



First Research Coordination Meeting
for the
Coordinated Research Programme (CRP) on
“The Use of Isotope Techniques in Investigating Acidic Fluids in Geothermal
Exploitation”

Report

by
Jane Gerardo-Abaya
Scientific Secretary

International Atomic Energy Agency
Wagramerstrasse 5, Vienna 1220
Austria

February 1998

30 - 07

L

Executive Summary

1. The First Research Co-ordination Meeting for the CRP on "The use of isotope techniques in problems associated with geothermal exploitation" was held from 21-23 October 1997 in the IAEA Headquarters, Vienna, Austria. It was attended by ten scientists from CRP-participating countries: China, Iceland, Indonesia, Philippines, Italy, Mexico, Turkey, Russia, U.S.A and Japan, as observer.
2. The role of isotopes in geothermal reservoir monitoring and exploration activities have been fully demonstrated in a number of Agency Technical Assistance (TA) projects. One recent excellent example of full integration in regular reservoir assessment is in the model project of El Salvador (ELS/8/005), where the impacts of isotope techniques are considered of high relevance. Its importance in geothermal investigations is also reflected in the numerous geothermal associated projects, currently constituting 18% of the TA on isotope hydrology. Further developmental activities, however, are impaired by the natural or induced occurrence of acidic water in most geothermal areas, particularly those associated with active volcanism. Both H_2SO_4 and HCl - causing problems in geothermal systems were discussed extensively under the CRP.
3. Acidic fluids could effectively be investigated by ^{34}S and ^{18}O in SO_4 , together with ^{18}O and 2H in H_2O . As they are not in equilibrium with their host rocks, the temperatures of acidic fluids at depths cannot be estimated by existing cationic geothermometers which are based on equilibrium conditions. With more field investigations, the equilibrium conditions and kinetics of the isotope reaction pairs of the system $SO_4-H_2S-H_2O$ would be better understood and temperature estimates more reliable. The potential of isotopes for calculating temperatures by the use of the H_2O-SO_4 pair is, therefore, strong. In fact, the same set of data could indicate the genesis of the acid fluids.
4. HCl is a natural constituent of magmatic water. Due to its volatility compared to acid sulfate species, it may be carried as a gas (in superheated steam) into geothermal wells where it may produce corrosion when the steam condenses. A greater understanding of this acid HCl occurrence would be, thus, be desirable and a further thermodynamic study should be made as part of the CRP.
5. Selected areas which represent a specific geological environment and where many wells are drilled must, therefore, be selected for the CRP. These areas should be characterized by different types of water which will allow comparison of their chemical and isotopic compositions. The following are proposed:
 - a) Rhyolitic area- Uzon caldera (silicic volcanic), Russia; Maly Semjachic (acid lake), Russia; The Geysers, USA
 - b) Andesitic areas- Los Humeros, Mexico; Mt. Apo, Bac-Man or Mahanagdong, Philippines; Sibayak, Indonesia; Sumikawa, Japan; Larderello, Italy
 - c) Basaltic area- Krafla, Iceland
6. The Agency would coordinate and encourage the participants in the group to work together in specific areas to strengthen the research. Exchange of samples for analysis will be considered. Selected samples would be sent to commercial laboratories for trace element and noble gas analysis.
7. It is important to share among the participants the sampling methods (e.g. for ^{34}S in SO_4 and H_2S or for noble gases). The available instruments and analytical capacities of each participating laboratory should be considered in analytical needs of the participating institute.

A. Introduction

For the last five years, the technical assistance programme on geothermal energy of the Section, Isotope Hydrology of the International Atomic Energy Agency expanded. At present, 18% of the Technical Cooperation activities of the Section deals with geothermal hydrology. In these activities, the role of isotopes has been fully demonstrated as essential towards understanding the complex processes in geothermal systems. One excellent example by which this has been fully integrated into regular developmental operations was the recent model project in El Salvador. In this project, the impacts of the isotope investigations have been considered of high relevance.

Geothermal exploration and development for electrical and non-electrical applications is taking place in more than 36 countries worldwide. Although the technology has fully emerged, there are still hindrances to the full exploitation of the available heat. Most of the high temperature geothermal areas are situated in volcanic environments that produce acidic fluids which are corrosive for wells, as well as pipelines. Developmental activities, either at an early phase of exploration drilling or during intensive exploitation of the reservoir, have reportedly encountered acidity at a pH of 1. Incidental drilling in those areas, for lack of better data, cause high economic losses at a cost of about USD 2 million per well. In addition, a potential natural resource for electricity remains untapped.

The need and the urgency for applying the isotope technique to problems encountered in geothermal exploitation, such as acidity, was recognized in the final meeting of the Coordinated Research Programme (CRP) on the *Application of Isotope and Geochemical Techniques to Geothermal Exploration in Middle East, Asia, the Pacific and Africa*. It was subsequently stressed in the Advisory Group Meeting on Geothermics held in June 1995 at IAEA Headquarters. In realization of the problems associated with geothermal exploitation and the potential role that isotope techniques could provide for a greater understanding of the complex behavior of geothermal systems, particularly those affected by acidic fluids, the **Coordinated Research Programme (CRP) on "The use of isotope techniques in problems associated with geothermal exploitation"** is being implemented from 1997-2000. An understanding of the phenomena will assist the scientific community involved in geothermal development. The information generated from the scientific investigations will be an input to management of the resource as well as to decision-making for monitoring and development of geothermal areas.

The First Research Coordination Meeting

The First Research Co-ordination Meeting for this CRP was held from 21-23 October 1997 in the IAEA Headquarters, Vienna, Austria. It was attended by ten scientists from CRP-participating countries: China, Iceland, Indonesia, Philippines, Italy, Mexico, Turkey, Russia, U.S.A as well as Japan, as observer (Appendix 1).

The meeting was opened by Mr. Sueo Machi, Deputy Director-General, Department of Research and Isotopes, with the participation of Mr. Ranga Iyer, Director of the Division of Physical and Chemical Sciences and Mr. Klaus Froehlich, Head of the Section of Isotope

Hydrology. The results of current investigations relating to acid fluids in the various geothermal systems were presented by the participants (Appendix 2).

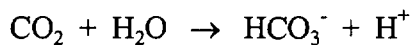
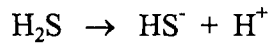
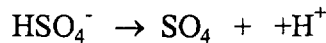
This report provides the hydrological concept, in the following section, on which the research on acid fluids is based. It would be noted that the CRP covers the more common causes of acidity associated with H₂SO₄ and HCl. It also includes the summaries of the researches (Appendix 3) under the CRP as well as the agreed actions for follow-up work.

B. ORIGIN OF ACID FLUIDS - GEOLOGY, FLUID FLOWS AND EQUILIBRIA

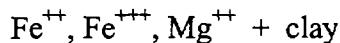
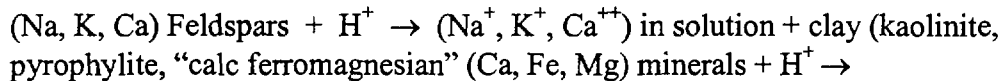
by A. Truesdell and F. D'Amore

1. Genesis of deep acid sulfate waters

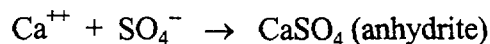
The geothermal fields which have the most problems with acid fluids are related to andesitic volcanism, particularly around the Pacific "Ring of Fire". This volcanism results from the subduction of wedges of sediments containing seawater, a rich source of water, carbon, sulfur and chloride, which are incorporated in andesitic volcanic magmatic fluid as H₂O, CO₂, SO₂, H₂S and HCl. When these fluids are released from the magma under supercritical conditions (Temperature > 374°C and P < 220 bars), these compounds are not reactive. However, when this fluid enters a fractured rock and is cooled by mixture with descending meteoric waters, the gas mixture becomes subcritical. The water condenses to liquid augmented by the meteoric contribution and the other gas dissolve to form an acid saline fluid. The gases dissolve to form ions in solution according to the reactions:

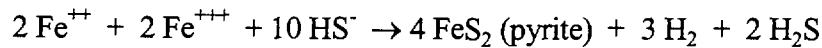
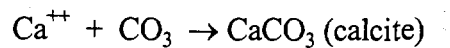


As indicated, the product of all of these dissociation reactions is the Hydrogen ion, a solution that is strongly acid. Moreover, the solution is oxidizing due to the formation of oxygen gas. This solution is then highly reactive and interacts with minerals of the host rock, as follows:



The products of these solution reactions are partially removed by the sulfur anions resulting from gas dissociation by the reactions:





Through these dissociations, neutralization and precipitation reactions, the oxidized magmatic gas, high in acid forming constituents has been changed to a reduced Na^+ , K^+ , Cl^- solution with moderate amounts of Ca^{++} , HCO_3^- and SO_4^{2-} , i.e. normal geothermal waters.

The reactions leading to formation of an acid fluid depend on the pressure in the volcanic system of chlorine, carbon and sulfur which have their source in the subducted seawater involved in the genesis of andesitic volcanism. Other volcanic systems are associated with hot spots under continental masses without access to seawater. These systems have much less chloride, calcium and sulfur and produce geothermal systems with much less acid potential acid-formed gases.

2. Genesis of HCl in geothermal systems with superheated steam

HCl is a natural constituent of magmatic water. Due to its volatility compared to acid sulfate species, it may be carried as a gas (in superheated steam) into geothermal wells where it may produce corrosion when the steam condenses. It is probably possible to form HCl in any hot ($>300^\circ\text{C}$) geothermal brine which boils to dryness.

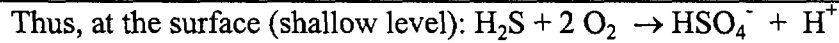
The mechanism of its formation is controversial. HCl could possibly be formed from chloride brines or solid reactions. Calculations and experimental studies of HCl volatility from hot NaCl brines differ by orders of magnitude and no comprehensive experimental studies has been made of the pressure of HCl over silicate - halite mineral assemblages in high temperature steam. However, thermodynamic calculations do suggest that solid reactions of halite could form more than 100 ppm HCl in steam. The fact remains that HCl occurs in superheated steam from Larderello and The Geysers' vapor-dominated geothermal systems in areas known to have temperatures above 300°C .

As a result it has been necessary to install expensive NaOH injection systems on numerous wells of both systems. At Larderello, a less direct but more comprehensive solution to this problem has been injection of liquid waters to decrease the temperature and the degree of superheat so that the HCl dissolves in reservoir liquid and becomes neutralized by rock minerals.

A greater understanding of this acid HCl occurrence would be, thus, be desirable and a further thermodynamic study should be made as part of the CRP.

3. Chemical Model Of Processes Converting Magmatic To Geothermal Waters

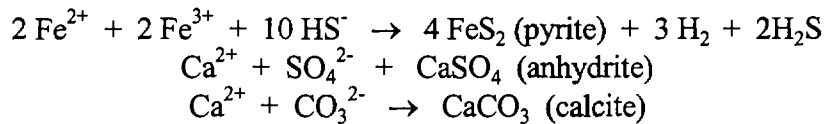
Below is a schematic representation of the chemical reactions as the magmatic gases rise to shallow levels (read bottom up)



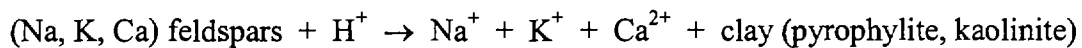
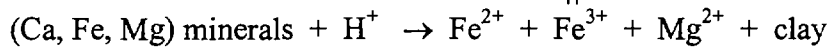
Final acidity is function of the mass balance between meteoric water recharge and the deep magmatic flow.

↑

The original magmatic solution → normal geothermal water

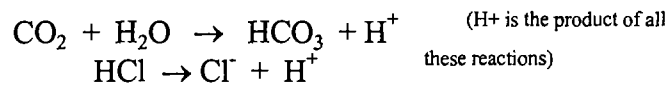


↑



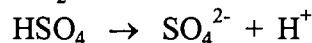
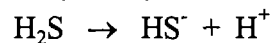
↑

HIGHLY REACTIVE SOLUTION INTERACTS WITH HOST ROCK



METEORIC

WATER RECHARGE



(oxidizing acid fluid)

↓

↓

↓



↗

⇒

↘ ⇌ ⇌

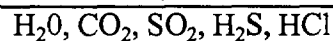
THE GASES DISSOLVE IN SOLUTION

geothermal fluid (t < critical point)

magmatic fluid (t > critical point, p > 220 bar)

condensation

entry through fractured rock



not reactive compounds ⇌

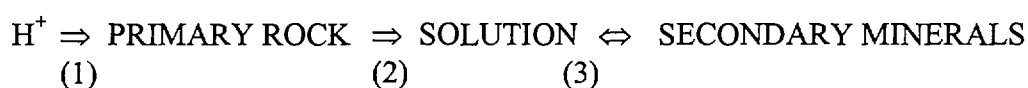
↑

MAGMATIC FLUID FLOW

Andesitic volcanism due to subduction of wedges of sediments containing sea water. The source of chloride, carbon and sulfur.

The reactions described above represent the complete conversion from volcanic to geothermal fluid. However, this has required an excess of rock minerals and enough addition of meteoric water to produce complete contact and reaction of fluid and solid reactants. If the meteoric water is not enough, the acidic products of the initial gas dissociation may remain in the fractures where they formed and react only with the local fracture walls without complete neutralization or precipitation of calcium, sulfate and carbonate. This remaining fluid will have a low pH, high Ca^{++} , Mg^{++} , Fe^{++} and high SO_4^- relative to Cl^- , a sulfate acid water on the margin between the geothermal and magmatic environments. In the Philippines though, it is more common to encounter acid fluids with high Cl^- relative to SO_4^{-2} . Increasing SO_4^{-2} with stable Cl^- concentrations have been observed, especially in Mt. Labo.

The process of conversion of magmatic fluids to the more benign neutral geothermal fluid was also presented by Arnorsson *et al.* (1995) and termed as H^+ ion metasomatism:



Both Giggenbach (1981) and Arnorsson *et al.* (1995) have proposed that most gaseous species and essentially all anions in volcanic-hosted geothermal systems are derived from an underlying magmatic source, while cations in solution are largely the product of primary neutralization and reduction reactions between the wall rock and the aggressive acid fluids (the latter produced from dissociation, as the magmatic gases in solution cool upon ascent).

From the above three reactions, only reaction (3) proceeds to equilibrium, as denoted by the double arrows, with reactions (1) and (2) being highly destructive resulting to rock dissolution in primary magmatic environments and rock alteration as the aggressive fluids are finally neutralized.

4. A general solution to the occurrence of acid fluids - Reinjection

Using the reinjection observed at Larderello (Italy) as a model, it seems likely that water injection could also cause the neutralization of acid sulfate waters. This takes place by inducing the movement of acid water away from the fractures that have already been acid altered, into other parts of the reservoir where fresh rock surfaces could still neutralize it. Any such injection experiment could, however, run the risk of moving acid into the feed zones of wells producing neutral water. Thus, injection quantity and the production fluids of nearby wells should be carefully monitored.

In addition, Palinpinon I (Philippines) is a well-documented case history of beneficial injection at the Odlumon Fault where the heated injection waters displaced the entry of shallow acid fluids in wells PN-22D and OK-10D. These benefits were identified using stable isotopes and the geo-indicators Cl , SO_4 , Mg and SiO_2 (Seastres *et al.* 1995).

As desirable as it is to fix wells with acid fluids, it is more desirable not to drill any. The realization that acid geothermal fluids are formed from insufficiently neutralized volcanic fluids suggests strongly that the development of a near-volcanic geothermal field should proceed from the part furthest from the volcano. Moderate temperature (280-300°C) fluids should be preferred to hotter fluids near the volcanoes that have a chance of become acid.

Similarly, it is worthwhile to carry out injection tests in acid wells which are usually located in high temperature horizons (>300°C) close to the volcanic heat source, and monitor the effects on nearby neutral or steam dominated production wells. The benefits of this type of injection are two-fold: 1) mining the heat from the high temperature horizon and 2) inducing the neutralization of acid waters by pushing the fluids to unaltered rock horizons. This is the current injection strategy at Mahanagdong B and is the same strategy planned for the Mindanao 2 development.

C. ASSESSMENT AND RECOMMENDATIONS OF THE MEETING PARTICIPANTS

1. *Definition of acid fluids*

A scheme or classification should be established for the different types of geothermal reservoir fluids. It is envisaged that it would involve measurement of pH of discharge water at room temperature. The pH buffers involved in each type of water must be identified and quantified.

2. *Evaluation of fluid and mineral equilibria*

The state of equilibration should be established in geothermal fields where both acid and neutral pH fluids occur. This requires water and gas chemical data, including trace elements, as well as the alteration mineralogy. The components that will be demonstrated to be out of equilibrium should be specifically studied with respect to their sources and kinetics. Use will be made of available thermodynamic data on mineral solubilities and aqueous speciation program for computing reaction quotients. Specific attention should be made to the applicability of gas and solute, as well as isotopic, geothermometers in acid waters. In addition, reaction path programs should be used for expanding the understanding of water-rock interaction for both types of water.

The physico-chemical processes happening within the reservoir should also be determined in interpreting the chemical species. In addition, the differences in the chemical composition of the fresh and altered rocks in particular with respect to the volatile components are considered useful.

Inasmuch as an early warning of acidity can be obtained from noble gases since they remain unaltered even to a great distance from the source, it is worthwhile to study the distribution of noble gases in selected areas having both acidic and neutral-pH fluids.

3. *Origin of the acid fluids* *by PNOC-EDC, Philippines*

Much emphasis has been given on the problem of deep fluid acidity associated with unreacted or un-neutralized condensed magmatic volatiles (e.g. SO₂, HCl, CO₂ and H₂S). Although the deep seated type of acidity is more corrosive (with pH<1), shallow acidity is a more common problem in exploited fields experiencing drawdown. Acidity from H₂SO₄ can have a deep seated (e.g. from H₂S and SO₂) or shallow origin (e.g. from H₂S oxidation in the air saturated or vadose zone). Hence, equal importance should be given on methods of characterizing the origins of acidity (deep or shallow) and identifying the useful geo-indicators for this purpose. This is required as solutions or mitigating measures may differ. In Mahanagdong, wells are targetted away from the zone of deep acidity. In Bac-Man, wells are drilled deeper relative to the zones of shallow acidity, while in Mt. Apo, drilling is terminated above the zone of deep acidity.

The use of ¹⁸O and ²H (in water) in identifying the origin of the acidic fluids which plot very close to the “andesitic” water region, as defined by Giggenbach (1992) would definitely indicate a magmatic origin.

The same holds true for the use of the noble gases, He and Ar together with N₂. Only for gas samples which plot very close to the magmatic corner of the N₂-He-Ar trilinear diagram are we certain that the source of acidity is magmatic in nature.

It is hoped that the use of S isotopes would determine the origin of acid fluids. However, past and on-going studies have shown that the use of ³⁴S may not always unequivocally distinguish whether H₂SO₄ acidity is of deep seated or shallow origin. This may be due to the following reasons:

1. Both types of acidity have a common S source, which is correlated to H₂S. It is very common to obtain δ³⁴S in H₂S with values close to 0 ‰, thereby signifying the magmatic origin of H₂S. Only if we obtain δ³⁴S of sulfates (in water) close to 0 ‰ are we then sure that acidity is due to shallow oxidation of H₂S. However, if δ³⁴S of sulfates is high, we are uncertain whether the source is deep seated, or from shallow sulfate water which have undergone isotopic fractionation at elevated temperatures.
2. The actual isotopic composition and origin of S in volcanic and geothermal systems has often been obscured by processes taking place at depth, e.g. boiling, mixing of fluids and vapor condensation (Robinson, 1987; Serrano *et al.* 1996). Most geothermal systems show that S isotopes are not in equilibrium in the present-day reservoir fluids.

It is possible that the source of oxygen may distinguish the two H₂SO₄ derived acidities. Shallow acidity from oxidation of H₂S should have a distinct ¹⁸O (in sulfates) signature from that of the deep SO₂ disproportionation reaction.

4. Areas

Specific areas must, therefore, be selected for this study. These areas should be characterized by different types of water which will allow comparison of their chemical and isotopic compositions. The criteria for selection are:

- areas with many drillholes
- area with crater lake
- one area for a specific geological environment

The following areas are tentatively proposed:

- | | |
|------------------|--|
| Rhyolitic area- | :Uzon caldera (silicic volcanic), Russia |
| | :Maly Semjachic (acid lake), Russia |
| | :The Geysers, USA |
| Andesitic areas- | :Los Humeros, Mexico |
| | :Mt. Apo, Bac-Man and Mahanagdong, Philippines |
| | :Sibayak, Indonesia |
| | :Sumikawa, Japan |
| | :Larderello, Italy |
| Basaltic area- | :Krafla, Iceland |

The Agency would coordinate and encourage the participants in the group to work together in specific areas to strengthen the research. Exchange of samples for analysis should be considered. Selected samples should possibly be sent to commercial laboratories for trace element and noble gas analysis.

5. Monitoring by geochemical tools during exploration

The following chemical and isotopic parameters can be monitored during field exploitation. Some of the data can be routinely obtained (type ¹), others require a high cost and time consuming analysis (type ²). Type 2 could be optional.

- (a) Gas/total water ratio (¹). Acidic wells are often very rich in gas because of the high pressure of CO₂.
- (b) Gas composition as: CO₂, H₂S, H₂, CH₄, N₂, Ar, NH₃ (¹).
Gas composition as: CO, He (+ Ne, Xe) (²).
The gas composition allows the calculation of the following reservoir parameters: temperature, P (CO₂), steam fraction, redox conditions [as log P (O₂) and log P (S₂)].
- (c) pH_{25oC} and water composition Na, K, Ca, Mg, Cl, SO₄, total CO₂, Li, SiO₂ (¹).
Fe, Al, Br (²).
- (d) δ²H and δ¹⁸O of water (recalculated using enthalpy data and proper fractionation factor (¹)).
- (e) δ¹³C (CO₂) (¹).
δ¹³C (CH₄), δ²H (CH₄), δ²H (H₂) (²).

The above data are very useful as absolute values and in the following pairs for geothermometry applications: CO₂ - CH₄, CH₄ - H₂, H₂O - H₂

(f) $\delta^{34}\text{S}$ for SO₄ and H₂S and $\delta^{18}\text{O}$ for SO₄ (1) - (2).

The data are very useful as absolute values (also to be compared with the $\delta^{34}\text{S}$ of volcanic SO₂) and for the geothermometric use in the pairs: SO₄ - H₂O and SO₄ - H₂S. The latter should, however, take into consideration that equilibration is also a function of the pH and kinetic must be investigated

(g) Isotopic composition of noble gases (2).

(h) For water, the most promising geothermometers are those based on Na-K-Ca and SiO₂ contents. The Na - K and K - Mg geothermometers are not expected to work.

Gas geothermometers must still be tested for acidic fluid, considering that the H₂S/H₂ ratio is generally very high (more than 50).

6. *Sampling conditions*

It is necessary to emphasise the use of appropriate sampling techniques, and report the necessary physical data together with the chemical data for interpretation. This should be supplemented by detailed well testing and sampling plans for acidic wells inasmuch as such wells can only be tested in very short period of time. In areas where acidic waters can be expected, it is considered to be feasible to take downhole samples after the well has recovered thermally to establish whether acidic fluids will be discharged. This information can affect the plans for discharges. Selection of the appropriate materials for sampling apparatus for acidic fluids should be established so that representative samples can be collected for major as well as trace element analysis.

Reservoir gas pressures should be established with the purpose of finding out whether they are fixed internally (if controlled by specific equilibria, e.g., specific minerals or gases) or externally.

It is important to share the sampling methods among the participants (e.g. for ³⁴S in SO₄ and H₂S or for noble gases).

7. *Application of sulfur and oxygen isotope geothermometers*

The temperature of acidic fluids at depth cannot be estimated by existing cationic geothermometers, especially since most acidic fluids are immature waters. However, the silica geothermometer may be applied to acidic fluids, as in the case of well fluids in Mt. Labo, wherein the quartz geothermometer gave temperatures close to measured temperatures.

The use of the SO₄-H₂O geothermometer is very promising, since the oxygen isotope exchange rate is faster than the sulfur isotope exchange rate in the temperature and pH range of geothermal reservoirs. The isotopic re-equilibration occurs within a couple of years. Hence, re-equilibration of the oxygen isotopes during ascent of the geothermal fluids is negligible and the calculated temperature is that of the deeper reservoir.

8. *Laboratory facilities*

The following are the available instruments and analytical capacities of each participating laboratory:

Indonesia:	^{18}O and ^2H in water, ^{13}C , ^{34}S , ^{18}O in sulphate; ^{14}C , XRF
Russia:	^{18}O and ^2H in water; ^{34}S in sulphide and sulphate; ICP for microelements
China:	ICP analysis of microelements; electron microprobe; XRD
Mexico:	^{18}O and ^2H in water; IC and GC, XRF, ICP
Iceland:	Si, B, Na, K, Ca, Mg, Fe, Al, Sr, Mn, SO_4 , CO_2 , NH_3 , NO_2 , NO_3 , PO_4 , H_2S , Cl, F in water samples; CO_2 , H_2S , H_2 , CH_4 , N_2 , O_2 , Ar in gas samples); ^{18}O and ^2H in water; access to ^{13}C and ^{14}C .
Philippines:	^{18}O and ^2H in water, chemical analyses in water and gas, IC, XRD
Italy:	CO and He, $^3\text{He}/^4\text{He}$, ^{13}C (CO_2), ^{13}C (CH_4), ^2H (CH_2), ^2H (H_2), ^2H (H_2O), ^{18}O (H_2O), tritium.

9. *Commercial use of the acid fluids*

It should be emphasized that the CRP aims to gather technical information to achieve a unified understanding of the origins and occurrence of acid fluids. This is to enable us to solve problems associated with and/or find viable methods of commercial exploitation of these resources.

The problems associated with acid fluids cannot be continually avoided. A bigger portion of the hot fluids in volcanic hosted systems are highly acidic. Exploitation of the neutral fluids located away from these regions can invite the migration of shallow acid fluids to deep regions or the lateral migration of magmatic acid fluids. There is an urgent need to find answers for the further sustainability of our present geothermal resources and to prepare for future drilling and production strategies.

References:

- Arnorsson, S., Gislason, S. R. and Andresdottir, A. Processes influencing the pH of geothermal waters. Proceedings of the World Geothermal Congress, 1995, 957-962.
- Giggenbach, W. F. (1981) Geothermal mineral equilibria. *Geochim. Cosmochim. Acta*, **45**, 393-410.
- Giggenbach, W. F. (1992) Isotopic shifts in waters from geothermal and volcanic systems along convergent plate boundaries and their origin. *Earth Planet. Sci. Lett.* **113**, 495-510.
- Robinson, B. W. (1987) Sulphur and sulfate-oxygen isotopes in New Zealand geothermal systems and volcanic discharges. In *Studies on sulphur isotope variations in nature* (edited by International Atomic Energy Agency), pp. 31-48. Vienna, Austria.
- Seastres, J. S., Hermoso, D. Z., Candelaria, M. N. R. and Gerardo, J. Y. (1995) Application of geochemical techniques in evaluating the reservoir response to exploitation at Palinpinon geothermal field, Philippines. Proceedings of the World Geothermal Congress, 1995, 1025-1030.
- Serrano, R. G. M., Jacquier, B. and Arnold, M. (1996). The $\delta^{34}\text{S}$ composition of sulfates and sulfides at the Los Humeros geothermal system, Mexico and their application to physicochemical fluid evolution. *Journal of Volcanology and Geothermal Research* **73**, 99-118.

Appendix 1

First Research Coordination Meeting for the Coordinated Research Programme (CRP) on “The use of isotope techniques in problems associated with geothermal exploitation”

LIST OF PARTICIPANTS

Mr. Zhong-He PANG* (CSI: Mr.Hong-Rui FAN) Institute of Geology Chinese Academy of Sciences P.O. Box 9825, Beijing 100029 PEOPLE'S REPUBLIC OF CHINA *Presently at IAEA	Fax: 0043-1-20607* 0086-10-64919140 e-mail: z.h.pang@iaea.org*
Mr. Wenbin ZHOU East China Geological Institute Linchuan, Jiangxi, 344000 PEOPLE'S REPUBLIC OF CHINA	Fax: 0086-794-8223877 e-mail: wbzhou@ecgi.jx.cn
Mr. Stefán Arnórsson Science Institute University of Iceland Dunhagi 3, 107 Reykjavík ICELAND	Fax: 00354-5254499 e-mail: stefanar@raunvis.hi.is
Mr. Zainal Abidin Center for Application of Isotopes and Radiation National Atomic Energy Agency Jln. Cinere Pasar Jumat P.O. Box 7002, JKSKL, Jakarta 12070 INDONESIA	Fax: 0062-21-7691607 e-mail: his45@bit.net.id
Mr. Franco D'Amore (CSI: Mr. Costanzo Panichi) Istituto Internazionale per le Ricerche Geotermiche Piazza Solferino 2, 56128 Pisa ITALY	Fax: 0039-50-47055 e-mail: damore@iirg.pi.cnr.it
Mr. Mahendra Verma (CSI: Mr. Enrique Tello) Geotermia Instituto de Investigaciones Electricas Apartado Postal 1-475 Cuernavaca, 62001, Morelos MEXICO	Fax: 0052-73-182526 e-mail: mahendra@iie.org.mx
Mr. Noel Salonga (CSI: Mr. Hermes Ferrer) PNOC Energy Development Corporation PNPC Complex, Merritt Road Fort Bonifacio, Makati City PHILIPPINES	Fax: 0063-2-8152747 e-mail: salonga@edc.energy.com.ph

Mr. Gennadiy Karpov
Institute of Volcanology
Piyp Blvd 9
Petropavlovsk-Kamchatsky 683006
RUSSIAN FEDERATION

Fax: 007-4152254723

e-mail: volcan@svyaz.kamchatka.su

Mr. Sakir Simsek
Hacettepe University
International Research and Exploration
Center for Karst Water Resources (UKAM)
06532 Beytepe, Ankara
TURKEY

Fax: 0090-312-2992136

e-mail: dogdu@jeo.hun.edu.tr

Mr. Alfred Truesdell (CSI: Mr. Mack Kennedy)
700 Hermosa Way
Menlo Park CA 94025
USA

Fax: 001-415-3244009

e-mail: ahtruesdell@lbl.gov

OBSERVER

Mr. Kanichi Shimada
Geothermal Department
West Japan Engineering Consultants, Inc.
Denki Bld., Bekkan
1-1-1 Watanabe-dori, Chuo-ku
Fukuoka-shi, Fukuoka
JAPAN

Fax: 0081-92-7515044

e-mail: shima@wjec.co.jp

RESPONSIBLE OFFICER

Ms. Jane Gerardo-Abaya
Isotope Hydrology
International Atomic Energy Agency
Wagramerstrasse 5, P.O. Box 100
Vienna, Austria

Fax: 00-431-20607

e-mail: j.gerardo-abaya@iaea.org

Appendix 2
First Research Coordination Meeting of the
CRP on The Use of Isotope Techniques in Investigating Acidic Fluids
in Geothermal Exploitation
21-23 October 1997
Room C0755 - IAEA Headquarters
Vienna, Austria
Agenda

Tuesday, 21 October

- 0900H Opening of the Meeting
 Administrative Arrangements
 Coffee Break
- 1030H Noble Gas Isotopes As An Indicator of Potentially Acid Reservoir Fluids: High Gas, HCl and ³He in the Northwest Geysers due to Active Magmatic Degassing by A.H. Truesdell, B.M. Kennedy and G.M. Shook, USA
- 1115H Acidic fluids in Los Humeros geothermal reservoir by M.P. Verma, E. Tello and E. Nieva, Mexico
- 1200H Lunch Break
- 1330H Chemical and isotopic composition of thermal and non-thermal water in Skagafjörður, Northern Iceland by S. Arnorsson, Iceland
- 1415H Geochemical and isotopic study in the Eastern Hebei Sector of the North China Basin - Preliminary Results by Z.H. Pang, H. Fan, J. Jin, M. Chen and X. Deng, China
- 1500H Coffee Break
- 1530H Experimental study of water-rock interaction in geothermal system: Preliminary study and future work by W. Zhou, China
- 1615H Isotopic Geochemistry of Thermal Waters of Uzon-Geyzerny and Karymsky Geothermal Areas (Kamchatka) by G. Karpov, Russia
- 1730H Reception

Wednesday, 22 October

- 0900H Mechanisms of chemical phenomena in high temperature geothermal systems by F.D. Amore, Italy
- 0945H Acid Fluids and ³⁴S Systematics in some of the Philippine Geothermal Fields by N. Salonga and F.E.B. Bayon, Philippines
- 1015H Coffee Break
- 1030H Geothermometer and acid fluids study in Sibayak Geothermal Field by Z. Abidin, Nugroho, Wandowo, Alip, Djiono and E. Ristin, Indonesia
- 1115H Research on isotope techniques for exploitation of geothermal reservoirs in Western Turkey by S. Simsek, Turkey
- 1200H Lunch Break
- 1330H Chemical and isotopic characteristics of acid geothermal-fluid in geothermal fields of Kyushu, Japan by K. Shimada, Japan
- 1415H IAEA Programmes on Geothermal Energy - Review of isotopic results from field investigations by J. Gerardo-Abaya
- 1500H Coffee Break
- 1515H Discussions on the Coordinated Research Programme
State of the Art, needs and directions of the collaborative research
- 1730H End of Session

Thursday, 23 October

- 0900H Discussions on Coordinated Research Programme - continuation
- 1200H Lunch Break
- 1330H Results of discussions, Summary of Recommendations and Agreed Actions
- 1700H End of Meeting