INTERNATIONAL ENERGY AGENCY

# Geothermal Implementing Agreement (GIA) - Annual Report 1999

L. Rybach *(ETH Zurich/Switzerland; GIA Executive Committee Chairman)*
J. Garnish *(CEC Brussels/Belgium; GIA Executive Committee Secretary)*

## BACKGROUND

The IEA Energy Technology Collaboration Program (ETCP) has already included Implementing Agreements with geothermal objectives in the past, like the MAGES Project ("Man-Made Geothermal Energy Systems"), 1978 - 1980 and "Geothermal Equipment Testing", 1979 - 1981 but there were no such activities in the following years.

In 1995 the IEA Secretariat (Paris) made an effort to revive geothermal activities within the ETCP. At an ad-hoc meeting in May 1995, convened in conjunction with the World Geothermal Congress'95 in Florence, representatives of 14 countries expressed general interest in international collaboration under the IEA ETCP umbrella. An IEA Geothermal Expert Panel was formed, especially to formulate the IA Annexes. In two subsequent meetings in Paris (November 1995, April 1996) the legal text and the technical Annexes of the IEA IMPLEMENTING AGREEMENT FOR A CO-OPERATIVE PROGRAMME ON GEOTHERMAL RESEARCH AND TECHNOLOGY (GIA) were formulated. The IEA Secretariat provided great help in all these activities.

The GIA officially went into effect in March 1997 and is designed to operate for four years.

## NATURE AND OBJECTIVES

The GIA represents and important framework for a broad international co-operation in geothermal R & D. It brings together significant national programs and focuses especially on assembling specific know-how and generating synergies by establishing direct co-operative links between geothermal groups/specialists in the different Participating Countries.

### *Task/Annexes*

Currently there are three active Annexes:

- *Annex I: Environmental Impacts of Geothermal Energy Development* (3 Subtasks)

  The Work Plan of Annex I is designed for 4 years. Operating Agent is the Institute of Geological and Nuclear Sciences, Ltd. (New Zealand); Task Leader is T. Hunt (Wairakei).
- *Annex III: Hot Dry Rocks* (4 Subtasks)

  The Work Plan of Annex III is designed for 4 years. Operating Agent is the New Energy & Industrial Technology Development Organization (NEDO, Japan). Task Leader is M. Kuriyagawa (Tsukuba).
- *Annex IV: Deep Geothermal Resources (3 Subtasks)*

  The Work Plan of Annex IV is designed for 4 years. Operating Agent is NEDO (Japan). Task Leader is K. Kimbara (Tsukuba).

Detailed Annual Reports of these Annexes (including activities in 1999, results, future plans, and references), prepared by the Task Leaders, are given in the **ENCLOSURE.** The 1999 Annex Reports are organized in the following format:

- Introduction
- Work performed in 1999
- Work plan for 2000
- References.

The following additional Annexes have been considered:

- Annex II: Shallow Geothermal Resources
- Annex V: Sustainability of Geothermal Energy Utilization
- Annex VI: Geothermal Power Generation Cycles.

The status of the preparations is different. At the 4th ExCo Meeting in Paris (see below for details) it was decided to defer the preparatory works for Annex II until new and prospective GIA participating countries could express the extent of their interest. Whereas Annex V is being further developed, preparation of Annex VI will not be pursued until Italy has signed the GIA. A proposal has also been put forward for a new Annex on Geothermal Drilling R&D; a survey of ExCo members will be carried out in order to determine whether there is sufficient interest in the participating countries.

***Nature of work***

The GIA activities aim primarily at the co-ordination of the ongoing national activities of the Participating Countries. In addition, new activities –as defined in the GIA- are initiated and implemented.

The GIA operates under the task-sharing mode of funding.

***Objectives***

Article 1 of the GIA defines the objectives as "international collaborative efforts to compile and exchange improved information on geothermal energy research and development worldwide concerning existing and potential technologies and practices, to develop improved technologies for geothermal energy utilization, and to improve the understanding of geothermal energy's benefits and ways to avoid or ameliorate its environmental drawbacks".

## PARTICIPATION

At present, 8 countries (Australia, Greece, Japan, Mexico, New Zealand, Switzerland, United Kingdom, USA) and 1 international organization (Commission of the European Communities, CEC) have signed the Agreement.

The involvement of the Participants in the different Annexes is shown in Table 1. In this context it must be mentioned that not all Participants are active in all Subtasks of the Annexes in which they participate. The ExCo is making an effort to harmonize this situation.

**Table 1. Task participants as by December 1999**

| | Participating country/organization | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Australia | CEC | Greece | Japan | Mexico | New Zealand | Switzer-land | UK | USA |
| I: Environmental Impacts | | | **x** | **x** | **x** | **x** | | | **x** |
| III: Hot Dry Rock | **x** | **x** | | **x** | | | **x** | **x** | **x** |
| IV: Deep Resources | | | | **x** | **x** | **x** | | | **x** |

***Member Countries***

Preparatory work to secure the participation of Italy has been completed, signature is expected for early 2000. Contacts to Turkey are sustained.

***Non-Member Countries***

So far, Iceland and the Philippines have shown interest to join the GIA which certainly would add to the GIA, by their substantial geothermal energy development programs. In fact, Icelandic and Philippine scientists are already actively participating in the work of Task I.

## ACTIVITIES

***Meetings***

The list of current ExCo members and Alternates is attached (see ALTERNATES).

The ExCo had one Meeting in 1999: on 8 November in Paris, France, organized by the IEA Secretariat. At this Meeting

- the ExCo elected Prof. L. Rybach (Switzerland) as Chairman and Dr. A. Jelacic (USA) as Vice-Chairman for 2000.
- Dr. J. Garnish (CEC) was adopted as ExCo Secretary.
- the 1999 activity reports of the ongoing Tasks, along with the work plans for 2000, were presented. For details see the **ENCLOSURE**.

A Special Issue of the journal *Geothermics* has been produced for Annex I and a special Workshop for Annex IV. Details about these can be found in the **ENCLOSURE**.

***Costs of Agreement***

The GIA operates, as mentioned above, in the task sharing mode. The actual amount of work carried out for the GIA cannot be quantified at this moment. As a general rule it can be assumed that the involvement of the individual countries is somewhere on the order of one to several man-year(s).

It has been agreed at the ExCo meeting in Paris that a common fund (=Cost sharing) will be needed to conduct ExCo business, especially to produce a GIA Brochure (see below) and to establish a GIA homepage. Currently it is under negotiation how to establish the necessary fund.

***Dissemination of Results***

It is envisaged that the GIA follows the normal way of results dissemination: publications in scientific/technical journals. Substantial results will be presented at the WORLD GEOTHERMAL CONGRESS 2000 (Japan, 30 May – 10 June 2000) and published in the Proceedings.

## IEA Geothermal Implementing Agreement Executive Committee (February 2000)

| Country / Name | Delegate | Organisation / address | e-mail / tel / Fax | Alternate | Address, etc. (where different) |
|---|---|---|---|---|---|
| **AUSTRALIA** | **Doone Wyborn** | **Australian National University**<br>Department of Geology<br>Canberra, ACT 0200<br>AUSTRALIA | dwyborn@geology.anu.edu.au<br>Tel. ++61-262 49 3224<br>Fax ++61-262 49 5544 | Prame Chopra | prame.chopra@anu.edu.au |
| **CEC** | **John Garnish**<br>*Secretary* | **CEC DG Research**<br>Research-D2; Mo75 5/22<br>Rue de la Loi 200<br>B-1049 Bruxelles<br>BELGIUM | john.garnish@dg12.cec.be<br>Tel. ++32-2-295 8518<br>Fax ++32-2-295 6995 | Enzo Millich | **CEC DG TREN**<br>TREN-D2; TERV 6/26<br>Tel. ++32-2-295 3625<br>enzo.millich@cec.eu.int |
| **GREECE** | **Constantine Karytsas** | **CRES**<br>19th Kim Marathanos Ave<br>GR-19009 Pikermi-Attiki<br>GREECE | kkari@cres.gr<br>Tel. ++30-1-6039900<br>Fax ++30-1-6039905 | George Kanavakis | **CRES** |
| **JAPAN** | **Haruka Watanabe** | **NEDO**<br>3-1-1 Higashi-Ikebukuro<br>Toshima-ku, Tokyo 170<br>JAPAN | watanabehrk@nedo.go.jp<br>Tel. ++ 81-3987 9453<br>Fax ++81-3986 8197 | Syunichi Iwakiri | **NEDO**<br>iwakirisni@nedo.go.jp<br>Tel. ++ 81-3987 9453<br>Fax ++81-3986 8197 |
| **MEXICO** | **David Nieva** | **Division of Alternative Energy Sources**<br>Instituto de Investigaciones Electricas<br>Av. Reforma N°113, Col. Palmira<br>62490 Temixco, Mor.<br>MEXICO | dnieva@iie.org.mx<br>Tel. ++52-73 18 24 54<br>Fax ++52-73 18 95 42 | Victor Manuel Arellano Gómez | **IIE** |
| **NEW ZEALAND** | **Trevor Hunt** | **Institute Geological & Nuclear Sciences**<br>Wairakei Research Centre<br>Private Bag 2000<br>Taupo<br>NEW ZEALAND | t.hunt@gns.cri.nz<br>Tel. ++64-7 374 8211<br>Fax ++64-7 374 8199 | Bruce Christenson | **INGS** |
| **SWITZERLAND** | **Ladislaus Rybach**<br>*Chairman* | **ETH Zurich**<br>Institute of Geophysics<br>ETH-Hoenggerberg<br>CH-8093 Zurich<br>SWITZERLAND | rybach@geo.phys.ethz.ch<br>Tel. ++41-1 633 26 05<br>Fax ++41-1-633 10 65 | Harold Gorhan | **Electrowatt Engineering Ltd**<br>Hardturmstrasse 161<br>CH-8037 Zurich |
| **UNITED KINGDOM** | **Roger Parker** * | Melrose House<br>Lanner, Redruth,<br>Cornwall TR16 6ER<br>UK | rhparker@melrose-lanner.demon.co.uk<br>Tel. ++44-1209-215551<br>Fax ++44-870-0558325 | * | |
| **USA** | **Allan Jelacic** | **Office of Geothermal Technologies**<br>US Department of Energy, EE-12<br>1000 Independence Ave SW<br>Washington, DC 20585<br>USA | allan.jelacic@hq.doe.gov<br>Tel. ++1-202-5866054<br>Fax ++1-202-5868185 | Marshall Reed | marshall.reed@hq.doe.gov |

*) until August 1999; successor to be nominated

# ENCLOSURE: Task Reports

**IEA GIA Annex I**

**ENVIRONMENTAL IMPACTS OF GEOTHERMAL ENERGY DEVELOPMENT – 1999 Annual Report**

***Prepared by Task Leader Dr. T. Hunt (IGNS Wairakei, New Zealand)***

## Introduction

There is world-wide concern about the environmental effects of energy use. Geothermal is generally regarded as a benign energy source (c.f. nuclear, coal and oil), but there are some environmental problems associated with its exploitation. To further the use of geothermal energy, possible environmental effects need to be clearly identified and countermeasures devised and adopted to avoid or minimize their impact. To assist in this, Task I of the GIA was set up. It is entitled "Environmental Impacts of Geothermal Energy Development" and is formulated in Annex I of the GIA.

The goals of this Task are:

- to encourage the sustainable development of geothermal energy resources in an economic and environmentally responsible manner;
- to quantify any adverse or beneficial impacts that geothermal energy development may have on the environment, and
- to identify ways of avoiding, remedying or mitigating such adverse effects have on the environment.

The Objectives of Task I are:

- To study the effects that existing geothermal developments have had on the environment and determine their cause.
- Identify the most likely and serious adverse effects that geothermal developments can have on the environment.
- Identify the development technologies that have proven to be environmentally sound.
- Publish the results of the studies in international journals and present the results at international forums.
- Improve communications between individuals and organizations in different countries, and between different professional groups involved in geothermal development by involvement in collective presentation of the results in international forums.

Countries formally participating in Annex I, at present, are: Greece, Japan, Mexico, New Zealand, and United States of America

The Operating Agent for Task I is the Institute of Geological & Nuclear Sciences, a Crown Research Institute owned by the New Zealand Government. The Task Leader is Dr T Hunt.

Milestones in Task I are:

- Production of a Special Issue of Geothermics journal on Environmental Aspects of Geothermal Developments
- Participation in a Special Session on Environmental Issues at the World Geothermal Congress 2000

The Task is sub-divided into three Sub-Tasks:

1. Sub-Task A: Impacts on natural features
2. Sub-Task B: Discharge and reinjection problems
3. Sub-Task C: Methods of impact mitigation and Environmental Manual

Since the last report no changes have been made to internal organisation of the Task.

## 2. Work performed in 1999

### *2.1 General*

- Editing of a Special Issue of *Geothermics* journal on "Environmental aspects of geothermal development " was been completed. The Special Issue contains 10 papers from: Japan (1), Iceland (1), Mexico (1), New Zealand (5), Turkey (1),and The Philippines (1). Subjects covered include:
  - Exploitation-induced ground subsidence
  - Effects of development on natural thermal features and methods for their preservation
  - Use of economic instruments to minimise environmental effects
  - Rainwater acidity
  - Sulphur gas emissions

The Special Issue is edited by Dr T. Hunt and contains a Foreword by Prof. L. Rybach. It was sent to *Geothermics* in June 1999 and publication is expected about March-June 2000.

- Information about Task I for an Internet website was prepared. However a suitable website to host the material needs to be found. It is suggested that IEA set up a website for all GIA Tasks.
- Several papers have been prepared for presentation in a Special Session on Environment at the World Geothermal Congress 2000, to be held in Japan from 30 May to 7 June 2000.
- A Plenary Session at the World Geothermal Congress 2000, on international scientific collaboration programmes, has been developed. It is planned that a senior member of IEA will attend and participate in this Plenary Session.

### *2.2 Sub Task A*

**Impacts on natural features (Sub-Task Leader: Dr Michael Sorey, United States Geological Survey (Menlo Park),USA)**

Work in this Sub-Task focuses on documenting known impacts of geothermal developments on natural geothermal features such as geysers, hot springs and silica terraces. Little of this information has been published either nationally or internationally, and much of that which has been published is not quantitative. The aim of this Sub-Task is to rectify this, and to provide a sound historical and international basis on which to devise methods to avoid or mitigate the impacts of development on such natural geothermal features which generally have significant cultural and economic value.

A paper was published (Glover & Hunt, 1998) and 7 more have been submitted to *Geothermics* or WGC2000.

### *2.3 Sub Task B*

**Discharge and reinjection problems (Sub-Task Leader: Dr Trevor Hunt, Institute of Geological & Nuclear Sciences (Wairakei), New Zealand)**

Work in this Sub-Task is focused on identifying and determining methods of overcoming the impacts of geothermal developments on other aspects of the environment. This includes the effects of gas emissions from geothermal power plants, effects of toxic chemicals in waste fluid that is discharged both into the ground and into rivers, effects of ground subsidence, and induced earthquakes.

- Seven papers have been submitted to *Geothermics* or WGC2000.

### *2.4 Sub Task C*

**Methods of impact mitigation and Environmental Manual (Sub-Task Leader: Dr Sue Goff, Los Alamos National Laboratory, USA).**

The objective of this Sub-Task is to contribute to the future of geothermal energy development by developing an effective, standard environmental analysis process

Work performed during the year includes:

- At the request of DOE Headquarters and with recommendations from the US geothermal community, Sue Goff served as a member of an environmental panel at the DOE Program Review in May.
- A chapter was written for the Encyclopaedia of Life Support Systems (EOLSS) on the Environmental Effects of Geothermal Power. The UNESCO sponsored EOLSS is intended to be a source of information and knowledge that presents the foundations and applications of science, policy and practice for informed actions towards sustainable world development. English translations of OLADE Environmental Impact Assessment manuals were obtained.
- A paper was written and submitted to the WGC 2000 Special Session that will present the results of the work accomplished under the auspices of this Annex. The paper reviews the OLADE guide, makes recommendations for improvements needed in the OLADE document and presents additional elements that should be part of a standard EIA format for geothermal development projects.
- Goff developed a charter and was appointed chair of the External Liaison Committee of the GRC. The purpose of this committee was to identify and pursue strategic alliances with other organisations. After re-combining with the Public Information Committee, Goff has been investigating several worldwide environmental organisations for their potential as potential strategic partners.

Accomplishments include:

- Obtained support from both the US and international geothermal communities that environmental issues must be a component of an R&D strategy.
- Identified, with the GRC Public Information chair (Charleen Wardlow, Calpine), appropriate environmental groups for forming strategic alliances.
- Two publications (as detailed below)
- Goff assigned the task of completing a GRC publication on the Environmental Issues in Geothermal Development that has been in draft for over 5 years.

## 3. Work Plan for 2000

- Publication of the Special Issue of Geothermics journal on Environmental Aspects of Geothermal Development.
- Complete setting up of a website on Internet to inform the general public about the aims of the Task and results obtained.
- Hold a Special Session on Environmental Impacts of Geothermal Energy Development at the World Geothermal Congress 2000 in Japan in June 2000.
- Expand the scope of the studies to include environmental impacts which are not yet covered in the Task, (such as exploitation-induced hydrothermal eruptions), or topics which are as yet poorly covered (such as social, medical and financial aspects of environmental effects).
- Organise a Workshop or Session on Environmental Aspects of Geothermal Development (covering “work in progress / results achieved”) at an international geothermal conference
- Define longer-term R&D needs.

## 4. References


Allis, R.G. Review of subsidence at Wairakei Field, New Zealand (submitted and accepted by *Geothermics*)

Allis, R.G. and X. Zhan Predicting subsidence at Wairakei and Ohaaki geothermal fields, New Zealand. (submitted and accepted by *Geothermics*)

Bromley, C.J. Natural Variations of Geothermal Features in New Zealand - Consequences for Monitoring Induced Changes (submitted to WGC2000)

Glover, R.B., and T.M. Hunt. Reversible and irreversible changes to natural thermal features due to human activity – some New Zealand examples. *Proceedings 19th Annual PNOC-EDC Geothermal Conference*: 257-267.

Glover, R.B., Hunt,T.M. and C.M.Severne. Impacts of development on a natural thermal feature and their mitigation - Ohaaki Pool, New Zealand. (submitted and accepted by *Geothermics*)

Goff, S.J. The Effective Use of Environmental Impact Assessments (EIAs) for Geothermal Development Projects (submitted to WGC2000)

Goff, S.J., Brophy, P., and F.Goff (in press) "Environmental Effects of Geothermal Power," Chapter 4.23.4.4 in *Encyclopaedia of Life Support Systems*, UNESCO, Paris, France.

Hunt, T.M. and C.J. Bromley Environmental changes resulting from development of Ohaaki Geothermal Field, New Zealand. (submitted to WGC2000)

Kristmannsdóttir, H. Environmental impact of geothermal utilisation in Iceland. (submitted to WGC2000)

Kristmannsdóttir, H., Sigurgeirsson, M., Ármannsson, H., Hjartarson, H., and M. Ólafsson Sulphur gas emissions from geothermal power plants in Iceland. (submitted and accepted by *Geothermics*)

Mroczek, E.K. Chloride and arsenic fluxes from the Kawerau Geothermal Field into the Tarawera River, New Zealand. (submitted to WGC2000)

O'Shaughnessy, B.W. Use of economic instruments in management of Rotorua Geothermal Field, New Zealand. (submitted and accepted by *Geothermics*)

Rossi, A. updating of the subsidence and gravity changes induced by exploitation in the Travale-Radicondoli Geothermal Field (Tuscany -Italy) (submitted to WGC2000)

Scott, B.J. and A.C. Cody Response of Rotorua Geothermal System to exploitation and varying management regimes. (submitted and accepted by *Geothermics*)

Şimşek, Ş., Günay, G., Elhatip, H. and M. Ekmekçi Environmental protection of geothermal waters and travertines at Pamukkale, Turkey. (submitted and accepted by *Geothermics*)

Sorey, M. Impacts of geothermal development on thermal features at several geothermal fields in the western United States. (submitted to WGC2000)

Verma, M.P., Quijano, J.L., Johnson, C., Gerado, J.Y. and V. Arellano Origin of rainwater acidity near the Los Azufres Geothermal Field, Mexico. (submitted and accepted by *Geothermics*)

Yusa Y., Ohsawa, S. and K. Kitaoka Long-term changes associated with exploitation of the Beppu Hydrothermal System, Japan. (submitted and accepted by *Geothermics*)

**IEA GIA Annex III**
**Hot Dry Rock – 1998 Annual Report**
***Prepared by Task Leader Dr. M. Kuriyagawa (NIRE, Tsukuba, Japan)***

# 1. Introduction

The objective of Hot Dry Rock Task may address HDR geothermal technologies as well as any other new and improved technologies which can be used to artificially simulate a geothermal resource to enable commercial heat extraction.

Countries and organization participating in Annex III are Australia, CEC, Japan, Switzerland, UK and USA.

The following four Subtasks are now being undertaken in this Annex (Task Leader: M. Kuriyagawa).

**Subtask A: Hot Dry Rock Economic Model**
(Subtask Leader: H. Herzog, MIT, USA)

This project has two major thrusts. First is to upgrade MIT's existing HDR economic model in three ways - review and revise databases, make the model accessible to a larger user base by upgrading to Windows and rewriting input/output capabilities, and add new capabilities to the model as required by task 2. Task 2 is to use the model to run case studies. The exact studies will be determined through discussions with DOE, industry, and our collaborators in the IEA Implementing Agreement.

This is a three-year project. Year 1 has focused on upgrading the model. In year 2, the focus will shift to the case studies.

**Subtask B: Application of Conventional Geothermal Technology to Hot Dry Rock Technology**
(Subtask Leader: Lynn McLarty, Princeton Economic Research, Inc, USA)

The U.S. Department of Energy's approach to this Subtask is to focus some of its research efforts on developing technology that is applicable to both hydrothermal resources (in the near term) and HDR resources (in the longer term). In other words, the approach is to focus efforts initially at the more permeable end of the spectrum - in lower permeability areas in or adjacent to commercial hydrothermal fields. The term "dual-use" has been coined to describe this approach because the technology to be developed will be used not only to salvage dry or marginal wells and improve production and injection at commercial hydrothermal fields but also to develop heat resources that are not associated with commercial hydrothermal resources. DOE is using the term Enhanced Geothermal Systems (EGS) to refer to the use of advanced technology to exploit heat reservoirs that have insufficient permeability and/or fluid for economic development with current commercial technology.

**Subtask C: Data Acquisition and Processing**
(Subtask Leader: R. Hopkirk, Polydynamics Engineering, Switzerland)

The overall aim of this Subtask is to provide a framework for the construction of a commercial HDR plant including project planning, availability of special tools and services and an overview of data, data analyses and experiences (in the way of lists of reports and publications with their abstracts) gained at the major HDR projects in the world.

**Subtask D: Reservoir Evaluation**
(Subtask Leader: Tsutomu Yamaguchi, NIRE, Japan)

The final objective of this Subtask is to understand how much, how fast and for how long geothermal energy can be extracted from a HDR reservoir system. This Subtask will make clear what kind of methods, techniques and tools are effective for reservoir evaluation, and finally will establish the evaluation method which can be applied to develop a new HDR site.

# 2. Work performed in 1999

## 2.1 General

*Subtasks C and D meeting*

Date: March 19, 1999 Place: Tohoku University, Japan

Attendees:

Dave Duchane, Kenji Fujimoto, Robert Hopkirk, Sunichi Iwakiri, A. Jupe, Hirokazu Karasawa, Michio Kuriyagawa, Lynn MacLarty, Hugh Murphy, N. Soma, Norio Tenma, Roger Parker, Doone Wyborn and Tsutomu Yamaguchi

Major items discussed:

1) How to input Hijiori and Ogachi projects data to the sheet prepared by Subtask C.
2) Finalize the questionnaire of Subtask D.

*Activities of HDR Task Subcommittee in Japan*

The HDR Task Subcommittee in Japan, which is operated by NEDO, met twice this year.

*3rd meeting*

Date: January 5, 1999 Place: NEDO, Japan

Attendees:

Michio Kuriyagawa, Tsutomu Yamaguchi, Isao Matsunaga, Norio Tenma, Makoto Miyairi, Masahiko Yagi, Masakazu Kadowaki, Koichi Kitano, Kenzo Kiho, Nobuo Shinohara, Takakazu Konishi, Shunichi Iwakiri, Yasukuni Okubo, Kazuhiro Karasawa, Nobuyori Bessho and Kenji Fujimoto.

*4th meeting*

Date: March 19, 1999 Place: Tohoku University, Japan

Attendees:

Michio Kuriyagawa, Hiroaki Niitsuma, Tsutomu Yamaguchi, Isao Matsunaga, Norio Tenma, Makoto Miyairi, Masahiko Yagi, Masakazu Kadowaki, Kenzo Kiho, Nobuo Shinohara, Shunichi Iwakiri, Kazuhiro Karasawa, Hiromi Murayama, and Kenji Fujimoto, NEDO

The subjects of discussion in these meetings were how to support the activities of Subtask C, and how to promote Subtask D.

## 2.2 Subtask A - Hot Dry Rock Economic Model

*Task to Update Model*

The primary focus of last year's work was to develop an economic model for general use based on our previous modelling efforts for DOE. The following specific tasks were successfully completed:

1. Review and update all model cost correlations.
2. Update code to be on an extensive (total MW) basis as opposed to an intensive (per MW) basis.
3. Port code to Windows from DOS.
4. Create a graphical user interface (GUI) so that the geothermal community can easily access the model.

The GUI is written in Visual Basic 6.0, while the simulator is written in Fortran 90. The software runs on Microsoft Windows with a Pentium 90MHz or higher microprocessor. At least 24 megabytes of RAM and 5 megabytes of hard disk space are needed. The model and all necessary documentation may be downloaded from the web at http://web.mit.edu/hjherzog/www/.

We have completed three case studies by evaluating the economics of HDR sites at Fenton Hill (USA), Soultz-sous-Forets (France), and the proposed site at Hunter Valley (Australia). In addition, we have started on case studies of the economics of Hijiori (Japan), Ogachi (Japan), and Rosemanowes (UK).

We submitted a paper to the World Geothermal Congress that will be held in Japan, May 28 - June 10, 2000 entitled "Economic Modelling of HDR Enhanced Geothermal Systems" (submission number E0560). This paper summarizes much of our work to date.

### 2.3 Subtask B - Application of Technology of Conventional Geothermal Energy to Hot Dry Rock Technology

The U.S. Department of Energy (DOE) has identified a number of technical reviews needed to determine current technology performance baselines for some of the above technologies, and concepts for improving their usefulness for both hydrothermal and Enhanced Geothermal Systems, including Hot Dry Rock. These technical reviews, some of which are in progress, are listed in the Table 1.

PERI recently completed the report “Definitions of Baseline Studies for Enhanced Geothermal Systems”. This report better defines the baseline studies included in the EGS Strategic Roadmap (see Table 1 above). The objective of the report is to help researchers focus proposals for these technical reviews.

The technical review of the Fenton Hill Hot Dry Rock Project (#1 in Table 1) is discussed in more detail under Subtask C below, and the technical review of reservoir simulation (#6 in Table 1) is discussed further under Subtask D below.

**Table 1. Baseline Studies for Enhanced Geothermal Systems**

| Technical Area | Origin | Comments |
|---|---|---|
| 1. Reviews of Fenton Hill hot dry rock project | Initiated in 1997. | Nearing completion. The Fenton Hill Peer Review and Data Study are complete. Indexing and Archiving (see Subtask C) is in progress. |
| 2. Rock fracturing and other well stimulation technologies | Strategic Roadmap Baseline 1 | Start from Republic Geothermal, Inc., work of early 1980’s |
| 3. Evaluate predictive and modelling technologies for sub-surface stimulation processes in geothermal, oil and gas, mining, and waste mitigation. | Strategic Roadmap Baseline 2 | Should be correlated with item 3. |
| 4. Detection and analysis of fractures in geothermal systems | Strategic Roadmap Baseline 5 & 6 | Start from National Research Council *Rock Fractures and Fluid Flow*. |
| 5. Rock mechanics and its relationships to well stimulation and fluid flow in geothermal reservoirs | Strategic Roadmap Baseline 3 | Suggested by LBNL at 1998 EGS Workshop. |
| 6. Advanced reservoir numerical simulation, modelling | Strategic Roadmap Baseline 4 | In progress, near completion (see Subtask D) |
| 7. Initial testing of low productivity wells | Identified in 1998 EGS Dual-Use workshop. | New – not included in EGS Strategic Roadmap. |

DOE's approach to EGS R&D is to first develop technology that is applicable to marginal hydrothermal systems and low permeability areas of commercial hydrothermal systems. As the technology improves it can be applied in EGS systems beyond hydrothermal fields. In this effort, during fiscal year 1999 (Oct 1, 1998 through Sep 30, 1999), DOE continued investigations of how permeability is maintained and what geophysical parameters control spatial variations in fault zone permeability in the Dixie Valley hydrothermal field in Nevada. The research focuses on relating the in-situ stress field, that is acting on the normal faulting system, to the permeability, anisotropy, heterogeneity, and magnitude of the geothermal reservoir and the fractures that comprise it. A very hot well that was drilled in an area of the field with low permeability was being studied to determine whether a massive hydrofracture operation in the well would connect it to the hydrothermal reservoir. Some data were obtained during experimentation in summer 1999, but problems with the well precluded obtaining all the data necessary to determine whether to progress with the hydrofracture. The future of this project is uncertain now because the owner of the commercial operation at the field has expressed its intent to sell the operation.

In August 1999, PERI/GX conducted EGS Workshop 3 at Lawrence Berkeley Laboratory in Berkeley, California. The purpose of the workshop was to develop inputs to tactical plans for research on ways to enhance near-commercial geothermal systems in the U.S. About 20 of the country's foremost geothermal and geophysical scientists were convened to discuss the state of the art of understanding geothermal reservoirs, and how that might be advanced.

During the Workshop, the participants nominated ideas for research on Enhanced Geothermal Systems. Two main Topics were developed: 1) improving permeability of hydrothermal systems, and 2) improving fluid contents of hydrothermal systems. For each Topic, four sets of Research Issues were nominated and discussed, in the following order:

1. Barriers to development of EGS,
2. Practical methods that need to be improved,
3. Measures to use (and improve) in developing EGS, and
4. Basic supporting research.

The Workshop participants developed criteria for ranking numbers 2 through 4 (Practical Methods, Measures to use and improve, and Basic research) and then voted on the relative importance of each. The results will be used as the basis for an implementation plan for future EGS research.

PERI's subcontractor, GeothermEx, recently completed its "Review of Potential EGS Sites and Possible EGS Demonstration Scenarios". The study provides reference points for evaluating what types of EGS experimental projects might be undertaken, where they might be located, and what the associated benefits are likely to be. The review of potential EGS sites adheres to selection criteria developed at EGS Workshop 1 conducted as part of DOE's Geothermal Program Review in April 1998. The study, which focuses on U.S. hydrothermal sites with commercial operations, incorporates input from geothermal operators and assesses water availability and transmission access for each site. The discussion of potential EGS experimental project scenarios addresses three alternatives:

1) a stand-alone experimental project in an area with no existing geothermal development;
2) a separate generating facility adjacent to an existing geothermal development; and
3) an EGS project that supplies an existing geothermal power plant with additional generating capacity.

## 2.4 Subtask C - Data Acquisition and Processing

*General*

The technical activities in this year are essentially continuations of those started already - the work proceeding at a detailed level and making satisfactory progress. We are extremely happy with the level of feedback from the other participants in subtask C. There follows a brief list of the domains where progress has been made on the organizational side.

*Collection and archiving of project data*

This work concerns the first and still the principal activity under subtask C. There are two distinct and related activities here, separable because of the concept of separate archiving and indexing of projects. These are physical archiving of data and literature and the continuing use and improvements to the HDR Project Data Index.

1: Project Indexing and Description

1. It has been discovered that certain blocks of data are often already available in tabular form. Since spreadsheets (in particular EXCEL) are mostly used to create such lists, a method has been developed to enter project data into the project-specific HDR-Data Index, using a previously prepared EXCEL table. A technical note was then written and circulated to describe this, believed to be the best method for undertaking the task.
2. Acting upon a suggestion from our Japanese colleagues at NIRE, we are undertaking a modification to the naming of data set types, in particular those referring to borehole logs. Similar logs and records tend to receive different names from different field tool and interpretation method developers, although fulfilling essentially the same function. Upon the recommendation of Roger Parker (U.K.) we have modified the HDR project Data Index application to accept the proprietary mnemonic name and the name of the supplier, or that listed by the Society of Professional Well Log Analysts (SPWLA). This should improve clarity and avoid ambiguities.
3. Cross-references to literature will in future include the storage medium name, together, where relevant, with the file name and its format in the same way as has been already used for referring to data sets.
4. Our U.S. colleagues at PERI have improved the flexibility and capacity of the Data Index introductory pages, which contain the project description and history. They have introduced the possibility of using several monitor screens full for each chapter or menu item. Since this seems an excellent idea, we hope to introduce such an option as standard.

2: HDR literature and literature archiving

An ideal method of archiving literature is one aim for a general library, but it is also vital for a project library-project reports, technical notes, presentations and publications. Experiments are being made with archiving both hard and soft copies, initially for the two European projects, Rosemanowes and Soultz, which, if successful, will enable demonstration CD's to be generated.

The general HDR literature list has now reached considerable dimensions. At present approximately 1900 published references have been collected and built into this bibliography, which is currently based upon the "EndNote" system. The latest update of "EndNote" has been acquired to improve compatibility. In addition some 600 reports from the Soultz project have been identified and located and some 50 of these archived as ACROBAT pdf-files. Several hundred more reports and technical notes have been identified from the Rosemanowes project.

In both projects progress has been made also in collecting abstracts of reports and publications, where available, for use in the Project Data Index.

One particular problem occurs at all the larger centralized project offices sites, which we have seen. This is the rather poor quality of the rooms and the climate available for archiving paper copies. To improve such aspects is a considerable cost item, especially after a project has been

closed down. This fact underlines the advisability of parallel methods of archiving - for example, maintaining both hard and soft copies.

*Generic Project Development*

Some background progress has now been made in this direction. The ultimate aim here is to provide a guide, based on experience gained during the long R & D history of HDR/EGS and in particular, from the recent experiences, both good and bad, as we move into the phase of pilot and commercial plants. Whereas the reservoir development and operation can be very different from site to site, we believe it to be possible to set up a globally valid procedural plan, including the basic decisions to be taken.

### 2.5 Subtask D - Reservoir Evaluation

(a) The questionnaire survey has been conducted using Internet Web for the convenience in replying the questionnaires. The entries in the questionnaire had been selected by the members of Subtask D according to their specialities. The trial version of the questionnaire had been put temporarily on the NEDO server. The members had submitted replies to the questionnaire to check the contents and operationality. Problems encountered during this trial were listed up and summarized.

(b) The Subtask meeting was held in March 18, 1999 at Tohoku-University, Sendai. In this meeting, discussions were made to improve and modify the trial version of the questionnaire. Main improvements were as follows.

- If the answerer wants to correct or modify the pre-answered data, he can easily retrieve his data by using his unique I.D. number.
- The categories of the questionnaire are grouped into five categories as follows:
    1. Numerical simulation
    2. Geology
    3. Tracer
        3-1. Field tracer experiment
        3-2. Laboratory (Basic) tracer experiment
    4. Geochemistry
        4-1. Fluid chemistry
        4-2. Gas chemistry
    5. Measurement techniques
        5-1. Microseismic monitoring
        5-2. Seismic logging
        5-3. Well logging
- If the answerer wants to answer more than two items in one category, the difference between two items will be distinguished by key word.

(c) This modified Internet questionnaire for reservoir evaluation was open to the public on NEDO server after August 1 at http://www.nedo.go.jp/gec/taskd/.

# 3. Work plan for 2000

We may have the next task meeting during WGC2000 which will be held in Japan next May to June. The following is the work plan for each Subtask.

### 3.1 Subtask A

The key milestones planned for the upcoming year include:

- Finish case studies of HDR pilot sites. Hijiori (Japan), Ogachi (Japan), and Rosemanowes (UK) studies need to be completed.
- To identify and perform additional case studies on EGS sites. We are currently consulting with the geothermal industrial and research communities to define specific studies. Locations such as the Geysers, Salton Sea, Coso, Dixey Valley, Soda Lake, Steamboat and Roosevelt have been identified as the most promising locations for increasing heat mining by the development of EGS systems. Some case studies may require the model to be enhanced.
- An MIT Masters' thesis will be published in January 2000 entitled „Power Generation from Geothermal Resources: Challenges and Opportunities"
- We will attend the World Geothermal Congress 2000 (WGC2000) and present a paper (see publications below). Also at WGC2000, we will attend meetings of the IEA GIA.

### 3.2 Subtask B

Upcoming activities are uncertain at this time because the U.S. Department of Energy is reorganizing its geothermal R&D program.

### 3.3 Subtask C

In Europe effort will continue to be put into the question of data collection and archiving. As the Japanese and U.S. teams have made considerable progress, continued feedback and exchange of experiences will be sought.

- More attention will be given to the setting up of principal plans technically necessary for carrying through a generic project and the integration of these with the timing necessary for financing, ordering services and materials and constructing reservoir and surface plant.
- Progress will be continued with a global HDR library.

### 3.4 Subtask D

During the trial period, the fundamental data about Hijiori and Ogachi test sites had been collected by the effort of Subtask D members. These efforts to collect further Hijiori/Ogachi data will be continued by Subtask D members. Subtask D will start to collect the data of other HDR field data, such as Fenton Hill, Rosemanowes and Soultz.

# 4. References

Kuriyagawa M., Howard Herzog, Lynn McLarty, Robert Hopkirk, and Tsutomu Yagaguchi: "Activities of HDR under Geothermal Implementing Agreement, IEA", to be presented at WGC2000.

Olga I. Kitsou, Howard J. Herzog, and Jefferson W. Tester: "Economic Modeling of HDR Enhanced Geothermal Systems", to be presented at WGC 2000.

Yamaguchi T., Michio Kuriyagawa., Isao Matsunaga, Norio Tenma and Hirokazu Karasawa: "Progress of the task of HDR evaluation under IEA Agreement", to be presented at WGC 2000

**IEA GIA Annex IV :**
**Deep Geothermal Resources – 1998 Annual Report**
***Prepared by Task Leader Dr. K. Kimbara (GSJ, Tsukuba, Japan)***

# Introduction

The objective of the task is to address the issues necessary for the commercial development of Deep Geothermal Resources which prevail at depths of approximately 3 000 meters. The Task was started in 1997 as a four-year international collaboration program under the IEA Geothermal Implementing Agreement (GIA) with participating five countries: New Zealand, Mexico, Australia, USA and Japan. The Task consists of three subtasks as follows:

Subtask A: Exploration Technology and Reservoir Engineering
Subtask B: Drilling and Logging Technologies
Subtask C: Material Evaluation Programme

Japan took the lead in developing an original entire work program for the task and NEDO has been taking a role of Operating Agent (OA). The subtask leaders make their detailed yearly plans which must be submitted to the Executive Committee (ExCo). In accordance with the IEA task sharing procedures, OA annually organizes meetings, workshops and field trips to conduct the work programs including information exchange through Internet in collaboration with the task members.

# 2. Work performed in 1999

## 2.1 General

OA organized a joint technical meeting with the researchers of ERGA/ENEL on November 10 in Pisa (see Appendix). More than 10 task members from Italy, Japan, Mexico and New Zealand attended the meeting and presented their papers in order to exchange the technical information concerning deep geothermal resources with the researchers of ERGA/ENEL. OA conducted a field trip, guided by a staff of ERGA/ENEL, to the geothermal fields in Italy: Larderello, Monte Amiata and Latera on November 11 and 12. The participants from Japan, Mexico and New Zealand got a lot of fruitful information related to deep geothermal resources during this trip.

## 2.2 Subtask A: Exploration Technology and Reservoir Engineering

*(Sub-task leader : H Muraoka, GSJ, Japan)*

A major issue of collaborative activity in the year 1999 was to achieve a comparative study among conceptual and numerical models of deep geothermal areas in the participating countries. This issue was successfully done by nine research groups from Italy, Japan, Mexico and New Zealand. These results were presented in the 4th task meeting held in Pisa. The succeeding 3rd task excursion to the Larderello and Monte Amiata geothermal fields also provided fruitful additional information to those results. A small database for deep geothermal wells and deep geothermal fields is under construction by NEDO and its supporting groups. Some of additional data were also obtained during the 3rd task excursion to the Larderello and Monte Amiata geothermal fields, as they are known to be representative of deep geothermal fields in the world.

### 2.3 Subtask B: Drilling and Logging Technologies

*(Sub-task leader : H Kobayashi, NIRE, Japan)*

The task was continued of collecting and storing information concerning drilling and logging technologies for geothermal wells. About 150 papers were gathered up to October 15, and they were classified into 8 technical fields:

- trouble assessment on drilling,
- drill bit,
- field report on drilling,
- cost evaluation on drilling,
- materials,
- new drill systems,
- logging technology and
- general reports.

An attempt was made to compare the job distribution of geothermal well drilling, based on the field data of Japan, USA, Italy and the Philippines, in order to know the effects of drilling cost reduction of each job. Although the classifications of these data were different in each field, we divided the original data into 6 temporal categories for comparison:

- drilling,
- L/C treatment & other troubles,
- casing cementing,
- logging & coring,
- well test, and
- others.

The progress and the status of 5 proposed programs of this subtask were mutually reported and exchanged through the human network. A field excursion regarding deep geothermal resources was conducted to three geothermal fields in Italy in November, which provided much important information on this subtask for the participants.

### 2.4 Subtask C: Material Evaluation Programme

*(Sub-task leader : N Sanada, TNIRI, Japan)*

Corrosion models were developed for downhole and wellhead environments under flowing conditions. These models include the corrosion chemistry and mineral corrosion product phase stability as well as the effect of fluid velocity on erosion and corrosion. The models could help to predict materials performance problems and to identify corrosion control options. A guideline of material selection was proposed for corrosion control and materials selection for deep and acidic geothermal wells. Application of pH adjustment and/or inhibitors for well bore corrosion control was advocated for pH values as low as 3. The Japan and New Zealand participants accompanied by other researchers and geothermal developers visited the related organizations in the Philippines and Japan to exchange information on the materials and chemistries. This new awareness is expected to stimulate additional informal collaboration and publication of relevant research results.

## 3. Work plan for 2000

### 3.1 General

OA plans a special technical session at the World Geothermal Congress 2000 (WGC2000) to be held in Japan in May-June 2000, in conjunction with the Technical Programme Subcommittee (TPSC) of WGC2000. The results of task activities for the past three years will be summarized and reported by the participants at the congress. The task activities will be accelerated in the year 2000 in order to accomplish the aim of task. Some recommendations for the technical and economical development of deep-seated geothermal resources will be discussed. OA will distribute a questionnaire calling for papers for a special volume of an international scientific journal to report the results of task activities to the geothermal community.

### 3.2 Subtask A: Exploration Technology and Reservoir Engineering

A major issue of collaborative activity in the year 2000 is to summarize overall results of the subtask A of the Task “Deep Geothermal Resources” and to disseminate the results of the program to the IEA participants as well as the world. One way to disseminate the results will be the presentation

at WGC2000 and the other will be the submission to a special volume of an international journal.
We visited the geothermal fields as three task excursions:
- the Geysers, Cerro Prieto and Salton Sea geothermal fields in the course of the 1st task excursion,
- the Wairakei, Ohaaki and White Island geothermal fields in the course of the 2nd task excursion,
- the Larderello and Monte Amiata geothermal fields in the course of the 3rd task excursion.

The remaining major deep geothermal fields include the Hachobaru and Kakkonda geothermal fields in Japan and the Great Tongonan, Mak-Ban and Palinpinon geothermal fields in the Philippines. We can visit Japan during WGC2000, and therefore, a possible 4th task excursion might be considered to visit the Philippines.

### 3.3 Subtask B: Drilling and Logging Technologies

Based on the database, an analysis and evaluation on drilling and logging technologies will be planned. The distribution of time and cost for drilling appeared to be different from field to field, so efforts will be put into finding an acceptable standard form of job and cost categories for the easy usage of data. Final progress reports of 5 proposed programs will be made and several papers on these programs will be presented at WGC2000. Proposal for the future program will be planned through the close discussion between the members of subtask B.

### 3.4 Subtask C: Material Evaluation Programme

The proposed work will be continued and summarized:
- Compiling references of the literature concerned with chemistries and materials performance
- Development of corrosion models in deep and acidic fluids
- Development of guidelines for materials selection

## Appendix

**Joint Technical Meeting with the researchers of ERGA/ENEL**
Place: Auditorium (ground floor), ERGA S.p.A., ENEL Group, Via Andrea Pisano 120, 56122 Pisa, Italy
Date: Wednesday, November 10, 1999

**Presentation by the ERGA researchers**

Guido Cappetti: Opening address on behalf of ERGA - Development of the deep exploration in Italy
Fausto Batini: - Exploration technologies for deep resources
Giovanni Bertini: - Stratigraphical sequence of the Tuscan geothermal fields
Giovanni Scandiffio: - Chemical composition of deep fluids
Roberto Bechini and Daniele Franceschini: - Deep drilling technology (including directional drilling)

**Presentation by the IEA Annex IV members**

Haruka Watanabe : - Opening address on behalf of the Operating Agent (OA)
Eduardo Iglesias (IIE, Mexico): - New toolboxes for the BDGEO geothermal application
Graham Weir (IRL, New Zealand): - Recent mathematical modelling work in deep geothermal at IRL
Giovanni Gianelli (IIRG, Italy): - Results of recent studies on the deep reservoir rocks of Larderello
Keji Kimbara (GSJ, Japan): - Task activities of IEA Deep Geothermal Resources for the past three years
Hirofumi Murahoka (GSJ, Japan): - Brittle-plastic transition penetrated by the well WD-1 beneath the Kakkonda geothermal field, Japan
Hideo Kobayashi (NIRE, Japan): - A proposing classification on time distribution of deep geothermal well drilling
Norio Sanada (TNIRI, Japan): - Progress on sub-task C - Materials evaluation program
Toshiyushi Tosha (NEDO, Japan): - NEDO's deep seated geothermal resources project: present and future
Kazumi Osato (GERD, Japan): - Deep Seated Geothermal Resources Survey Project (NEDO) - Development of hole-to-surface EM tomography system and the field survey result in Kakkonda