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CONTINUOUS MEASUREMENT OF GASES FOR EFFECTIVE GEOTHERMAL RESERVOIR MANAGEMENT AND EARTHQUAKE PREDICTION

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ABSTRACT

An on-line Modular Environmental Data Acquisition System (MEDAS) at MG5D pad in Mahanagdong sector of the Leyte Geothermal Production Field continuously monitors the presence of radon gas and other chemical parameters in the geothermal brine and steam. Radon gases are to be used as indicator of any major fault movement or earthquake in the field. Other parameters like conductivity, redox potential and CO_2 concentrations will be applied as possible additional tools in geothermal reservoir management. Initial results indicate that wells MG18D, MG9D, MG23D and MG32D that were drilled through different fault structures have distinct levels of radon concentration. Anomalies in the level of radon in each well, therefore, could be attributed to specific faults intercepted by the wells. Among the other parameters monitored, significant changes were observed in the conductivity values of MG23D and redox potential in MG18D. Additional on-line monitoring data has to be established to determine what causes these changes in the geothermal reservoir in correlation with standard chemical monitoring parameters.

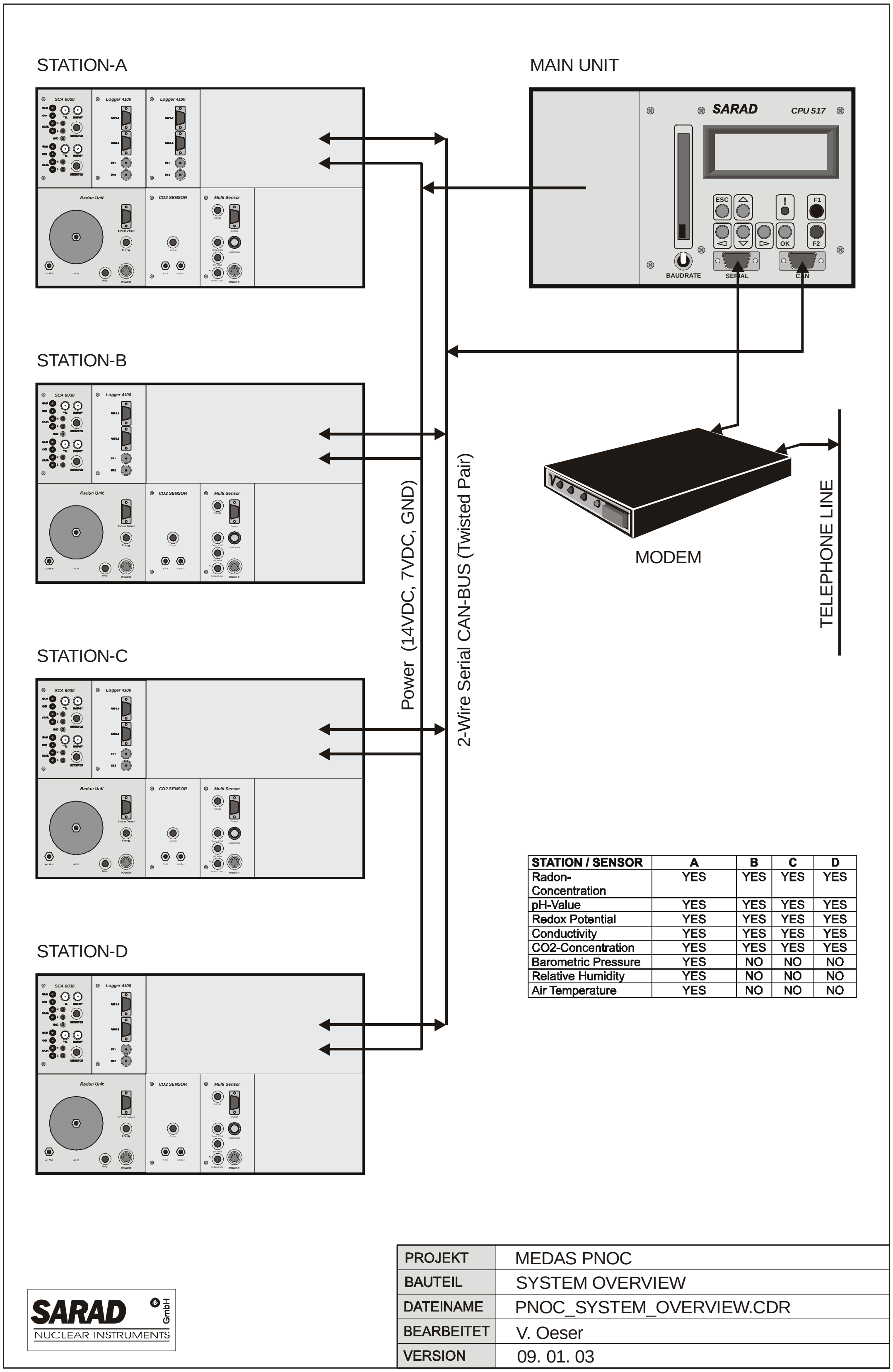
1.0 INTRODUCTION

Efficient and sustainable production of geothermal energy requires constant monitoring of changes occurring in the reservoir. These changes, which may result from mass extraction for production, waste fluid injection for disposal and pressure support, and from natural geologic processes, are usually manifested in the chemistry and physical characteristics of the wells. Experience has also shown that these changes are related to the structure of the reservoir - the faults that transect the field as well as smaller fractures contained in the reservoir rocks. Identification and evaluation of chemical changes, and their correlation with the structural features, require among others the constant analysis of hot brine and gases discharged by the wells.

Changes in water and gas chemistry, for example, can indicate: 1) lowering of the water level of the reservoir, 2) invasion of cold and degassed injection fluids, 3) entry of shallow acidic steam condensates and deep corrosive volcanic-related fluids, 4) precursor of an earthquake (Streil, 2002), etc. Any of these changes can significantly alter the short- and long-term viability of the geothermal operation. Hence, it is critical that up-to-date collection and analysis of water and gases be undertaken. The common procedure for obtaining geochemical data of the deep reservoir is by collecting two-phase samples from production wells in the field. However, this process is time consuming especially if there are several wells to be monitored. In addition, there is a significant lapse between the time when samples are collected and the time when laboratory analysis of samples are made available. With this method, the data becomes useless when the changes that are being tracked are almost instantaneous like in the case of earthquakes. There is therefore a pressing need for a continuous and on-line system of measuring chemical parameters in the field.

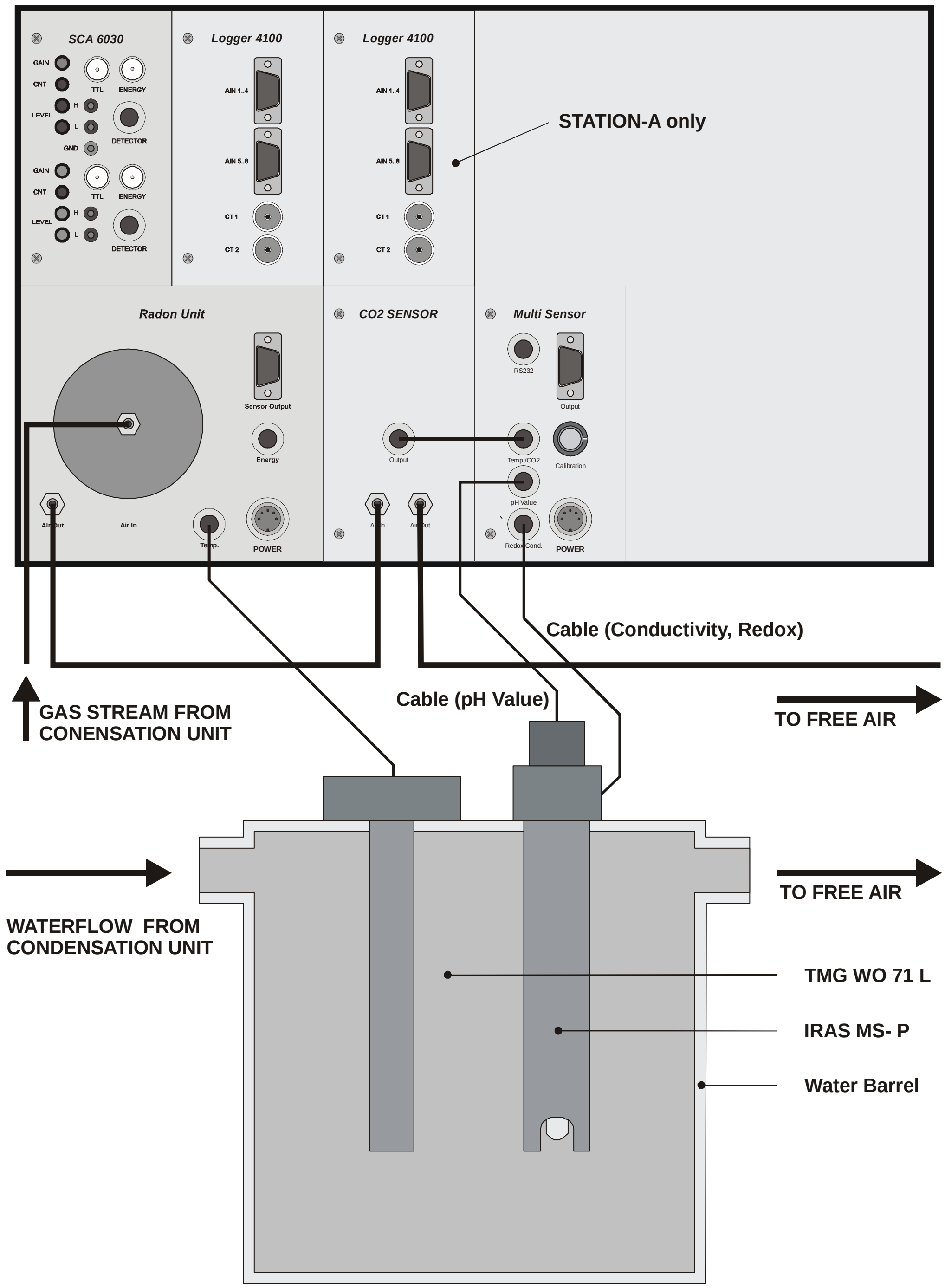
2.0 METHODS

A progress in this field is presented in this paper with the development of a new versatile measuring system called MEDAS (MEDAS - Modular Environmental Data Acquisition System) based on experiences and recent results from different research groups. MEDAS is an innovative multi-parameter station (Figs. 1 and 2), which can continuously record as a function of time up to more than 100



STATION / SENSOR	A	B	C	D
Radon-Concentration	YES	YES	YES	YES
pH-Value	YES	YES	YES	YES
Redox Potential	YES	YES	YES	YES
Conductivity	YES	YES	YES	YES
CO2-Concentration	YES	YES	YES	YES
Barometric Pressure	YES	NO	NO	NO
Relative Humidity	YES	NO	NO	NO
Air Temperature	YES	NO	NO	NO

Figure 1. Overview from a MEDAS Multi parameter measuring system for geochemical data acquisition in a geothermal field.



SARAD GmbH NUCLEAR INSTRUMENTS

PROJEKT	MEDAS PNOC
BAUTEIL	MEDIA FLOW, SENSOR CONNECTION
DATEINAME	PNOC_FLOWCHART_SUBSTATION.CDR
BEARBEITET	V. Oeser
VERSION	09. 01. 03

Figure 2. Overview of a substation for continuous measurement of geochemical parameters in a geothermal field.

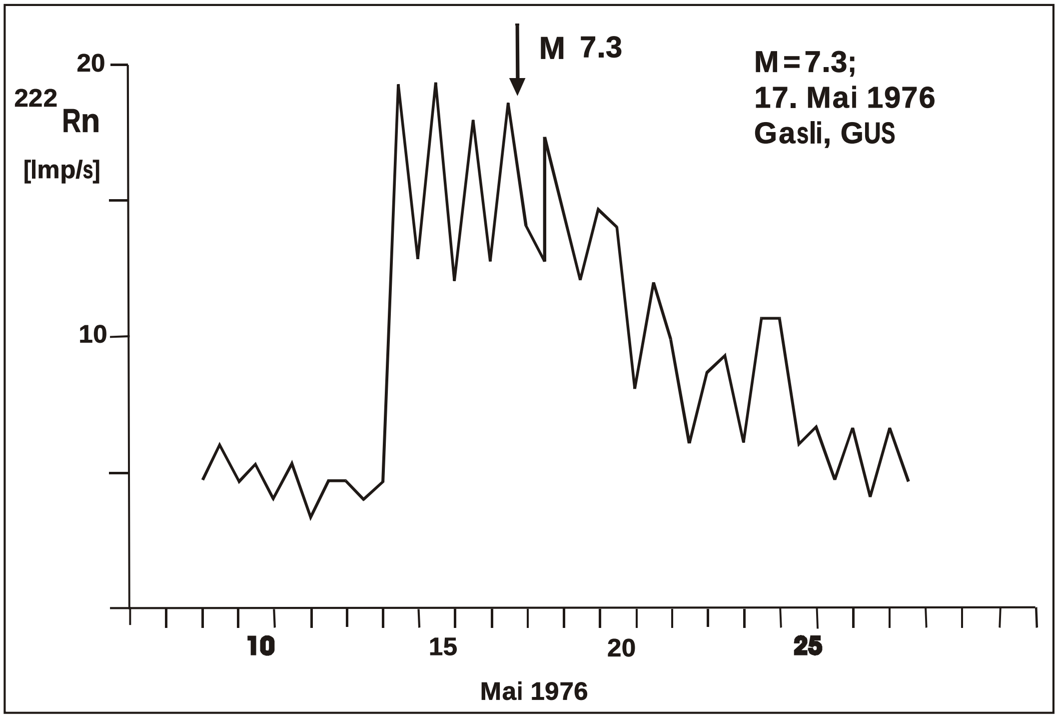


Figure 3. Radon-222 concentration during the Gasli earthquake, GUS (Hauksoon, 1981).

geochemical and physical parameters suitable to earthquake research and other applications. A microcomputer system inside the MEDAS handles data exchange, data management and control and it is connected to a modular sensor system. The number of sensors and modules can be selected according to the needs at the measuring sites.

A MEDAS has been installed in four production wells in the Mahanagdong production sector of the Leyte Geothermal Production Field located in the island of Leyte, Central Philippines. This field is chosen because: 1) it is the largest geothermal field in the Philippines with five separate power plants with total installed capacity of about 700 MWe, and 2) the area is bisected by the Philippine Fault, a major left-lateral transcurrent fault similar to the San Andreas fault.

Figure 3 illustrates the impressive field measurement on the reaction of Radon-222 in groundwater before, during and after an earthquake event. Some days in advance, micro-seismic stress that occur before an earthquake lead to an increased release of Radon to the groundwater. It can be assumed that pore pressure fluctuations and volume strain, micro-fissures in minerals and grains opened and released Radon. Further, Poro-elastic changes in sediments around the vicinity of a well due to tensile stress will cause sudden groundwater level anomalies accompanied by a mixing of different aquifer waters.

The use of radon emissions in earthquake prediction had long been established. It is generally accepted that no earthquake will appear as a sudden event but announced by certain precursor steps as discussed in the following (Zongjin, 1990):

Stage I. Elastic strain builds up along a fault due to plate movement: All parameters are at their normal state. No uplift, radon increase, etc.

Stage II. Cracks begin to develop in crustal rocks in the pre-quake area. The build-up begins to be visible as an uplift of the area. The cracked rocks do not propagate P-waves as easily and their velocity slows in the area. Radon gas can escape through the newly formed cracks, and electrical resistivity decreases. The newly forming cracks and increasing stress may also result in a tiny increase in local seismicity.

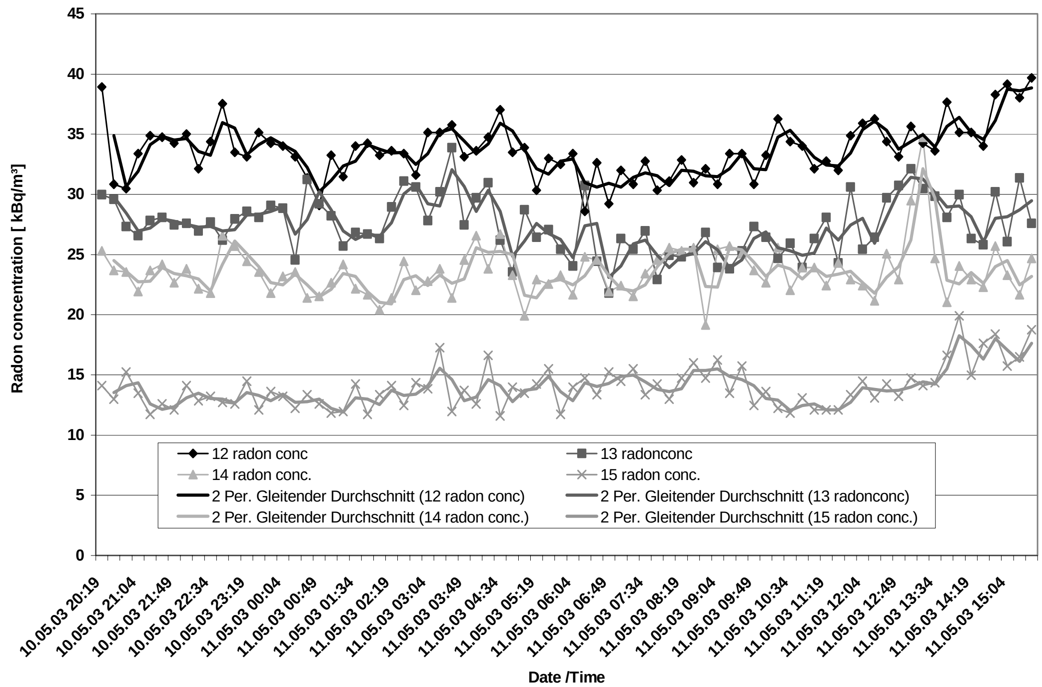


Figure 4. Daily fluctuation of the Radon concentration in 4 production wells.

Stage III. Groundwater from surrounding areas can now flow into the new cracks. Because the cracks are now filled again, the P-wave velocity can increase back to normal. The ground's uplifting also ceases and radon gas emission decreases. Electrical resistivity is still decreasing.

Stage IV. THE EARTHQUAKE

Stage V. This begins as soon as the main shock stops and consists of all the aftershocks

This indicates that different phenomena might be observed dependent on the distance to the earthquake epicentre and the distance to a fault system as the aquifer around the observation well may either be drained or filled. Therefore, a detailed knowledge on the behaviour of the water chemistry including Radon gas concentration is of major importance. In addition, diurnal variation of the Radon concentration needs to be observed to separate them from a real earthquake signal. As the Radon concentration in the soil gas is influenced by numerous parameters including anthropogenic sources, the measurement of radon from a production well is highly recommended since the well's discharge is derived directly from the deep geothermal reservoir.

3.0 RESULTS

Collection of data started after the installation of MEDAS on Pad MG-5D of the Mahanagdong production sector. Four online substations are hooked up to the four production wells of the pad to collect and analyze the water and gas chemistry of the production wells. The computer at the main station logs all the data from the four substations. The following are the CAN (Cable Area Network) address of the four substaions and the corresponsing production wells assigned to each:

Address	Production Well
CAN 12	MG-19
CAN 13	MG-23D
CAN 14	MG-18D
CAN 15	MG-32D

Figures 4 and 5 show the trends of the Radon concentration and redox potential from the four substations. From the trends, the normal fluctuation of Radon gas, which is uniform in all the substations, is about 5 kBq/m^3. Any variation in the Radon gas concentration within this value will be interpreted as a stable trend and not as an indicator of an incoming seismic event. Another observation is that CAN 15 (MG-32D) Radon gas level is distinctively lower at

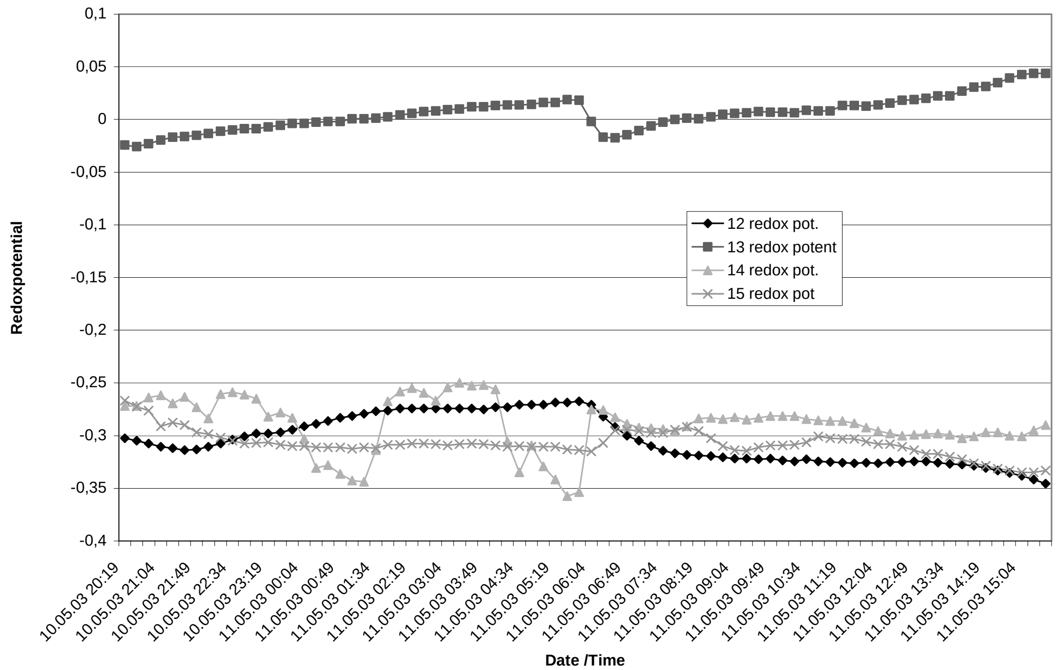


Figure 5. Daily fluctuation of the Redox potential in 4 production wells.

12-18 kBq/m^3 compared to the other three which are clustered in the range of 22-35 kBq/m^3. This probably has to do with the fact that MG-32D is the only shallow well among the four. It has a depth of -619 mRSL (meters Reduced Sea Level) while the other three has a depth range of -1040 to -1782 mRSL. Radon gas could be distributed to a lesser extent at the upper regions of the Mahanagdong reservoir.

Figure 6 shows the trends of the different monitored parameters of well MG-19. The chart shows wide fluctuations in Radon concentration from 25 to 40 kBq/m^3 and also in the redox potential. This fluctuations could be caused by seismic activity.

Preliminary analyses of data in MG23D (Fig. 7). showed a distinct reduction on conductivity from September 22 to October 2, 2003, and almost steady pH and Redox concentrations. Long term continuous data collection is necessary to determine what causes such fluctuations, which could either be due to changes in the geothermal reservoir or seasonal fluctuations.

Figure 8 presents the Redox potential in MG18D, which showed a steady decline from September to December 2003. Such changes are caused by introduction or release of metals in the fluids. However, its application in geothermal environment remains to be preliminary.

4.0 CONCLUSIONS

The preliminary data of the online monitoring of Radon gas concentration, gas flow, temperature and humidity; water temperature and pH; the redox potential and conductivity will provide more detailed understanding on the changes in the geothermal reservoir. The observed fluctuations beyond the normal levels especially in radon concentrations and redox potential could possibly be caused by seismicity. These parameters will be correlated with the historical and current data from the PNOC-EDC established monitoring set-up for seismicity, micro-gravity and precise leveling surveys, wellhead pressure trends and production well chemistry changes from the regular monthly monitoring. Further data acquisition is necessary to establish the relationship of the different parameters being monitored, and to determine how these data could be of use in geothermal reservoir management.

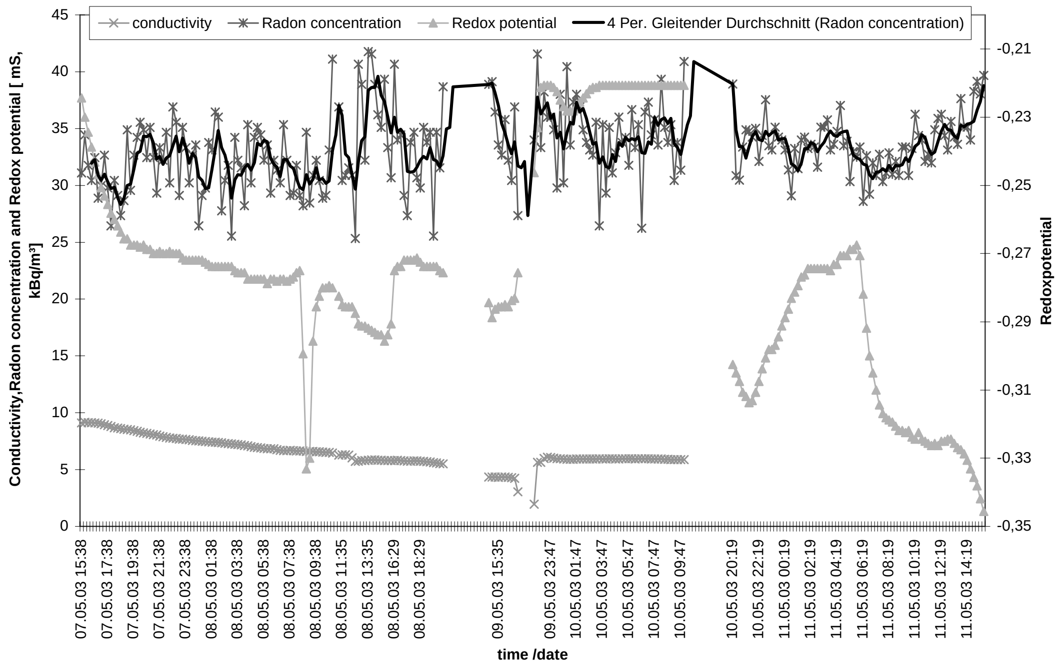


Figure 6. Fluctuation of the conductivity, radon concentration and Redox potential in the production well MG9D.

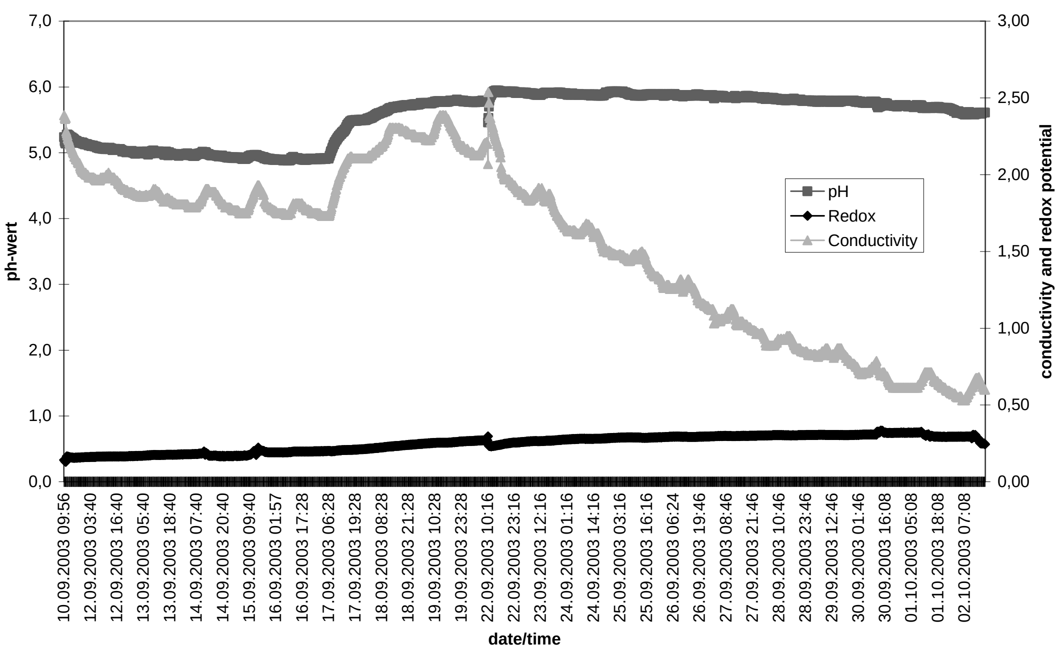


Figure 7. pH-value, Redox potential and conductivity in bore hole MG23D.

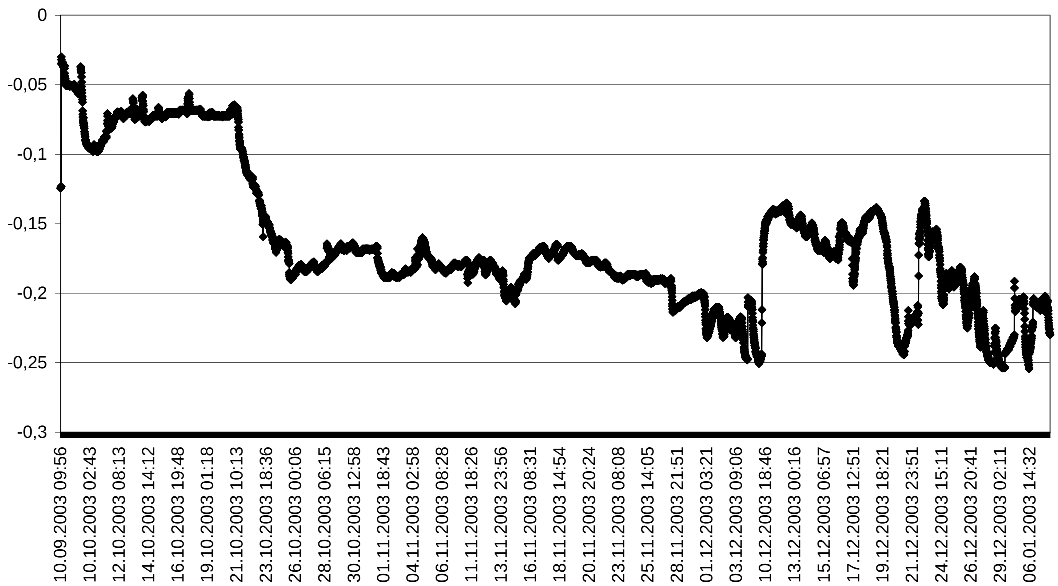


Figure 8. Continuous long time measurement of the Redox Potentials in well MG18D.

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REFERENCES

Hauksson, E. (1981). Radon content in groundwater as an earthquake precursor: evaluation of worldwide data and physical basis. J. Geophys. Res. 86: 9397-9410.

Hauksson, E. (1981). Radon Content of Groundwater as an Earthquake Precursor: Evaluation of Worldwide Data and Physical Basis. Journal of Geophysical Research, vol. 86, no. B10, 9397-9410.

Koch, U. and Heinicke, J. (1996). Earthquake prediction research by radiometric-geochemical methods in the Vogtland-NW Bohemian region: new results and aspects. In: Seismology in Europe - Proc. of the XXV. General Assembly of the ESC, Reykjavik, 9-14.9. 241-246.

Streil, T. Klinke, R., Grundke, W., Surbeck, H., and James, A.C. (1996). Int. Conf. Technol. Enhanced. Naturally Radioactivity (TENR) Caused by Non- Uranium Mining, Szyrk, Poland, October 141-146.

Streil, T. Balcazar, M. Oeser, V. (2002). EPOS- a Multiparameter Measuring System To Earthquake Research. Geofisica International vol. 41, Num 3, 289-293.

Zongjin, M.A. (1990). Earthquake Prediction. Nine Major Earthquakes in China (1966-1976). Seismological Press, Beijing.