950.00	229.12	
1000.00	232.00	
1050.00	233.85	
1100.00	235.27	
1150.00	237.27	

TABLE 6: MILOS WELL M-1 PRESSURE MEASUREMENT

Date 871030 Time 0940 Gauge KP-29271 Measured by PPC
Wellhead pressure 16.41 bar Injection rate 6.17 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	15.75	SECOND REINJECTION
100.00	21.97	STARTED 87.10.26
200.00	31.27	
300.00	40.52	
400.00	49.02	
500.00	58.58	
600.00	67.06	
700.00	76.07	
790.00	83.96	
850.00	89.28	
900.00	93.46	
950.00	98.01	
1000.00	102.55	
1050.00	106.84	
1100.00	110.40	
1150.00	114.90	

TABLE 7: MILOS WELL M-1 PRESSURE MEASUREMENT

Date 871102 Time 0915 Gauge KP-29271 Measured by PPC
Wellhead pressure 14.82 bar Injection rate 6.11 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	14.82	
100.00	21.83	
200.00	31.12	
300.00	40.37	
400.00	48.92	
790.00	85.74	
1150.00	114.92	

TABLE 8: MILOS WELL M-1 TEMPERATURE MEASUREMENT

Date 871102 Time 1245 Gauge KT-872426 Measured by PPC
Wellhead pressure 14.82 bar Injection rate 6.11 kg/s

DEPTH m	TEMPERATURE °C	REMARKS
0.00	197.72	
100.00	209.37	
200.00	209.43	
300.00	209.55	
500.00	210.96	
600.00	213.64	
700.00	215.28	
790.00	217.36	
850.00	221.93	
900.00	223.34	
950.00	231.92	
1000.00	233.78	
1050.00	235.22	
1100.00	240.51	
1150.00	241.07	

TABLE 9: MILOS WELL M-1 PRESSURE MEASUREMENT

Date 871119 Time 1240 Gauge KP-29271 Measured by PPC
Wellhead pressure 16.55 bar Injection rate 6.03 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	12.99	WHP COULD BE OFF
200.00	29.89	
400.00	47.73	
600.00	66.22	
790.00	83.20	
1000.00	101.82	
1150.00	114.62	

TABLE 10: MILOS WELL M-1 TEMPERATURE MEASUREMENT

Date 871120 Time 0938 Gauge KT-872426 Measured by PPC
Wellhead pressure 16.55 bar Injection rate 6.06 kg/s

DEPTH m	TEMPERATURE °C	REMARKS
0.00	209.25	WHP COULD BE OFF
100.00	211.38	
200.00	210.47	
300.00	210.53	
400.00	211.00	
500.00	212.54	
600.00	213.70	
700.00	215.22	
790.00	217.36	
900.00	222.60	
1000.00	231.98	
1100.00	242.56	
1150.00	243.81	

TABLE 11: MILOS WELL M-1 PRESSURE MEASUREMENT

Date 871120 Time 1500 Gauge KP-29271 Measured by PPC
Wellhead pressure 0.00 bar Injection rate 6.06 kg/s

DEPTH m	PRESSURE bar	REMARKS
1150.00	114.85	ONE CHECK POINT

TABLE 12: MILOS WELL M-1 PRESSURE MEASUREMENT

Date 871209 Time 0921 Gauge KP-29271 Measured by PPC
Wellhead pressure 16.05 bar Injection rate 6.08 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	16.05	
100.00	21.67	
200.00	30.78	
400.00	49.09	
600.00	67.64	
700.00	76.07	
790.00	84.61	
850.00	89.70	
900.00	93.40	
950.00	97.99	
1000.00	102.60	
1050.00	106.93	
1100.00	110.67	
1150.00	114.94	

TABLE 13: MILOS WELL M-1 TEMPERATURE MEASUREMENT

Date 871209 Time 1308 Gauge KT-872426 Measured by PPC
Wellhead pressure 16.05 bar Injection rate 6.08 kg/s

DEPTH m	TEMPERATURE °C	REMARKS
0.00	207.91	
200.00	210.35	
400.00	210.71	
600.00	212.49	
790.00	216.75	
900.00	222.54	
950.00	229.73	
1000.00	232.53	
1050.00	234.70	
1100.00	242.63	
1150.00	244.50	

TABLE 14: MILOS WELL M-1 PRESSURE MEASUREMENT

Date 871211 Time 1114 Gauge KP-29271 Measured by PPC
Wellhead pressure 16.00 bar Injection rate 6.19 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	16.00	BEFORE FALLOFF
790.00	84.39	TEST
1150.00	115.22	

TABLE 15: MILOS WELL M-1 PRESSURE MEASUREMENT

Date 880108 Time 1210 Gauge KP-29271 Measured by PPC
Wellhead pressure 15.86 bar Injection rate 6.17 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	15.23	
100.00	22.62	
200.00	31.97	
300.00	40.56	
400.00	50.02	
500.00	59.30	
600.00	67.78	
700.00	77.20	
790.00	84.88	
900.00	94.87	
950.00	99.64	
1000.00	104.15	
1050.00	108.26	
1100.00	112.07	
1150.00	116.62	

TABLE 16: MILOS WELL M-1 TEMPERATURE MEASUREMENT

Date 880109 Time 0940 Gauge KT-872426 Measured by PPC
Wellhead pressure 15.86 bar Injection rate 6.22 kg/s

DEPTH m	TEMPERATURE °C	REMARKS
0.00	205.69	
100.00	207.91	
200.00	207.36	
300.00	207.60	
400.00	208.28	
500.00	209.37	
600.00	210.96	
700.00	212.60	
790.00	214.49	
900.00	220.10	
950.00	228.94	
1000.00	230.58	
1050.00	233.00	
1100.00	242.88	
1150.00	244.75	

TABLE 17: MILOS WELL M-1 PRESSURE MEASUREMENT

Date 880116 Time 1000 Gauge KP-29271 Measured by PPC
Wellhead pressure 15.56 bar Injection rate 6.53 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	15.56	
200.00	31.25	
400.00	50.24	
600.00	68.14	
790.00	84.90	
900.00	94.93	
1000.00	103.82	
1100.00	111.79	
1150.00	116.23	

TABLE 18: MILOS WELL M-1 PRESSURE MEASUREMENT

Date 880118 Time 1221 Gauge KP-29271 Measured by PPC
Wellhead pressure 15.51 bar Injection rate 6.53 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	15.51	SAME DAY MEASURED
790.00	85.68	WITH P-GAUGE
1000.00	103.65	KP-16470
1150.00	116.17	

TABLE 19: MILOS WELL M-1 PRESSURE MEASUREMENT

Date 880118 Time 1500 Gauge KP-16470 Measured by PPC
Wellhead pressure 16.55 bar Injection rate 6.53 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	15.23	ANOTHER PRESSURE
400.00	49.40	ELEMENT KP-16470
500.00	58.58	CALIBRATED BY
600.00	67.91	OTIS IN GREECE
700.00	77.18	
790.00	85.86	
1150.00	117.51	

TABLE 20: MILOS WELL M-1 PRESSURE MEASUREMENT

Date 880122 Time 1021 Gauge KP-29271 Measured by PPC
Wellhead pressure 15.29 bar Injection rate 6.36 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	15.29	
200.00	31.42	
400.00	49.51	
600.00	67.33	
790.00	84.54	
1150.00	116.00	

TABLE 21: MILOS WELL M-1 PRESSURE MEASUREMENT

Date 880225 Time 1030 Gauge KP-16470 Measured by PPC
Wellhead pressure 15.70 bar Injection rate 6.33 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	15.70	
200.00	31.15	
400.00	49.75	
600.00	69.65	
790.00	84.91	
900.00	95.02	
1000.00	104.13	
1100.00	113.13	
1150.00	117.62	

TABLE 22: MILOS WELL M-1 TEMPERATURE MEASUREMENT

Date 880227 Time 1131 Gauge KT-872426 Measured by PPC
Wellhead pressure 16.55 bar Injection rate 6.72 kg/s

DEPTH m	TEMPERATURE °C	REMARKS
200.00	209.74	
400.00	211.75	
600.00	213.21	
790.00	216.69	
900.00	221.62	
1000.00	230.71	
1100.00	242.20	
1150.00	243.87	

TABLE 23: MILOS WELL M-1 PRESSURE MEASUREMENT

Date 880301 Time 0945 Gauge KP-16470 Measured by PPC
Wellhead pressure 16.55 bar Injection rate 6.69 kg/s

DEPTH m	PRESSURE bar	REMARKS
400.00	48.80	BEFORE FALLOFF
600.00	67.86	TEST
790.00	84.66	
1000.00	103.39	
1150.00	117.23	

TABLE 24: MILOS WELL M-1 TEMPERATURE MEASUREMENT

Date 880301 Time 1540 Gauge KT-872426 Measured by PPC
Wellhead pressure 17.03 bar Injection rate 0.00 kg/s

DEPTH m	TEMPERATURE °C	REMARKS
0.00	116.30	AT END OF FALLOFF
200.00	133.10	TEST
400.00	158.96	CLOCK STOPPED AT
600.00	197.55	DEPTHS 200, 400,
790.00	270.34	600, AND 790 m
1000.00	282.25	
1150.00	295.42	

Mr. N. Koutroupis
Public Power Corporation
Direction of Alternative Energy Forms
Milos Field Office

Milos 1988.03.03

Re: Milos 2 MW Geothermal Power Plant

At your request Virkir/NEA has reviewed two letters of to-day from Mirsubishi's site representative Mr. T. Fukuda on the subject of modifications of the wellhead of M-2, performance tests, and presence of MHI engineers to the end of the 12 month operation. These two letters are the last in a series of letters exchanged between Public Power Corporation and Mitsubishi on the subject of the contractor's responsibilty in fulfilling the contract between the two parties.

The first letter form Mr. Fukuda (ref. MHI SITE-31) describes MHI proposal to clean and modify the branch between the X'mas tree and the main throttling valve. Mesurements have shown that the well flow is not sufficient for full load operation due to flow restrictions in the three small-diameter pipes connecting the well to the steam separator. The present X'mas tree zarrangement of three paralell pipes is the result of earlier modifications made to overcome the same problem.

The design of connecting the well with a 3" pipe only is flawed, because the two phase flow velocity is close to 80 m/s at the design condition. This is two to three times greater velocity than is the convention in designing geothermal two-phase piping. Conventional design calls for a pipe size of at least 6" in this case. To solve this problem with three parallel 3" pipes can only be considered a temporary set-up until a final modification can be made. The present arrangement ties up the valve on top of the X'mas tree, which was installed to enable down-hole logging of the well.

Considering the above points Virkir/NEA recommend's that PPC does not approve MHI's modification, as described in their letter. We recommend that a new, or greatly modified wellhead be installed. This wellhead should have a larger pipe diameter capable of supplying the design flowrate, and have a single by-pass line. At this time we, however, recommend that MHI clean the pipes so that the turbine can reach full output, for the performance test to take place. At the time of cleaning the present X'mas tree should be inspected for the thickness and type of scale, as this information can be used in the new wellhead design to make it less prone to plugging, and to design it for ease of cleaning the scales.

The second letter of Mr. Fukuda (ref. MHI SITE-32) deals with the intention of MHI to start Commercial Operation on March 8, and make the Performace Test on March 10. We feel it is in order for PPC to proceed to the Performace Test at this time. There is concern on part of PPC's operating personel that the spraying of the courregated plates in the moisture separator is being carried on to the turbine, which may in time and lead to erosion of turbine blades. This water is condensate of H.P. steam, and thus the chemical analysis methods used to determine steam purity and separator carry over are not applicalble to determine the dryness of stream.

PPC has additional guarantees in the contract with MHI, other than the guarantee figures. The one year guarnatee and the presence of a MHI guarantee enginner on Milos for that period should insure that MHI can be held responsible for premature failiures.

Sincerely yours,

Sverrir Thorhallsson, proj. mgr.
Virkir/NEA

Mrs. Rea Tassiou, Directolr
Direction of Alternative Energy Forms
Public Power Corporation
10, Navarinou Street
ATHENS 106 80
GREECE

Milos 1988.03.03

Re: Field report of Mr. Sverrir Thorhallsson and
Mr. Omar Sigurdsson, February 29 - March 5, 1988

At the request of PPC Mr. Sverrir Thorhallsson proj. mgr. and Mr. Omar Sigurdsson res.eng. of Virkir/NEA travelled to Milos a week ago. The purpose was to witness a falloff test in the reinjection well and to reveiw operating experience and data collected to date on the reinjection system and steam collection system. The last mission by a Virkir/NEA expert to Greece under our contract for consultancy services was almost a year and a half ago at the time of the first reinjection falloff test. During this period there have been exhanges of telexes and telephone conversations on the progress of the project, and on advice given by Virkir/NEA.

During our visit now we had the first hand opportunity of seeing the plant in operation and of discussing the latest developments with persons of your department and of the Thermal Production Department. We were accompanied by Mr. Koutinas to Milos and there we had discussions with Mr. Koutroupis and Mr. Chlamboutakis. From the power plant Mr. Vernikos took part, and Mr. Gelegenis from the Technical University. In the concentrated time of three days we managed to complete our mission on Milos with the good cooperation of these persons.

Our travel schedule was the following:

Febr. 29 Travel to Athens from Iceland.

March 1 Travel to Milos on early morning flight.
Witeness falloff test and visit to plant.

March 2 Collection of available data, meetings.

March 3 Sheduled departure from Milos delayed for one day due to cancellation of flight.
Day used for additional discussion, visit to plant, and a letter was prepared for PPC on the subject of two MHI letters received by your site representative the same day.

March 4 Travel by ferryboat from Milos to Athens.
Parts of field report written on board ship.

March 5 Day of travel from Athens to Iceland.

March 7 Extra day for Mr. Thorhallsson for finishing field report and handing it in.
This extra day is due to the two day shift in schedule caused by flight cancellation and time spent in sailing from Milos which left no time in Athens. (Other days for private business at his expense)

Enclosed please find our field report. An interim report will be prepared in Iceland and sent to you later this month.

Sincerely yours,

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Sverrir Thorhallsson, proj. mgr. Virkir/NEA

Virkir/NEA
STh/OS

FIELD REPORT TO PPC:

MILOS 2 MW POWER PLANT

VISIT TO MILOS TO WITNESS FALLOFF TEST AND TO REVIEW DATA AND OPERATING EXPERIENCE TO DATE

Athens March 6, 1988

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1. FALLOFF TEST

The reinjection into well M-1 was started for the second time on October 26, 1987. Since then only minor stops in the reinjection have occured when modifications of the power plant have been implemented, or falloff tests made. Earlier falloff tests have been measured on December 11, 1987, January 25, 1988 and the last on March 1, 1988 which was witnessed during this mission by Virkir/NEA representatives.

The falloff test was performed by running a KUSTER pressure gauge to the bottom of M-1 well. Then the flow was diverted from the well by opening the pipe to the M-1 pond and closing the valve at the wellhead. The falloff test started at 11:35 on March 1, 1988 and ended about four houres later. The temperature at the bottom of M-1 well was before the falloff test about 244°C. During the falloff test the temperature recovered rapidly and was after 385 minutes about 295°C. This rapid thermal recovery completely masks the falloff in the well after the first 15 minutes. Therefore it is very doubtful whether it is possible to interpret the falloff test in conventional manner for transmissivity and skin factor.

The calibration for the pressure gauges available is only in the range up to 250°C. The Milos geothermal reservoir has, however, temperatures up to 320°C. Since the pressure gauges are not calibrated to that temperature, the pressure measurements made at higher temperature, as during falloff tests or when static profiles are measured, can not be temperature corrected. This makes it impossible at the moment to remove the temperature effect from the falloff measurement. It is recommended that the pressure gauges be calibrated soonest possible at temperature up to at least 300°C. Such a calibration could be done in Iceland at PPC's request.

The M-1 well has been responding favorably to the injection. It's respond indicates that the transmissivity of the well has improved and is better now than it was estimated during the first reinjection test in April 1985. Any reinjection well has, however, a limited longevity, so it has to be cleaned or replaced after a period of time. When the transmissivity of the reservoir formation is changing as is the case for M-1 it is impossible to predict with any certanty the longevity of the well. To make a rough estimate of the minimum longevity for M-1 one can proceed as follows: The injection has now been going on for about 130 days. The injection rate has been in the range 22-24 T/hr. During this time the pressure at the bottom of M-1 well has increased about 1.5-2.0 bar. The liquid level in the well is near the wellhead so the pressure difference available for injection is about 13 bar. Assuming now a linear pressure increase during the injection period and a similar behaviour of the well in the future as in the past, the minimum longevity of the well can be estimated as 2 years.

2. REINJECTION SYSTEM

The reinjection system was not shut down during the fall-off test on March 1, and therefore visual inspection could not be made by us of the critical parts. In discussions with Mr. N. Koutroupis PPC's site representative and Mr. M. Vernikos director of Milos power plant the experience gained to date in operating the reinjection system was rewieved. Excelent photographs taken by one of the operators of the plant Mr. Zanetis of pump parts and the turbine were shown, and Mr. Thorhallsson showed similar photographs he had made in Iceland at three geothermal power plants.

The present reinjection has been continous from October 26, 1987, except for short stops. This shows that the reinjection system can operate for an extended period of time, but only by frequent cleaning of scales from critical pieces of equipment.

The following have been identified as the main problem areas:

1. The high pressure reinjection pumps have to be opened and cleaned of scale every 20-30 days. The reason is that scales reduce the output of the pump below what is required to reinject all of the brine, and the electric motor becomes overloaded. This has not resulted in a complete shutdown of the reinjection system as the stand-by pump takes over.
2. Scales cause sticking of the control valve, and it must be replaced with a spare every 20 days or so, while it is being cleaned. The scale accumulation is begining to affect operation of other parts, such as shut-off valves which are not tight.
3. The orifice flow meter in the reinjection pipeline requires dayly attention to stay operative. A device has been installed at the pressure taps so that they can be cleaned, but the flow reading will become unaccurate in time due to scaling of the pipe and orifice.
4. Scales are deposited quite rapidly in the first few hundred meters of the reinjection pipeline from the plant to the reinjection well. In time this will require cleaning, which is not an easy task. A thorough inspection is required to confirm the scaling rate along the pipeline.

The following suggestions are made for areas of further study. Some of these will be described in our interim report:

1. The thickness of scale at different locations in the reinjeciton pipe should be measured to show the depoisition rate as a function of time. Indications are that the relatively rapid deposition may be reduced by longer retention time of the brine in the hot water collecting tank. By increasing the size of the tank the scaling rate down-stream in the pumps etc. may be reduced.
2. Acid cleanig of the scales with hot inhibited acid should be investigated. Good results have been obtained in Iceland where several kilometers of pipes have been cleaned of silica-rich scales by circulating a specially formulated acid.

3. Because of a lower scaling rate at the reinjection well, the main flowmeter readings should be taken at the orifice meter set-up there. In scaling conditions a differential pressure indicator with a sealing fluid is preferred.

3. STEAM COLLECTION SYSTEM

Consultancy on the steam collection system was introduced for the first time in the Virkir/NEA - PPC supplement Nr. IV, recently signed. The three days we had on Milos were therefore also used to learn more about the problems and operating experience gained in it's operation to date, and to review measurement data.

The steam collection system is partly clogged at the moment in the three pipe branches leading from the X'mas tree to the H.P. separator. The steam production is affected and the turbine can therefore not operate at full load. During our stay a letter was sent by Mr. Fukuda MHI's site representative to Mr. Koutroupis requesting that PPC approved cleaning and modifications of the wellhead branches. These modifications were scheduled to start the next day. Virkir/NEA was asked to comment on these suggestions, and we did so in writing the morning we left Milos (see att.) Virkir/NEA recommended that PPC approve the cleaning, but that the modifications should not be approved by PPC as more radical changes are called for on MHI's part. The request for a Performance Test on March 10 could take place after the cleaning operation. We feel that PPC should agree to such a test now in spite of the short notice given.

Considerable modifications have recently been made by MHI on the steam separation equipment, to improve the steam purity. Measurements show improvement's in the steam purity, but as was shown by data presented by Koutroupis this is not dramatic. Data presented by Mr. Vernikos showed that the gradual rise in steam chest pressure due to scaling of the inlet nozzles in the past has now been reversed. Self cleaning is thus taking place during normal operation at appr. 1 MW load, and the pressure is now close to normal. For this reason they voiced the concern that the improvements are not solely due to improvements in steam purity, but in part attributable to self-cleaning due to wet-steam operation. If this is the case abnormal erosion of the turbine blades may occur.

The following suggestions were offered:

1. The branch to the H.P. separator should be increased in diameter, and be designed for ease of cleaning. A single by-pass pipe should also be provided.

2. The steam should be monitored carefully to make sure that the steam entering the L.P.separator is wet (de-superheaters working properly) and that the steam entering the turbine is of the specified dryness. The abnormally high drain-water from the steam pipe to the turbine should be analysed for chloride. Also the abnormally high flow of "condensate" at the chimney and from the drain before the steam orifice meter should be checked, as this indicates wet-steam operation.

3. The present tests used to determine the steam purity by analysis of silica, chloride, and dissolved solids are complicated and require the services of a chemist. We suggest that a simpler sodium analysis method be used for every-day analysis of the steam purity. An operator can be trained to measure sodium (Na) with a flame photometer, and the results should be every bit as reliable. Such an instrument can be purchased for

approximately 1500 pounds sterling. Details of it were left with the plant director. The plant should also measure the non-condensible gas in the steam and the pH of the condensate at least three times a week.

4. CONCLUSIONS

- The pressure gauges need to be calibrated for temperatures up to 300°C to correct fall-off tests for thermal recovery in well M-1 .
- The minimum longevity of M-1 well is now estimated over 2 years.
- The high frequency of cleaning the scales in the high pressure reinjection pupms, control valves etc. needs to be improverd. Methods of reducing the scaling rate or of using acid in place cleaning should be investigated.
- The wellhead of well M-2 should be redesigned with a larger pipe diameter of the branch to the separator.
- Rapid build-up of steam chest pressure in the past due to scaling, has now been reversed by changes in the steam system design.
- Measurements of sodium in the steam for routine steam purity checking is suggested. Adding measurements of non-condensible gas and pH is also suggested. These measurements can be made by the plant operators without the assistance of a chemist.
- Careful visual inspections should be made of equipment where scaling is observed during overhauls. A major inspection should take place before the guarantee period expires. The valuable photographic evidence and measurements that have been made to date by PPC'operating personel should be collected in a systematic way to identfy areas needing furter study, and to document the experience gained in operating the first geothermal power plant in Greece.

Sverrir Thorhallsson, proj. mgr.
Virkir/NEA

and

Omar Sigurdson, res. eng
Virkir/NEA