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Isotope Techniques and Geothermal Resources Management

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ABSTRACT

Since the beginning of the new century, while isotope data and hydrological information continued to be gathered for new exploratory geothermal prospects, environmental isotopes and artificial radiotracers have been increasingly used to monitor changes in the geothermal reservoirs of producing fields to ensure sustainability of production.

State of the art in the application of isotope techniques for geothermal resources management, in particular in developing countries in Africa, Asia and Latin America, is reviewed and case examples given.

INTRODUCTION

Isotope techniques have been used in hydrological studies of geothermal systems for almost five decades and have made significant contributions to geothermal energy development programmes across the world. Practical applications of isotope techniques to geothermal exploration also date back to 1970s and extensive applications were in the late 1980s and early 1990s. In the last five years, applications have been augmented with the following major progress: the increased availability of isotope data and hydrological information derived for development of new geothermal prospects and management of producing geothermal fields, wider use of isotopes of sulphur species (S-34 and O-18 in H2S and aqueous SO4), increased use of noble gas isotopes including those at the scale of individual fields and in limited cases even for reservoir monitoring, application of Sr and boron isotopes for improved understanding of water-rock interaction processes, implementation of regular isotope monitoring Programme on producing fields, recognition of fresh water and other environmental issues in geothermal development and potential contributions of isotope hydrology, improved capacity and more field applications using radiotracers (I-131 and I-125).

This current survey intends to review recent progress and current status in the application of isotope techniques for geothermal reservoir management based on mainly the IAEA projects.

SUSTAINABILITY: AN ISSUE OF SIGNIFICANCE IN GEOTHERMAL RESOURCES MANAGEMENT

Until recently, the focus of Agency's projects had been on the exploration aspects of geothermal prospects. However, two recent projects have emphasis on the management of geothermal resources in producing fields. For example, in Miravalles geothermal field in Costa Rica, observations show that the steam pressure in the underground geothermal reservoir has dropped about 2.0 bars per year in the lat 7 years of production (Figure 1). This behavior of the field has posed a major challenge for the sustainability of development of the field. Injection of wastewater from the power plant has been considered a solution to this kind of problems in many geothermal fields. However, this may be ineffective if handled inappropriately or it may cause cooling of the reservoir too quickly.

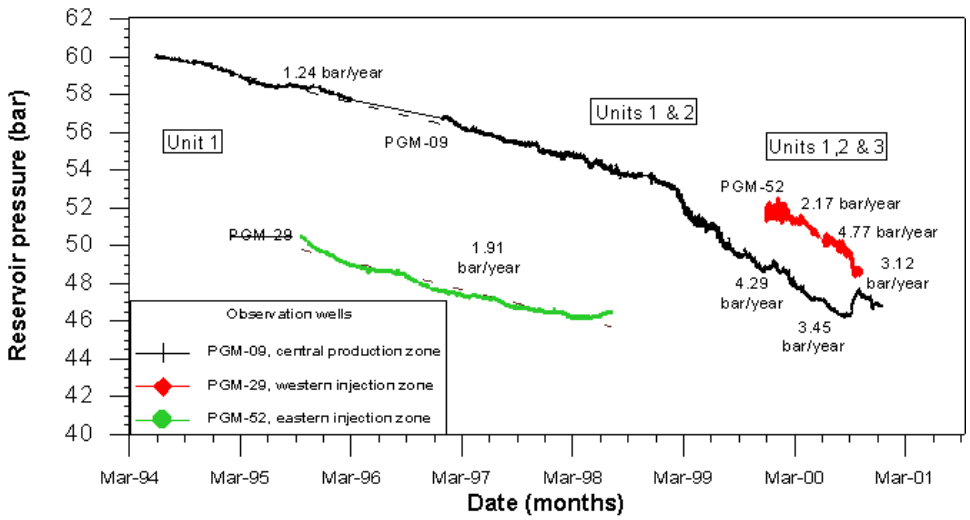


Fig. 1. Pressure decline in Miravalles geothermal field responding to production since 1994.

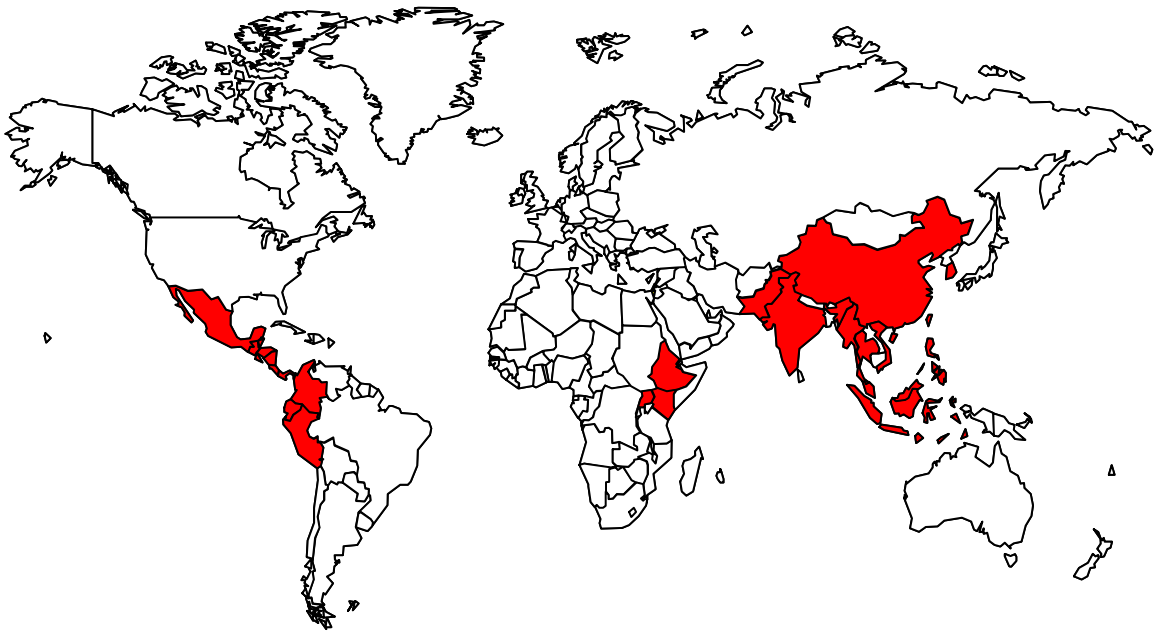


Fig. 2 Recipient countries of technical assistance in IAEA projects 2000-2004

Based on experience form other regions and especially that of developed countries, like Iceland, New Zealand and the US, environmental isotopes such as 18O and 2H of water, are useful tools in providing information on geothermal reservoir processes. The Agency has therefore established projects to transfer technology on geothermal reservoir monitoring and management using isotope techniques to Africa, Asia and Latin America.

In the last five years, the IAEA has implemented isotope hydrology projects in geothermal resources development and management in Africa, Asia and Latin America, in which 22 countries are recipient countries (Fig. 2).

As an example, Central American region is very rich in geothermal resources due to its tectonic setting along a chain of volcanoes. Actual development of geothermal resources for electric energy generation started in 1980s. Now, there are 7 producing fields in 4 countries, Costa Rica, El Salvador, Guatemala and Nicaragua. The contribution of geothermal energy to the total electricity consumption is considerable, with 23% for El Salvador and 14 % for Nicaragua, 10% for Costa Rica and 10% for Guatemala in 2002. There are 7 geothermal reservoirs altogether currently producing a total capacity of 300 Mwe in the region. This has therefore become one of the focuses of the IAE Programme on geothermal resources management using isotope techniques.

Environmental isotopes: Monitoring programme in geothermal reservoir management

Monitoring program is a must for any strategy of geothermal reservoir management. The knowledge of reservoir changes using the appropriate chemical and isotopic parameters will make it possible to establish a management strategy for more efficient and more sustainable production of the field. However, monitoring programs for geothermal producing fields in different countries are found to be quite different in terms of parameters analyzed, controls used and responses of reservoir as a result of production (Table 1), indicating the need for standardization and common guidelines related to isotopic techniques for geothermal reservoir management. The main changes in the reservoir have been recognized as cold water incursion and boiling of reservoir water as well reinjection return. For a better control it is always necessary to include isotope analysis in the monitoring program. Success of sustainable producing fields has shown that isotope monitoring is effective if integrated into a regular chemical monitoring program. For example, isotope data in Mahanagdong geothermal field in the Philippines indicates flow patterns in the field with production load (Dacillo and Salonga, in press).

Since year 2001, isotopic analysis has been added to the monitoring programs of geothermal producing fields in four countries in Central America: El Salvador, Costa Rica, Guatemala and Nicaragua.

Isotopic monitoring, like chemical motoring, of geothermal reservoirs require establishment of baseline as the starting point of a monitoring program. Subsequent regular sampling of well discharges will show changes with production if any. Generally speaking, the frequency of sampling is higher during the early stages of discharge. Occasionally, samples should be taken for analysis of all major components in both water and gas samples but otherwise partial analysis is considered sufficient (Arnorsson, 2000). The number and frequency of samples can be optimized by following the history of chemical evolution of the reservoir.

Artificial radioisotopes: Tracing the interconnections between wells in the geothermal field and need for improved tools for tracer data interpretation and cooling prediction

During a workshop in Kenya in 2002, a survey was conducted among the participants to collect information on the application of radiotracers in geothermal reservoir management. The participating countries were China, Costa Rica, El Salvador, Guatemala, Indonesia, Kenya, Mexico, Nicaragua and the Philippines (IAEA, 2002). The results showed an urgent need to transfer technology on this subject including interpretation tools. In the last two years, IAEA has provided support to countries wanting to apply radiotracers. Two more countries in Central America, i.e. Guatemala and Nicaragua, have become new users of radiotracers for interwell tracer tests (Table 2).

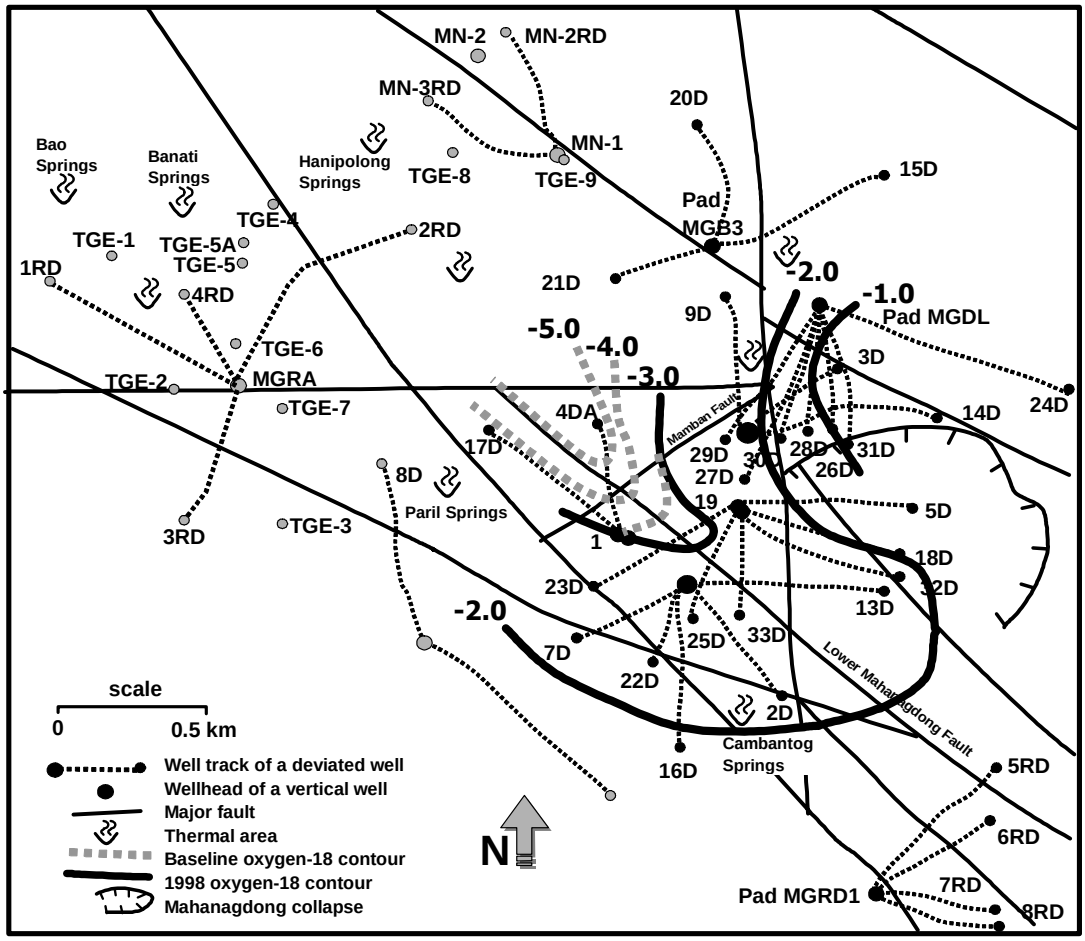


Fig. 3 The present $\delta^{18}O$ contour (in per mille VSMOW) of the deep reservoir fluids in Mahanagdong showing increased indentation of isotopically depleted fluids from the northwestern sector (Dacillo & Salonga, in press).

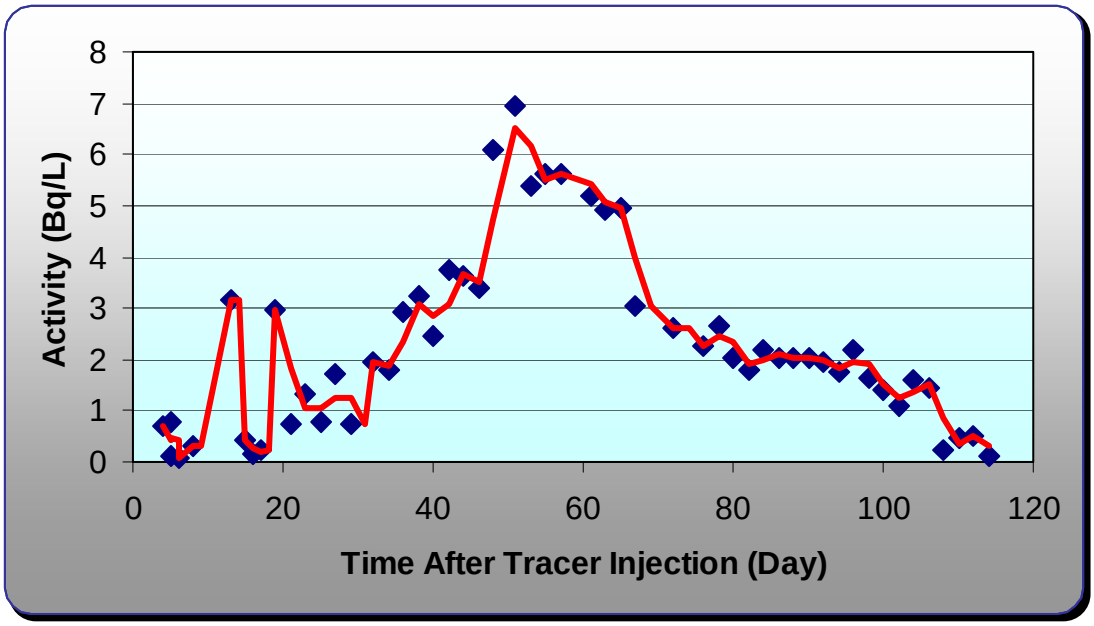


Fig. 4. Tracer return curve for the tracer test using I-125 in Tianjin, China (Zhao, 2002)

More tracer tests have been implemented in other fields, especially in interwell connection studies. They have proven to be very useful in the management of the geothermal reservoirs involved. In Tianjin geothermal field of China, where there are 200 wells supplying hot water for space heat during winter time, injection has been a major challenge because it is a sandstone aquifer. In downtown Tianjin, the geothermal water is mainly used for space heating, bathing and recreation. Only 20% of the geothermal water is injected into the reservoir. To evaluate the flow path of injected brine in the reservoir, three injection projects have been implemented since 1996. Initially KI and KBr were used as tracers. But the tests resulted in non-detectable level of tracer return in the observation wells. Recently radiotracer I-125 was introduced in the tests and tracer return curve was successfully established that provided essential information on the inter-well connections in the geothermal reservoir (Figure 3).

However, comprehensive interpretation, and consequent modeling for management purposes (cooling predictions of production wells), has been rather limited. The only country where tracer test data have been interpreted on a regular basis, and used as basis for cooling predictions, is El Salvador (IAEA, 2004). Therefore, increased emphasis should be placed on full use of this tool for management purposes. Software related to tracer test analysis, and re-injection simulation, such as the *ICEBOX* software package, has proven to be very effective. The program is based on simple models but is able to simulate the relevant data quite accurately. The utilization of more advanced numerical models (such as TOUGH2) is seldom warranted, at least as the first stage analysis, but could be the next step of integration in a comprehensive reservoir management programme.

The IAEA has just published a guidebook on radiotracer techniques that includes geothermal reservoir management. The IAEA has also started a new coordinated research project on radiotracers to further develop their applications in geothermal reservoir management.

CONCLUSIONS

Hydrological studies using isotope techniques in geothermal reservoir management, including the use of environmental isotopes as well as artificially introduced radiotracers, have seen considerable progress in the last several years. Developing countries, such as those in the Central America region, have acquired and are applying the advanced technology.

Although isotope techniques are powerful tools for geothermal reservoir management, their applications are still rather limited, in particular, the interpretation tools of tracer test results are not fully developed and utilized. Further development and wider use are considered beneficial to many countries with producing geothermal fields.

International cooperation has promoted the application of novel technology. Further strengthening such cooperation will help to speed up geothermal energy programme expansion in the future.

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REFERENCES

IAEA, Report of the interregional workshop under INT0060 held in Nairobi, Kenya, March 2001, 45pp.

IAEA, Report of the third project coordination meeting under RLA8032 held in Managua, Nicaragua, 70pp.

Arnorsson, S.(ed.), 2000, Isotopic and chemical techniques in geothermal exploration, development and uses, IAEA, Vienna

IAEA, 2004, Radiotracer applications in industry-a guidebook, ISBN 92-0-114503-9, pp.281

Dacillo, D. And Salonga, N., Conceptual flow patterns from stable isotope systematics , of the Mahanagdong geothermal field, Philippines, in Z. Pang & A. Truesdell (eds.), 2005, Special Issue of isotope techniques in geothermal investigations, Geothermics, in press.

Zhao, P., 2002, Project report for China in project Ras8092, Proceedings of IAEA RAS8092 project meeting, Beijing, China

TABLE 1. GEOTHERMAL RESERVOIR MONITORING PROGRAMS IN AFRICA, ASIA AND LATIN AMERICA REGIONS

Country	Field	Water Chemistry	Gas chemistry	Water isotopes	Main reservoir changes	Key parameters used for control
China	**Yangbajing**	1/y	1/3y	1/3y	Temp.& press. Drops, output decline	Gas/steam, SiO_2, Cations, Cl, B, pH, ^{2}H, ^{18}O, C, S, He, Sr
Costa Rica	**Miravalles**	4/y	4/y	1/ 2y	Boiling, reinjection return	Cl, ^{2}H, ^{18}O, enthalpy
El Salvador	**Ahuachapan**	4/y	4/y	4/y	Boiling, colder flow	Cl, $T_{SiO2,}$ $T_{NaKCa,}$
El Salvador	**Berlin**	1/m	1/m	1/m	Boiling	Cl, $T_{SiO2,}$ $T_{NaKCa,}$
Guatemala	**Zunil-1**	4/y	4/y	1/y	n.a.	Cl
Guatemala	**Amatitlan**	4/y	4/y	1/y	no changes	Cl
Indonesia	**Kamojang**	1/m	2/y	1/y	Reinjection return	D, O
Kenya	**Olkaria**	2/y	2/y	n.a.	no changes	Cl, T_{SiO2},Tcations, gas, enthalpy
Mexico	**Cerro Prieto**	2/y	2/y	1/2y	Boiling, colder water inflow	Cl, SiO_2, Tcations, ^{18}O, ^{2}H
Mexico	**Los Azufres**	3/y	3/y	1/2y	Boiling, reinjection return	Cl, ^{2}H, ^{18}O, N_2
Philippines	**Tongonan**	1/m	1/m	As needed	Pressure drop, colder water inflow, reinjection return	Cl, T_{SiO2}, Cl/Ca, pH, SO_4, Mg, ^{2}H, ^{18}O

TABLE 2. TRACER TESTS USING CHEMICAL AND RADIOTRACERS IN THE REGIONS

Country	Field	Year	Tracer used	Interpretation	Cooling predictions	IAEA support
China	Yangbajing, Tibet	1980's	KI	No return	No	No
	Tianjin	2000	KI and KBr	No return	No	No
	Tianjin	2001	^{125}I and ^{35}S	Some return, not yet completed	Not yet	Yes
	Xiaotangshan, Beijing	2002	KI	Not yet completed	Not yet	No
Costa Rica	Miravalles	1990's	^{131}I	Some	No	No
	Miravalles	early 2000	Na-fluorescein	No return	TRCOOL	Yes
	Miravalles	early 2000	^{125}I	No return	TRCOOL	Yes
	Miravalles	late 2000	^{125}I	Minor return in one well	No	Yes
El Salvador	Ahuachapan	80's-90's	^{131}I	Several tests, some w. TRINV	Some w. TRCOOL	No
	Ahuachapan	2001	^{131}I	TRINV	TRCOOL	No
	Chipilapa	2001	^{125}I		No	No
	Berlin	1990's	Alcohol	Some	Some	No
	Berlin	2000	^{131}I	TRINV	TRCOOL	Yes
Guatemala	Amtitlan and Zunil	2004	^{125}I			Yes
Indonesia	Kamojang	1992	^{133}Xe	No return	No	No
	Kamojang	1992	^{3}H	Preliminary interpretation	No	No
	Kamojang	1999	Alcohol	No return	No	No
	Lahendong	2004	HTO	Return		Yes
Kenya	Olkaria East	1991	Na-fluorescein	Preliminary interpretation	No	No
	Olkaria NE	1994	KI	Preliminary interpretation	No	No
	Olkaria East	1996	Na-fluorescein	Preliminary interpretation	No	No
Mexico	Cerro Prieto	1996?	^{131}I	Some return, limited analysis	No	No
	Loz Azufres	2000?	Ethyl Alcohol	Some return, limited analysis	No	No
Nicaragua	Momotobo	2004	^{125}I			yes
Philippines	Mahanagdong	1999	^{125}I	Preliminary interpretation	No	Yes