INTERNATIONAL ENERGY AGENCY

Geothermal Implementing Agreement (GIA) - Annual Report 2000

L. Rybach *(ETH Zurich/Switzerland; GIA Executive Committee Chairman)*
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BACKGROUND

The IEA Energy Technology Collaboration Programme (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 three 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 five years.

NATURE AND OBJECTIVES

The GIA represents an important framework for a broad international co-operation in geothermal R & D. It brings together significant national programmes 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 which started in March 1997:

- *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 was K. Kimbara (Geological Survey of Japan) from the beginning until February 2000 when M. Sasada (Geological Survey of Japan) took over.

Detailed Annual Reports of these Annexes (including activities in 2000, results, future plans, and references), prepared by the Task Leaders, are given in **ATTACMENTS 2 to 4.** The Annual Reports are organized in the following format:

- Introduction
- Work performed in 2000
- Work plan for 2001
- Output (publications).

During 2000, the Executive Committee has considered also the following additional Annexes:

- Annex II: Shallow Geothermal Resources
- Annex V: Sustainability of Geothermal Energy Utilization
- Annex VI: Geothermal Power Generation Cycles
- Annex VII: Advanced Geothermal Drilling Technologies

The status of the preparations is different. At the 5th ExCo Meeting in Soultz/France (see below for details) it was decided to close Annex II but to consider geothermal heat pumps within the IEA Market Initiative. Annex V and Annex VI are still in preparation whereas at the 5th ExCo meeting the start of Annex VII has been approved (with Japan and USA as participants so far).

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, 11 countries (Australia, Germany, Greece, Iceland, Italy, Japan, Mexico, New Zealand, Switzerland, United Kingdom, USA) and 1 international organization (Commission of the European Communities, CEC) have signed the Agreement. Three of these countries signed the GIA during 2000: Italy in May, Germany in July, and Iceland in December.

The involvement of the Participants in the different Annexes is shown in Table 1 (overleaf). 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.

Member Countries

In order to further extend the GIA the IEA Secretariat is investigating a possible participation of France.

Non-Member Countries

Contacts to China, Turkey and the Philippines to join the GIA are sustained; in fact, Philippine scientists are already actively participating in the work of Annex I.

Table 1. Task participants as at December 2000

Participating country/organization	Annex I (Environment)	Annex III (Hot Dry Rock)	Annex IV (Deep resources)
Australia		**x**	**x**
CEC		**x**	**x**
Germany		**x**	**x**
Greece	**x**		
Iceland	**x**		
Italy	**x**	**x**	**x**
Japan	**x**	**x**	**x**
Mexico	**x**		**x**
New Zealand	**x**		**x**
Switzerland		**x**	
United Kingdom		**x**	
USA	**x**	**x**	**x**

ExCo ACTIVITIES

Meetings

The list of current ExCo members and Alternates is attached (see **ATTACHMENT 1**).

The ExCo had one Meeting in 2000: on 6 October in Soultz-sous-Forêts, France, organized and hosted by SOCOMINE. At this Meeting

- the ExCo elected Prof. L. Rybach (Switzerland) as Chairman and Dr. A. Jelacic (USA) as Vice-Chairman for 2001;
- the 2000 activity reports of the ongoing Tasks, along with the work plans for 2001, were presented. For details see **ATTACHMENTS 2 to 4**.

Renewable Energy Working Party (REWP)

The IEA REWP organized, on 11 October in Paris, a Workshop on "Developing a New Generation of Sustainable Energy Technologies – Long Term R&D Needs". This Workshop aimed to summarize and to evaluate appropriate long-term R&D topics, their benefits and possible market pathways. In his contribution to the Workshop, the ExCo Chairman identified relevant geothermal R&D topics already covered by ongoing GIA Annexes as well as some which are not yet covered. These topics are now included in the Workshop Report.

IEA Market Initiative

At the 5th GIA ExCo meeting Rick Sellers (Head, IEA Renewable Energy Unit) informed the ExCo about this new initiative. As a first step, in late 2000 the IEA Renewable Energies Unit funded an initial study by Laurent Dittrick, leading to first drafts of a market strategy: "Elements for a Geothermal Market Initiative" and "Developing Options to Accelerate Geothermal Markets". The ExCo has not yet had an opportunity to take a considered view of these drafts, which will also be treated further by the REWP.

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 was agreed at the 5th ExCo meeting in Soultz that a common fund (= cost sharing) will be needed to conduct ExCo business – including the market initiative, to produce a GIA Brochure, to establish a GIA homepage, and to carry out secretarial work. Currently it is under negotiation how to establish the necessary fund.

Dissemination of Results

The GIA follows the normal method of disseminating research results: publications in scientific/technical journals and Conference Proceedings. An extensive presentation of GIA activities and results took place at the WORLD GEOTHERMAL CONGRESS 2000 (Japan, 30 May – 10 June 2000). During Plenary Session IV "International Co-operation in Geothermal R&D" (Morioka, 5 June) Dr. H.-J. Neef, Head of Energy Technology Collaboration Division of IEA, reported on IEA activities in renewable energy technology in general, and about the GIA activities in particular. At WGC2000, 7 Special GIA Sessions were held with 34 oral presentations accompanied by 13 poster presentations. Corresponding contributions have been published in the Proceedings. For details see **ATTACHMENT 5** and the Annex reports (**ATTACHMENTS 2 to 4**).

PLANS FOR 2001

Annexes

The existing Annexes I, III and IV all complete their initial 4-year duration in 2001. As indicated above, these Annexes will be extended during 2001.

Detailed arrangements for financing and participation in Annex VII will be finalized during 2001, and the proposed new Annexes V and VI will be considered further and, if appropriate, started.

Market Initiative

The Market Initiative of the IEA will have a significant bearing on the GIA future activities. The ExCo has established a Planning Committee to advise the ExCo on how the GIA should evolve and how the ExCo may need to operate in order to

- identify technical issues influencing geothermal development,
- develop strategies for the market introduction of geothermal technologies, and
- address problems of policy and perception.

It will almost certainly be necessary to make substantial changes to the mode of operation of the GIA following its (planned) extension beyond March 2002.

At present, the GIA Annexes all operate exclusively in the task-sharing mode. The ExCo had already recognized a need to put in place a small common fund for dissemination activities, etc. (see above), but the work involved in moving along the lines indicated by the Market Initiative will almost certainly entail a new Annex with a substantial cost-sharing element and a common fund administered by an Operating Agent.

These issues will be discussed further at a meeting of the ExCo scheduled for 8-9 March 2001. This meeting will also be addressed by representatives of the World Bank and the Global Environment Fund, with a view to co-operation over a common policy of market and policy initiatives for geothermal development in both IEA Member and Non-Member countries. Preliminary contacts suggest that there will be many points of common interest, and that a common – or at least closely co-ordinated – strategy may be possible.

ATTACHMENT 1
Executive Committee

IEA Geothermal Implementing Agreement Executive Committee

(December 2000)

Country / Name	Delegate	Organization / address	e-mail / tel / Fax	Alternate	Address, etc. (where different)
AUSTRALIA	**Doone Wyborn**	**Australian National University** Department of Geology Canberra, ACT 0200 AUSTRALIA	dwyborn@geology.anu.edu.au Tel. ++61-262 49 3224 Fax ++61-262 49 5544	Prame Chopra	prame.chopra@anu.edu.au
European Commission	**John Garnish** *Secretary*	**EC - DG Research** Research-J3; Mo75 5/22 Rue de la Loi 200 B-1049 Bruxelles BELGIUM	john.garnish@ cec.eu.int Tel. ++32-2-295 8518 Fax ++32-2-295 6995	Enzo Millich	**EC - DG TREN** TREN-D2; TERV 6/26 Tel. ++32-2-295 3625 enzo.millich@cec.eu.int
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‡ *New participating countries in 2000*

* *Mr Hashimoto replaced Mr Watanabe in July 2000*

(continued…../)

ATTACHMENT 1
Executive Committee

IEA Geothermal Implementing Agreement Executive Committee (continuation)

Country / Name	Delegate	Organization / address	e-mail / tel / Fax	Alternate	Address, etc. (where different)
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NEW ZEALAND	**Trevor Hunt**	**Institute Geological & Nuclear Sciences** Wairakei Research Centre Private Bag 2000 Taupo NEW ZEALAND	t.hunt@gns.cri.nz Tel. ++64-7 374 8211 Fax ++64-7 374 8199	Bruce Christenson	**INGS**
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[x] *Mr McGovern replaced Dr Parker in April 2000*
[+] *Dr Goldman replaced Dr Reed in June 2000*

ATTACHMENT 2
Annex I report

IEA GIA Annex I

ENVIRONMENTAL IMPACTS OF GEOTHERMAL ENERGY DEVELOPMENT
2000 ANNUAL REPORT

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

1. Introduction

World-wide concern about the environmental effects of energy use continues. Geothermal is generally regarded as a benign energy source compared with nuclear and fossil fuels, 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 entitled "Environmental Impacts of Geothermal Energy Development" was set up, 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 term "development" here is used in a broad sense to encompass not only energy production but also use for social purposes such as tourism.

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 the start of 2000 were: Greece, Japan, Mexico, New Zealand, and United States of America. Iceland joined during 2000. At the Executive Committee Meeting held in September 2000 it was decided to continue operation of Task I for a further 4 years. Those countries that have, to date, signified their intention to continue participation are: Iceland, Mexico, and New Zealand.

The Operating Agent for Annex 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.

The Annex 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 organization of the Task

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Annex I report

Milestones in Task I set for completion in 2000 were:

- Publication of a Special Issue of *Geothermics* journal on Environmental Aspects of Geothermal Development.
- Organization and accomplishment of Special Technical Sessions on Environmental Issues at the World Geothermal Congress 2000.

These milestones were completed successfully.

2. Work performed in 2000

2.1 General:

Work in the Task was slower this year because many of the key Task members of Task I were occupied with preparations for the World Geothermal Congress 2000, which was held in Japan from 30 May to 7 June 2000. However the results of previous years work have been published.

- A Special Issue of *Geothermics* journal on "Environmental aspects of geothermal development " was published. This journal is one of the leading international scientific journals focussed on geothermal. The Special Issue (Vol 29, 4/5) is 175 pages long, was edited by Dr T. Hunt, and contains a Foreword by Prof. L. Rybach. It 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 minimize environmental effects
  - Rainwater acidity
  - Sulphur gas emissions
- Two IEA Special Sessions on Environment were held at the World Geothermal Congress 2000, on Tuesday 6 June 2000 at Morioka (Japan). The sessions contained the following orally presented papers (full references are listed at the end of this report):

  IEA Environment (1) chaired by Dr T. Hunt (NZ) and Dr K. Shimada (Japan).

  - *An enforcement project on environmental impact of geothermal exploitation in Iceland* - presented by Dr H. Kristmannsdottir (Iceland).
  - *The influence of effluent water discharged from the Namafjall geothermal field on local groundwater* - presented by Dr S. Hauksdottir (Iceland).
  - *Monitoring of geyser activity in Whakarewarewa, New Zealand*- presented by Dr Y. Nishi (Japan).
  - *Development and verification of a method to forecast hot spring interference due to geothermal power exploitation* - presented by Dr H. Tokita (Japan).

IEA Environment (2) chaired by Dr. M. Sorey (USA) and Dr M. Verma (Mexico).

- *Geothermal development and changes in surficial features: examples from the western United States* - presented by Dr M. Sorey (U.S.A.).
- *Environmental changes resulting from development of Ohaaki Geothermal Field, New Zealand* - presented by Dr T. Hunt (New Zealand).
- *Hot spring interference study for predicting hot spring change in a geothermal field* - presented by Dr K. Shimada (Japan).
- *Elevation and gravity changes at geothermal fields on the Reykjanes peninsula, SW Iceland* - presented by Dr H. Eysteinsson (Iceland).
- *An investigation of boiling processes in hydrothermal eruptions* - presented by Ms T. Smith (New Zealand).
-

◆ Information about Annex I for an Internet website was prepared. However a suitable website to host the material needs to be found.

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.

Five papers were published at WGC 2000, and two in the Geothermics Special Issue; full references are given below.

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.

Three papers were published at WGC 2000, and 7 in the Geothermics Special Issue; full references are given below.

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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. Unfortunately, no funding could be obtained by Dr Goff for this project and so it will be left in abeyance.

3. Work Plan for 2001

- Complete setting up of a website on Internet to inform the general public about the aims of the Task and results obtained.
- Expand the scope of the studies to include environmental impacts which are not yet covered (such as exploitation-induced hydrothermal eruptions), or topics which are as yet poorly covered (such as social, medical and financial aspects of environmental effects).
- Organize 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. Outputs (publications)

Allis, R.G. (2000) Review of subsidence at Wairakei Field, New Zealand *Geothermics, **29***: 455-478.

Allis, R.G. and X. Zhan. (2000) Predicting subsidence at Wairakei and Ohaaki geothermal fields, New Zealand. *Geothermics, **29***: 479-497.

Eysteinsson, H. (2000) Elevation and gravity changes at geothermal fields on the Reykjanes peninsula, SW Iceland. *Proceedings World Geothermal Congress 2000*: 559-564.

Glover, R.B., Hunt,T.M. and C.M.Severne. (2000) Impacts of development on a natural thermal feature and their mitigation - Ohaaki Pool, New Zealand. *Geothermics, **29***: 509-523

Goff, S.J. (2000) The Effective Use of Environmental Impact Assessments (EIAs) for Geothermal Development Projects. *Proceedings World Geothermal Congress 2000*: 597-602.

Hunt, T.M. and C.J. Bromley. (2000) Environmental changes resulting from development of Ohaaki Geothermal Field, New Zealand. *Proceedings World Geothermal Congress 2000*: 621-626.

Hauksdottir, S., Kristmannsdóttir, H., Axelsson, G., Ármannsson, H., Bjarnason and M. Olafsson. (2000) The influence of effluent water discharged from the Namafjall geothermal field on local groundwater. *Proceedings World Geothermal Congress 2000*: 603-608.

Kristmannsdóttir, H., Ármannsson, H. and K. Arnason. (2000) An enforcement project on environmental impact of geothermal exploitation in Iceland. *Proceedings World Geothermal Congress 2000*: 633-638.

Kristmannsdóttir, H., Sigurgeirsson, M., Ármannsson, H., Hjartarson, H., and M. Ólafsson. (2000) Sulphur gas emissions from geothermal power plants in Iceland. *Geothermics, **29***: 525-538

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Loppi, S. (2000) Lichen biomonitoring as a toll for assessing air quality in geothermal areas.. *Proceedings World Geothermal Congress 2000*: 645-649.

Mroczek, E.K. (2000) Chloride and arsenic fluxes from the Kawerau Geothermal Field into the Tarawera River, New Zealand. *Proceedings 21st Annual PNOC-EDC Geothermal Workshop*: 61-68.

O'Shaughnessy, B.W. (2000) Use of economic instruments in management of Rotorua Geothermal Field, New Zealand. *Geothermics, **29***: 539-555.

Nishi,Y., Ishido, T., Sugihara, M., Tosha, T., Matsushima, N., and B.J. Scott. (2000) Monitoring of geyser activity in Whakarewarewa, New Zealand. *Proceedings World Geothermal Congress 2000*: 1509-1605.

Scott, B.J. and A.C. Cody. (2000) Response of Rotorua Geothermal System to exploitation and varying management regimes. *Geothermics, **29***: 573-592.

Shimada, K., Inuyama, F., and H. Tokita (2000) Hot spring interference study for predicting hot spring changes in geothermal fields. *Proceedings World Geothermal Congress 2000*: 757-762.

Şimşek, Ş., Günay, G., Elhatip, H. and M. Ekmekçi. (2000) Environmental protection of geothermal waters and travertines at Pamukkale, Turkey. *Geothermics, **29*:** 557-572.

Smith, T.A. and R. McKibbin. (2000) An investigation of boiling processes in hydrothermal eruptions. *Proceedings World Geothermal Congress 2000*: 699-704.

Sorey, M. (2000) Geothermal development and changes in surficial features: examples from the western United States. *Proceedings World Geothermal Congress 2000*: 705-711.

Tokita, H., Takagi, H., Kiyota, Y., Matsuda, K., Hatanaka, H., Shimada, K., Inuyama, H., Young, R., Bayrante, L.F., and O.T. Jordan. (2000) Development and verification of a method to forecast hot spring interference due to geothermal power exploitation. *Proceedings World Geothermal Congress 2000*: 725-730.

Verma, M.P., Quijano, J.L., Johnson, C., Gerado, J.Y. and V. Arellano. (2000) Origin of rainwater acidity near the Los Azufres Geothermal Field, Mexico. *Geothermics, **29***: 593-608.

Yusa Y., Ohsawa, S. and K. Kitaoka. (2000) Long-term changes associated with exploitation of the Beppu Hydrothermal System, Japan. *Geothermics, **29***: 609-625.

ATTACHMENT 3
Annex III report

IEA GIA Annex III
HOT DRY ROCK – 2000 ANNUAL REPORT

Prepared by Task Leader Dr. M. Kuriyagawa (NIRE, Tsukuba, Japan)
with input from the sub-task leaders

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 organizations participating in Annex III are Australia, Germany, Japan, Switzerland, UK, USA and CEC.

The following four Subtasks are now being undertaken in this Annex.

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

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

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

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

2. Work performed in 2000

2.1 general

Presentations at WGC2000

Four oral sessions for IEA HDR were held at WGC2000 in Japan, at which 20 papers were presented. The full references are listed in Section 5. Eighteen papers were also presented at poster session.

2.2 Subtask A - Hot Dry Rock Economic Model

2.2.1 Overview

We are currently in the last year of a 3-year project to perform economic analyses of Enhanced Geothermal Systems (EGS), including Hot Dry Rock (HDR) systems. The first two years of the project focused on the development of an economic model and application of the model to several case studies. The model has been completed and was posted on the Internet in April 1999, where the world geothermal community can easily download it for use. Applying the model to case studies of enhanced geothermal systems, generic studies evaluated different levels of resource (high-, mid-, and low-grade) for a variety of conditions (water availability, distance from electrical transmission grid, cost of capital, etc.). Specific studies looked at individual locations, including the current HDR pilot sites worldwide.

Our analysis showed several major barriers to development of EGS and HDR systems in today's electricity market, including high investment costs and high busbar electricity costs, especially when compared to natural gas power plants. Hopes to become more competitive in the future include restrictions on greenhouse gas emissions or lowering EGS costs through R&D programs. However, the former is highly political and the timing is uncertain, while the later currently lacks the necessary R&D investments to achieve the desired goals. Therefore, in the last year of our project, we are investigating two alternate paths to economic development of EGS systems: (1) EGS as part of a sustainable development portfolio and (2) EGS co-generation systems.

2.2.2 The Economic Model

In developing the economic model, we:

1. reviewed and updated all model cost correlations.
2. updated code to be on an extensive (total MW) basis as opposed to an intensive (per MW) basis.
3. ported code to Windows from DOS.
4. created 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. The model and all necessary documentation may be downloaded from the web at http://web.mit.edu/hjherzog/www/.

We have conducted case studies by evaluating the economics of HDR sites at Fenton Hill (USA), Soultz-sous-Forêts (France), and the proposed site at Hunter Valley (Australia). We presented a paper to the World Geothermal Congress in Japan (May 28 - June 10, 2000) entitled "Economic Modelling of HDR Enhanced Geothermal Systems" summarizing this part of the project. In addition, based on this work Olga Kitsou wrote her thesis (February 2000) entitled "Power Generation from Geothermal Resources: Challenges and Opportunities".

2.2.3 Current Activities

We are now investigating and analyzing two approaches for the increased development and commercialization of enhanced geothermal systems. We have hired a research assistant for each approach, which will result in two masters' theses.

The first project is investigating EGS from the viewpoint of sustainable development. There are many features of enhanced geothermal systems that make them a good candidate for sustainable development portfolios, including positive environmental aspects (e.g., low greenhouse gas emissions) and use of endogenous resources. We want to understand from a corporate perspective, what attributes make a technology attractive. This information, coupled with economics, will allow us to understand better an R&D and commercialization path for EGS. The RA for this project is Esther Kim. We are also collaborating with Shell on this project.

The second project is analyzing opportunities to use EGS for co-generation systems. We will do an economic analysis to identify opportunities where co-generation has advantages over electricity-only systems. Co-generation systems have a thermodynamic advantage that we would like to exploit. We will look at several case studies and identify potential targets by both industry and geography.

ATTACHMENT 3
Annex III report

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

2.3.1 Background

The charge of Subtask B is: "The Participants shall review new and future developments such as horizontal drilling, fracture mapping, and pumping in conventional geothermal energy, and shall determine their applications to hot dry rock technology."

Additional work in support of other subtasks within Annex III is also reported.

Three activities described as ongoing in the previous report (October 29th, 1999) to the GIA Executive Committee have since been completed. These include the Fenton Hill Data Index, preparation of a report on an Enhanced Geothermal Systems (EGS) workshop held in Berkeley, California, in August 1999, and an assessment of EGS numerical simulators.

2.3.2 Data Index

Princeton Energy Resources International (PERI), under contract to the U.S. Department of Energy, completed the Fenton Hill HDR Project Data Index. The Index is similar to ones being created for the Soultz and Rosemanowes HDR projects under Subtask C, "Data Acquisition and Processing". The Data Index includes bibliographic information on approximately 520 technical reports related to Fenton Hill and HDR research in the U.S. The index accommodates searches by author, keywords, and activity identifiers which tie the documents to major test activities at Fenton Hill over two decades from the mid-1970s to the mid-1990s. Most of the documents can be downloaded in pdf format from the LANL online library Internet site. The Data Index is available on compact disc.

2.3.4 Workshop

PERI completed its report of the EGS Workshop conducted at Lawrence Berkeley National Laboratory in Berkeley, California in August, 1999. 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 current understanding of geothermal reservoirs, and how that understanding might be advanced.

2.3.5 Numerical Simulators

PERI's subcontractor, GeothermEx, Inc., completed a report, "Assessment of the State-of-the-Art of Numerical Simulation of Enhanced Geothermal Systems." The study examines existing numerical simulators designed for hydrothermal systems, hot dry rock systems, groundwater contaminant transport systems, and nuclear waste isolation systems. Shortcomings in the existing systems, with regard to EGS applications, are identified along with the optimum features necessary for an effective EGS simulator. The report recommends research for developing those features and implementing them in a simulator. This work also supports Subtask D, "Reservoir Evaluation".

2.3.6 Current Activities:

During FY-2000 PERI completed the report "Monitoring EGS-Related Research," which reviews technologies that could be applicable to the development of EGS. The study reviews current literature in order to describe and publicize a number of technical developments where emerging technologies could be of value to improving the use of the moderate-quality hydrothermal reservoirs. These

reservoirs could become the test beds for EGS in the U.S. These technologies are being developed in both the petroleum (oil and gas) industry and in research being sponsored by the U.S. Department of Energy's Geothermal Program.

PERI is reviewing technical literature to determine if there are new advances or promising developments in fracture detection, which might be applicable to EGS. The review will also include interviews with U.S. experts in the areas of fracture detection and rock mechanics. A report on this work is scheduled for September 2001.

PERI is analyzing the likely costs and performance of EGS for electric power generation. PERI will examine the cost and performance of four EGS type cases typical of the sort of projects that industry might pursue. These cases will include:

1) converting a failed hydrothermal well into either a production well or an injection well;
2) connecting a sizeable impermeable area within, or adjacent to, an existing hydrothermal operation using a new injection or production well;
3) connecting a sizeable impermeable area within, or adjacent to, an existing hydrothermal operation with multiple new injection and production wells; and
4) a stand-alone "Soultz–like" project.

The cases will include a parametric analysis of the most important cost determinants for the appropriate EGS systems. The analysis will be done in conjunction with ongoing activities under Subtask A, "Economic Analysis". PERI will prepare a report of the results by June 2001.

2.4 Subtask C - Data Acquisition and Processing

2.4.1 Collection and archiving of project data

This subject comprises the first activity under subtask C. There are two distinct but related tasks to be undertaken here, separable because of the concept of separate archiving and indexing of projects. The two tasks 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. Major progress has been made with the Data Index for the Soultz project. Nearly all on-site measurements made between 1987 and 1999 in the main boreholes, in the circulating fluid system and in observation boreholes (microseismic event locations and groundwater levels) have been located, collected and indexed. The collection includes at present 990 data sets. A first CD-mounted version of the resulting Microsoft Access application is planned for 2001.
2. The data themselves gathered at Soultz are being made available centrally at the project site.
3. An application for credit to the European Commission under a programme for financing of "Accompanying Measures" has not been accepted, but some progress has been made on archiving and organizing the data from the former U.K. project at Rosemanowes Quarry, thanks to ABB Offshore Systems Ltd..
4. A listing of all the data collected by our Japanese colleagues at NIRE from the Hijiori project site has been received.
5. A Data Index application for the Fenton Hill project has now been set up and mounted on a Compact Disk. We have now received a copy of this from our U.S. colleagues (PERI, Rockville, Maryland).

2) HDR literature and literature archiving

One of the aims of the archiving activity is to set up a general library of HDR/EGS published literature and at the same time encourages the setting up of project libraries. These latter will, it is hoped, contain project reports, technical notes, presentations and publications.

The general HDR literature list has now reached considerable dimensions. At present more than 2200 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 over 50 of the more significant reports 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.

2.4.2 Generic Project Development

The progress on this theme has been limited in the year 2000. It was planned from the beginning to tie the task to the activities and experiences gained in the course of the Swiss Deep Heat Mining pilot plant development programme. This has suffered some delays. However, some progress has now been made in the pre-planning and preparatory phases.

2.5 Subtask D - Reservoir Evaluation

(a) The questionnaire survey was open to the public on NEDO server from August 1st, 1999 at http://www.nedo.go.jp/gec/taskd/. Because of the security problem of the NEDO server, the questionnaire has moved to the new server, http://www.penguins.co.jp/cgi-bin/taskd/index.cgi. As the old URL redirect to the new URL, the respondents can use both URLs.

The items in 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

If the respondent wants to correct or modify the pre-answered data, he can easily retrieve his data by using his unique I.D. number given at his first access. And if the respondent wants to answer more than two items in one category, the difference between two items will be distinguished by key word.

(b) The purpose of the Subtask D was announced at WGC 2000 in Morioka both at the poster session and the HDR presentation session on 6th June 2000.

(c) Total of 22 people has joined the questionnaire up to now. Nationalities and names of respondents are as follows;

Japan (17);

Hajime SUGITA, Hideshi KAIEDA, Hiroaki NIITSUMA, Hiroshi ASANUMA, Hisatoshi ITO, Isao MATSUNAGA, Kazuhiko TEZUKA, Kenzo KIHO, Makoto MIYAIRI, Masahiko YAGI, Masaji KATO, Masakazu KADOWAKI, Nobukazu SOMA, Norio, TENMA, Tsutomu YAMAGUCHI, Yasuki OIKAWA, Yuzuru EGUCHI,

Swiss (3);

Dominique BAECHLER, Robert J. HOPKIRK, Thomas KOHL

Germany (1)

Daniel PRINBOW

France (1)

Dominique BRUEL

(d) As for Japanese HDR test sites such as Hijiori and Ogachi, enough information for category from 1 to 5 has been collected from respondents consisting mainly of Japanese Subtask D members.

2.6 HDR Activities in Australia and Germany

In this section, HDR activities in Australia and Germany are introduced. The report on Australian activity has been prepared by Prame Chopra (Australian National University) and that on Germany activity by Reinhard Jung (BGR).

2.6.1 Australia HDR Activities for 2000

1. Hunter Valley Project

Activities at the Hunter Valley project site south of Muswellbrook, New South Wales continued on a number of fronts. This project is a collaboration between the Australian National University's geothermal program (http://hotrock.anu.edu.au) and Pacific Power (http://www.pacificpower.com.au). Funding is provided by the Australian Greenhouse Office (AGO) (http://www.ago.gov.au) and Pacific Power.

Milestone 1

The results of a shallow drilling survey over the Muswellbrook geothermal anomaly were assembled and analyzed in a report to the AGO. Twelve shallow exploration holes were drilled to depths of 300 – 900 meter and geophysical and temperature logging done soon after drilling was completed. These holes were therefore not thermally equilibrated, but the results nevertheless confirmed the existence of the geothermal anomaly and allowed a site to be chosen for a deeper exploration hole.

Deeper Exploration Hole

Drilling of a 2km deep slim hole was commenced in October. At 14 December, the hole had reached 1500 meter and completion is expected by year's end.

Seismic Reflection Survey Planning

Planning for a 19 km long seismic reflection survey using three 40 000 lb vibroseis trucks and a split spread has been completed. The survey is scheduled for January 2001.

2. Cooper Basin

After several years of lobbying, the South Australian government has announced competitive tenders for three exploration tenements for geothermal energy. These Cooper Basin tenements are in the vicinity of Innamincka in northeastern South Australia. There has been quite a bit of commercial interest. The closing date for the tenders is 1 February 2001.

Details can be found on the PIRSA website (http://www.pir.sa.gov.au).

2.6.2 German subprojects within the European Hot-Dry-Rock-Project Soultz

Previous history

The last 5 years of the European Hot-Dry-Rock project at Soultz represent a significant step forward in the development of the Hot-Dry-Rock technology. In the depth region at around 3000 m the world's biggest and most effective Hot-Dry-Rock system was created by massive hydraulic-fracturing. The vertical NNW-SSE striking fracture system has a surface area of 3 km^2 and connects the two operational boreholes of the test site GPK1 and GPK2 over a distance of about 500 m. The performance of the system was tested by conducting a 4-months circulation experiment. The thermal power and circulation flow rate exceeded 10 MW and 25 kg/s respectively and for the first time approached the scale of a commercial system. Fluid losses, one of the major problems in previous Hot-Dry-Rock systems, were completely prevented by using a downhole pump in the production borehole. The use of a downhole pump also enabled to maintain an overpressure in the surface loop thus preventing the escape of CO_2 and the intrusion of oxygen into the system. By this scaling and corrosion in the system was avoided despite the highly mineralized fluid.

The success of these experiments attracted a group of French, German and Italian electricity companies (EDF, RWE, ENEL, EDS, Pfalzwerke) as well as Shell. These companies founded a joint venture and joined the Soultz-project in 1998. They proposed to continue further development at greater depth at rock temperatures of about 200°C in order to achieve a higher efficiency for electric power production.

Work performed During the Current Project Period (1998 – 2000)

During the present project period the objective was to investigate the geothermal, geological, tectonic, and hydraulic conditions as well as the effect of a moderate stimulation at greater depth. For this reason one of the existing boreholes (GPK2) was deepened from 3900m to 5080m during the winter 1998/2000. A rock temperature of 201°C was measured at the bottom of this borehole. This temperature confirmed the predictions based on the temperature profile in the upper section and on numerical calculations. This temperature would allow power production with relatively high efficiency. Sampling of the drill cuttings, a core section and geophysical logging proved that the

granite, whose top is at about 1400m, extends down to the final depth of the borehole. The granite in the new borehole section, however, is more inhomogeneous and is similar to the upper section, intensely altered in faults or fracture zones.

In order to withstand the high thermal forces created by the varying temperatures during injection and production, a novel completion technique was applied. The 7"-casing running down to 4400m was fixed at the bottom by using 7 inflatable metal casing packers developed within the project. After filling 440m of the annulus with fly ash and 250m with cement these packers were permanently inflated by injecting cement. The top of the casing is not fixed but can slide in a rubber seal installed in a cellar some meters below the wellhead.

Several hundred cubic meter of formation fluid were produced during a long-term production test. Its chemical composition was similar to that of the fluid produced in the upper part of the granite. It is rich in sodium-chloride (> 100 g/l TDS). The high silica concentration indicates a source temperature of the fluid of more than 240°C. A massive hydraulic-fracturing experiment was carried out during the summer 2000. The test was started by injecting 600m^3 of saturated brine. As a result fractures were opened, as intended, predominantly in the lower part of the uncased borehole section (4440 - 5080m). The fractures were propagated further by injecting more than 23 000m^3 of water at flow rates of up to 50 l/s. The overpressure needed for fracture propagation was surprisingly low (13 MPa) and was almost equal to the overpressure observed during the hydraulic-fracturing tests at around 3000 m. More than 20 000 micro-seismic events were induced during the test and recorded with geophones and hydrophones in 5 observation boreholes and at the surface. The spatial distribution of the sources of these events show that a NW-SE striking vertical fracture system was stimulated during the test whose lateral and vertical extent is about 1.5 km. A post-frac injection test showed that this fracture system has a high internal hydraulic conductivity similar to the fracture system at 3000 m. Its periphery however seems to be tighter. Contrary to the tests at 3000m there was no significant reaction of the water table in the seismic observation boreholes.

Activities for the upcoming years

Applications and contracts for the next 3 year project period are now under preparation. Funds are expected from the EC, the German Ministry of Economy and Technology via Forschungszentum Jülich (BEO), from the French Ministry for Research via ADEME, and from industry. The industrial consortium (GEIE) will co-ordinate the project and will manage the on-site operations. Scientific investigations will be performed by the French and German institutes involved in the project since the beginning.

Two new boreholes will be drilled and stimulated massively in order to complete the HDR-system at around 5000m depth. The completed system will consist of one central injection borehole and two symmetrically deviated production boreholes. The separation between the injection borehole and the production boreholes will be 500 m at depth. The system will be tested during circulation experiments by producing the brine with two submersible pumps in the production boreholes and by reinjecting it in the central injection borehole after cooling. We are aiming for a total flow rate of 80 l/s. This is equivalent to a total thermal power of 50 MWt. Electric power production is not planned during this project period but, if successful, several 1.5 MWe modules will be installed during the following phase.

Internet

www.soultz .net

ATTACHMENT 3
Annex III report

3. Work plan in 2001

This is the last year for Annex III. However, it is intended that Annex III will be extended. Each subtask, especially Subtasks A and B, will be reviewed before work in 2001 is planned.

3.1 Subtask C - Data Acquisition and Processing

- 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. The first issue of a Data Index for the Soultz project in the form of a CD is planned.
- More attention will be given to the establishment of the basic outline plans which would be 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. A report on the initial and already completed project stages is proposed for 2001.
- Progress will be continued with a global HDR library. In order to make this accessible to more people, work has been started on creating additionally a Spreadsheet version in the much more widespread Microsoft Excel to supplement the original EndNote version.

3.2 Subtask D: Reservoir Evaluation

- Responses related to HDR fields at Soultz and in Australia are not yet adequate. The efforts to collect the data will be continued through the Internet questionnaire.
- In order to refine and confirm the contents of answers, the answers from all respondents will be formatted and will be sent back to each respondent.
- Subtask D will continue its work until the year of 2002, when the major results of Japanese Hijiori field experiments is supposed to be obtained.

The subtask will start to discuss about distribution of the results of the questionnaire by way of a CD ROM in 2002.

4. Output (ublications)

R. Baria, J. Baumgärtner, A. Gérard and J. Garnish (2000): The European HDR programme; main targets and results of deepening the well GPK2 to 5000m. *Proceedings World Geothermal Congress 2000*: 3643-3652

J. Baumgärtner, A. Gérard, R. Baria and J. Garnish. (2000) : Progress at the European HDR Project at Soultz-sous-Forêts; preliminary results from the deepening of the well GKP-2 to 5000m.- *Proc. 25th Workshop on Geothermal Reservoir Eng.*, Stanford Univ., Cal., Jan. 24-26, 2000.

P. Durst and F. D. Vuataz (2000): Fluid-rock interactions in hot dry rock reservoirs – a review of the HDR sites and detailed investigations of the Soultz-sous-Foret system. *Proceedings World Geothermal Congress 2000*: 3677-3682

A. Y. Genter, H. Traineau, B. Ledesert, B. Bourgine and S. Gentier (2000): Over 10 years of geological investigations within the HDR Soultz project, France. *Proceedings World Geothermal Congress 2000*: 3707-3712

K. F. Evans (2000): The effect of the 1993 stimulations of well GPK1 at Soultz on the surrounding rock mass: evidence for the existence of a connected network of permeable fractures. *Proceedings World Geothermal Congress 2000*: 3695-3700

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R. Hopkirk, (2000): Data collection and organization for the development of HDR/EGS systems - A subtask within the hot dry rock annex of the new IEA-GIA. *Proceedings World Geothermal Congress 2000*: 3737-3742

H. Ito and K. Kitano (2000): Fracture investigation of the granitic basement in the HDR Ogachi project, Japan. *Proceedings World Geothermal Congress 2000*: 3743-3748

R. Jung, D. Pribnow and C. Clauser, (1998): Heat- and Fluid-Flow at the Soultz Hot-Dry-Rock System in the Rhine Graben. – *Proceedings of the 1998 annual AGU meeting*, San Francisco.

H. Kaieda, R. H. Jones, H. Moriya, S. Sasaki and K. Ushijima (2000): Ogachi HDR reservoir evaluation by AE and geophysical methods. *Proceedings World Geothermal Congress 2000*: 3755-3760

K. Kitano, Y. Hori and H. Kaieda (2000): Outline of the Ogachi HDR project and character of the reservoirs. *Proceedings World Geothermal Congress 2000*: 3773-3778

O. J. Kitsou, H. Herzog and J. Tester, (2000): Economic modelling of HDR enhanced geothermal systems. *Proceedings World Geothermal Congress 2000*: 3779-3784

P. Kruger, H, Karasawa, N. Tenma and K. Kitano (2000): Analysis of heat extraction from the Hijiori and Ogachi HDR geothermal resources in Japan. *Proceedings World Geothermal Congress 2000:* 2677-3682

M. Kuriyagawa, H. Herzog, L. MacLarty, R. Hopkirk and T. Yamaguchi, (2000): Activities of HDR under geothermal implementing agreement, IEA, *Proceedings World Geothermal Congress 2000*: 3785-3786

I. Matsunaga, H. Tao and N. Tenma (2000): Geochemical evaluation of the Hijiori HDR reservoir at Yamagata, Japan. *Proceedings World Geothermal Congress 2000:* 3787-3792

L. McLarty, P. Grabowski, D. Entingh and A. Robertson-Tait, (2000): Enhanced geothermal systems R&D in the United States. *Proceedings World Geothermal Congress 2000*: 3793-3796

H. Moriya, H. Niitsuma and H. Kaieda (2000): Re-evaluation of reservoir structure at Ogachi HDR field by precise source location of AE multiplet. *Proceedings World Geothermal Congress 2000*: 3801-3806

H. Murphy, H. Niitsuma and H. Asanuma (2000): The more-than-cloud and successor projects: international joint research on new mapping and HDR/HWR reservoir development technologies. *Proceedings World Geothermal Congress 2000*: 3813-3818

D. Pribnow, T. Kohl, R. Jung, L. Rybach and C. Clauser, (1999): The European HDR Project in Soultz: An Unconventional Reservoir Type?. *Proc. 1999 GRC Annual Meeting*, Reno, Nevada, USA

D. Pribnow and C. Clauser (2000): Heat and fluid flow at the Soultz hot dry rock system in the Rhine Graben. *Proceedings World Geothermal Congress 2000*: 3835-3840

A. Robertson-Tait, C. Klein and L. McLarty, (2000): Utility of the data gathered from the Fenton Hill Project for the development of enhanced geothermal system. *Proceedings World Geothermal Congress 2000*: 3847-3852

N. Soma, H. Niitsuma and R. Baria (2000): Reflection imaging of HDR reservoir at Soultz by means of the AE reflection method. *Proceedings World Geothermal Congress 2000*: 3883-3888

H. Suenaga, T. Yamamoto, Y. Eguchi, K. Kitano and H. Onishi (2000): A fully three-dimensional thermo-hydraulic computation of the Ogachi HDR reservoir. *Proceedings World Geothermal Congress 2000*: 3895-3900

D. Swenson, P. N. Chopra and D Wyborn (2000): Initial calculations of performance for an Australian hot dry rock reservoir. *Proceedings World Geothermal Congress 2000*: 3907-3912

H. Tenzer, U. Schanz and G. Homeier (2000): Development and characterization of a HDR heat exchanger at the HDR site at Soultz-sous-Foret: flow log, joint systems and hydraulic active fractures. *Proceedings World Geothermal Congress 2000*: 3921-3927

K. Tezuka and K. Watanabe (2000): Fracture network modelling of Hijiori Hot Dry Rock reservoir by deterministic and stochastic crack network simulator. *Proceedings World Geothermal Congress 2000:* 3933-3942

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S. Yamaguchi, S. Akibayashi, S. Rokugawa, Y. Fujinaga, N. Tenma and Y. Sato (2000): The numerical modeling study of the Hijiori HDR test site. *Proceedings World Geothermal Congress 2000*: 3975-3980

T. Yamaguchi, M. Kuriyagawa, I. Matsunaga, N. Tenma and H. Karasawa, (2000): Progress of the task of HDR evaluation under IEA agreement. *Proceedings World Geothermal Congress 2000*: 3981-3983

ATTACHMENT 4
Annex IV report

IEA GIA Annex IV :
DEEP GEOTHERMAL RESOURCES – 2000 ANNUAL REPORT

Prepared by Task Leader Dr. M. Sasada (GSJ, Tsukuba, Japan)

1. Introduction

The task of Deep Geothermal Resources was started from 1997 as a four-year international collaborative program under the IEA Geothermal Implementing Agreement (GIA). Japan took the lead in developing an original entire work program for the task and NEDO undertook the role of the Operating Agent (OA). The subtask leaders develop the details of their annual work plans which are submitted to the Executive Committee (ExCo) each year. In accordance with the IEA task sharing methodology, the OA organizes annual meetings, workshops and field trips to conduct the work programmes including information exchange through the Internet in collaboration with the participants.

Objective of Annex IV:

The objective of the Task "Deep Geothermal Resources" is to address the issues necessary for the commercial development of deep geothermal resources at depths of about 3,000 meters and deeper. This task consists of the three Subtasks: (A) exploration technology and reservoir engineering, (B) drilling and logging technology, and (C) material evaluation program.

Participating countries:

Annex IV officially came into effect on March 10th, 1997, with the signing by New Zealand and Japan. Mexico joined in the Annex on July 4th, 1997, United States and Australia on November 10th, 1997. Then Germany joined on May 1st, 2000, and Italy on May 3rd, 2000.

Subtask A:

The objective of the subtask A "Exploration Technology and Reservoir Engineering" is to carry out collaborative research on exploration technology, including geothermal modelling, geophysical, geological and geochemical explorations, and on reservoir engineering, including reservoir characterization and reservoir modelling. As of October 2000, four countries are participating in Subtask A of Annex IV: New Zealand, Mexico, Italy and Japan.

Subtask B:

The objective of subtask B is to carry out collaborative research on drilling and logging technologies, including the reviews of drilling and logging records of deep geothermal wells, exchange of information on improvements of drilling and logging tools. There are 13 members in task B network. These are organizations from Australia (1), Italy (2), Japan (4), Mexico (1), USA (4), and Philippines (1).

Subtask C:

The objective of subtask C is to exchange experience on materials and chemistries among the group. The group gathers information, both published and unpublished, on past, present and planned experiences, tests and research on materials in deep and aggressive geothermal systems. The information obtained is summarized in a database. Some members of the group, principally from IRL (NZ), TNIRI (Japan) and NEDO (Japan), perform corrosion tests of materials in field trials and laboratory tests as are required to help in the materials selection process.

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Annex IV report

2. Work performed in 2000

2.1. General

The OA organized the special session of "IEA Deep Geothermal Resources" at the WGC 2000 in Morioka, Japan. Twelve papers were presented at the oral and poster sessions. A special issue of Geothermics was planned to summarize the task activities, and its editorial work was started.

2.2. Subtask A

A major issue of collaborative activity is to achieve general models and strategy of development of deep geothermal resources in the participating countries. This issue has been done successfully by nine research groups. These results were presented in the IEA Deep Geothermal Resources Session of WGC2000 in Morioka. Final results are also being prepared for publication in a special volume of *Geothermics*. A small database for deep geothermal wells and deep geothermal fields is under construction by NEDO and the supporting groups.

2.3. Subtask B

Information on geothermal well drilling and logging continued to be collected and was stored in the database of the DGR Web Site. About 180 papers were stored by September 2000. Most of these papers are from USA (72) and Japan (64), with others from Italy (10), New Zealand (5), Mexico (4), Germany (4), Russia (4), Indonesia (5), etc. These papers were classified into 8 categories such as trouble assessment on drilling (20), drill bit (12), field report on drilling (69), cost evaluation on drilling (13), materials (13), new and/or conventional drilling systems (51), logging technology (44), general report on DGR (16) and others (5). Based on the database, a comparison on the time distribution of drilling wells at several geothermal fields in different countries was attempted. Unfortunately, different data sources categorize the information in different ways.. For easy comparison and evaluation, the original data were divided into 6 temporal categories: drilling and tripping, L/C treatment and other troubles, casing cementing, logging and coring, well test, and others. If we add the time ratio of L/C treatment and other troubles to the time ratios of drilling, the values of 5 different fields are almost the same at about 70 % of the total drilling time. It is clear that reduction of L/C treatment and other troubles can provide a higher percentage of actual drilling time even if the drilling category includes both real drilling time and tripping time. Up to now, we have not been able to present an acceptable standard form of job categories. However, it seems necessary to make a standard classification of job categories for easy and effective usage of the database and for compiling drilling knowledge and experiences.

Fifteen papers related to drilling and logging technology for DGR were presented at WGC2000. Four reports of these have been preparing for a special volume of *Geothermics* as a final open report on subtask B of the DGR task.

2.4. Subtask C

(1) Compile references: Compilation of literature references from the last 10 years, concerned with chemistries and materials' performance experienced in geothermal activities, has continued. Over 200 papers have been listed from *Geothermics*, *GRC Transactions*, *Geochemical Journal*, Proceedings, et al.

(2) Corrosion model: Corrosion models have been developed for downhole and wellhead environments under flowing conditions. These models include the corrosion chemistry and

phase stability of mineral corrosion products as well as the effect of fluid velocity on erosion corrosion. The models have been applied to predict materials performance problems and to identify corrosion control options.

(3) Guidelines of materials selection: A guideline has been proposed for corrosion control and materials selection for deep and acidic geothermal wells with pH values as low as 3; Application of pH adjustment and/or inhibitors for well bore corrosion control has been advocated for pH values as low as 3.

(4) Information exchanges through the WGC 2000: The Japan and New Zealand participants in the subtask C attended the WGC 2000, 30 May to 7 June 2000 in Japan to present their papers and to exchange information on the materials corrosion controls. Information exchanges of relevant research results were done with those of Italy, Turkey, USA, The Philippines, et al., as well as Japan and New Zealand.

3. Work Plan for 2001

3.1. General

Editorial work will be continued until the end of 2001 to publish the special issue of *Geothermics*. Further development of each subtask will also be done.

3.2. Subtask A

Final results are now being prepare for a special issue of *Geothermics*. In a planned schedule, preliminary manuscripts were submitted up to September 2000 and revised manuscripts after referee reviews will be completed by January 2001. However, further editing work adapted for the special issue could be required and publication will take the entire year 2001.

3.3. Subtask B

An attempt will be made to formulate a standard classification of job categories for easy and effective usage of the database and for compiling drilling knowledge and experience. Final progress reports of proposed programmes will be produced. A proposal for the future programme will be planned through close discussions between participating members.

3.4. Subtask C

Further compilation of literature references concerned with chemistries and materials performance is expected. Further development of the corrosion models and materials guidelines on deep and acidic wells will also be expected. Two papers will be printed in the special issue of *Geothermics*.

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Annex IV report

4. Output (publications)

Christenson, B.W., E.K.Mroczek, M.K.Stewart, G.Lyon and B.M.Kennedy (2000): Ohaaki reservoir chemistry: insights into the nature of the heat source(s). *Proceedings World Geothermal Congress 2000:* pp.1059-1064.

Fridleifsson, G.O. and A. Albertsson (2000): Deep geothermal drilling on the Reykjanes ridge opportunity for international collaboration. *Proceedings World Geothermal Congress 2000*: pp.3701-3706.

Gianelli, G. and G. Riggineri (2000): Contact metamorphism in the Larderello geothermal system. *Proceedings World Geothermal Congress 2000*: pp.1163-1168.

Kasai, K., Y.Hishi, D.Fukuda, O.Kato, N.Doi, K.Akaku, T.Ominato and T.Tosha (2000): The fluid geochemistry and reservoir model for the Kakkonda geothermal system, obtained by NEDO's Deep-Seated Geothermal Reservoir Survey, Japan. *Proceedings World Geothermal Congress 2000*: pp.1325-1330.

Kimbara, K., H.Muraoka, H.Kobayashi, N.Sanada, K.Fujimoto and K.Osato (2000): A summary of results of the IEA task activities of Deep Geothermal Resources. *Proceedings World Geothermal Congress 2000*: pp.2653-2658

Kobayashi, H. (2000): Activity report on drilling and logging technology of the IEA Deep Geothermal Resources Task. *Proceedings World Geothermal Congress 2000*: pp.2365-2370.

Muraoka, H., K. Yasukawa and K.Kimbara (2000): Current state of development of deep geothermal resources in the world and implications to the future. *Proceedings World Geothermal Congress 2000*: pp.1479-1484.

Nielson, D. and J. Moore (2000): The deeper parts of the Geysers thermal system – implications for heat recovery. *Proceedings World Geothermal Congress 2000*: pp.1503-1508.

Rowley, J., S.Saito, and R.Long (2000): Advanced drilling system for drilling geothermal wells - an estimate of cost savings. *Proceedings World Geothermal Congress 2000*: pp.2399-2404.

Sanada, N., Y.Kurata, H.Nanjo, H.Kim, J.Ikeuchi and K.Lichti (2000): IEA Deep Geothermal Resources Subtask C: materials, progress with a database for materials performance in deep acidic geothermal wells. *Proceedings World Geothermal Congress 2000*: pp.2411-2416.

Tosha, T., K.Koide, T.Ominato, K.Akaku and N.Doi (2000): Recent results of "Deep-Seated Geothermal Reservoir Survey" project in the Kakkonda geothermal field, Japan. *Proceedings World Geothermal Congress 2000*: pp.1877-1882.

Weir, G.J. (2000): A mathematical model coupling heat and mass flow and extension rate in the Taupo volcanic zone, New Zealand. *Proceedings World Geothermal Congress 2000*: pp.889-893.

ATTACHMENT 5
Presentations at WGC2000

PRESENTATION OF
IEA GEOTHERMAL IMPLEMENTING AGREEMENT RESULTS
AT THE *WORLD GEOTHERMAL CONGRESS 2000*

(28 May – 10 June 2000, Japan)

ORAL PRESENTATIONS AT SPECIAL IEA SESSIONS

Tuesday, June 6

9:00 - 10:40	**Session F2: IEA Hot Dry Rock (Hijiori)**	**Room F**
	Chair: Michio Kuriyagawa and Paul Kruger	

9:00	F2-1	Activities of HDR under the IEA Geothermal Implementing Agreement *M. Kuriyagawa, H. Herzog, L. McLarty, R. Hopkirk and T. Yamaguchi*
9:20	F2-2	Geochemical evaluation of the Hijiori HDR reservoir at Yamagata, Japan *I. Matsunaga, H. Tao and N. Tenma*
9:40	F2-3	Fracture network modeling of Hijiori Hot Dry Rock reservoir by deterministic and stochastic crack network simulator (D/SC) *K. Tezuka and K. Watanabe*
10:00	F2-4	The numerical modeling study ot the Hijiori HDR test site *S. Yamaguchi, S. Akibayashi, S. Rokugawa, Y. Fujinaga, N. Tenma and Y. Sato*
10:20	F2-5	Analysis of heat extraction from the Hijiori and Ogachi HDR geothermal resources in Japan *P. Kruger, H. Karasawa, N. Tenma and K. Kitano*
Reserve Papers		Analysis in preparation for Hijiori long term circulation test *T. Okabe, K. Kirihara, K. Hayashi, K. Karasawa, D. Swenson and R. Schroeder* Determination of stress state at the Hijiori HDR site from focal mechanisms *S. Sasaki and H. Kaieda*

11:00 - 11:20	**Session F3: IEA Hot Dry Rock (Ogachi)**	**Room F**
	Chair: Yoshinio Hori and Howard J. Herzog	

11:00	F3-1	Outline of the Ogachi HDR project and character of the reservoirs *K. Kitano. Y. Hori ancl H. Kaieda*
11:20	F3-2	Fracture investigation of' the granitic basement in the HDR Ogachi project, Japan *H. Ito and K. Kilano*
11:40	F3-3	A fully three-dimensional thermo-hydraulic computation of the Ogachi HDR reservoir *H. Suenaga, T. Yanamoto, Y. Eguchi, K. Kitano and H. Ohnishi*
12:00	F3-4	Ogachi HDR reservoir evaluation by AE and geophysical methods *H. Kaieda, R.H. Jones, H. Moriya, S. Sasaki and K. Ushijima*
12:20	F3-5	Reevaluation of reservoir structure at Ogachi HDR field by precise source location of AE multiplet *H. Moriya, H. Niitsuma ancl H. Kaieda*
Reserve Papers		Stress state at the Ogachi site *K. Shin, H. Ito and Y. Oikawa*

ATTACHMENT 5
Presentations at WGC2000

11:00 - 11:20	**Session G3: IEA Environment (1)**	**Room G**
	Chair: Trevor Hunt and Kan-ichi Shimada	

11:00	G3-1	An enforcement project on environmental impact of geothermal exploitation in Iceland *H. Kristmannsdóttir, H. Armannsson and K. Arnason*
11:20	G3-2	The influence of effluent water discharged from the Námafjall geothermal field on local groundwater *S. Hauksdóttir, H. Kristmannsdóttir, G. Axelsson, H. Armannsson, H. Bjarnason and M. Olafsson*
11:40	G3-3	Monitoring of geyser activity in Whakarewarewa, New Zealand *Y. Nishi, T. Ishido, M. Sugihara, T. Tosha, N. Matsushima and B.J. Scott*
12:00	G3-4	Development and verification of a method to forecast hot springs interference due to geothermal power exploitation *H. Tokita, H. Takagi, Y. Kiyota, K. Matsuda, H. Hatanaka, K. Shimada, H. Inuyama, R. Young, L.F. Bayrante, O.T. Jordan, J.M. Salera and F.E. Bayon*
12:20	G3-5	~~Lichen biomonitoring as a tool for assessing air quality in geothermal areas : *S. Loppi*~~ ***(not given)***

13:40 - 15:20	**Session G4: IEA Environment (2)**	**Room G**
	Chair: Michael Sorey and Mahendra Verma	

13:40	G4-1	Geothermal development and changes in surficial features: examples from the Western United States *M.L. Sorey*
14:00	G4-2	Some environmental changes resulting from development of Ohaaki geothermal field, New Zealand *T.M. Hunt and C.J. Bromley*
14:20	G4-3	Hot spring interference study for predicting hot spring change in geothermal field *K. Shimada, F. Inuyama and H. Tokita*
14:40	G4-4	Elevation and gravity changes at geothermal fields on the Reykjanes peninsula, SW Iceland *H. Eysteinsson*
15:00	G4-5	An investigation of boiling processes in hydrothermal eruptions *T.A. Smith and R. McKibbin*

13:40 - 15:20	**Session F4: IEA Hot Dry Rock (Soultz)**	**Room F**
	Chair: Hiroaki Niitsuma and Hisatoshi Ito	

13:40	F4-1	Over 10 years of geological investigations within the HDR Soultz project, France *A.Y. Genter, H. Traineau, B. Ledesert, B. Bourgine and S. Gentier*
14:00	F4-2	Heat and fluid flow at the Soultz hot dry rock system in the Rhine Graben *D. Pribnow and C. Clauser*
14:20	F4-3	Reflection imaging of HDR reservoir at Soultz by means of the AE reflection method *N. Soma, H. Niitsuma and R. Baria*
14:40	F4-4	The effect of the 1993 stimulations of well GPK1 at Soultz on the surrounding rock mass: evidence for the existence of a connected network of permeable fractures *K.F. Evans*
15:00	F4-5	*S*oultz-sous-forets: main technical aspects of deepening the well GPK2 . *J. Baumgärtner, A. Gerard and R. Baria*
Reserve Papers		Steps towards a comprehensive thermo-hydraulic analysis of the HDR test site Soultz-sous- Forets *T. Kohl, D. Bächler and L. Rybach*

ATTACHMENT 5
Presentations at WGC2000

Wednesday, June 7

9:00 - 10:40	**Session F6: IEA Deep Geothermal Resources (1)**	**Room F**
	Chair: Masakatsu Sasada and Graham J. Weir	

9:00	F6-1	Current state of development of deep geothermal resources in the world and implications to the future *H. Muraoka, K. Yasukawa and K. Kimbara*
9:20	F6-2	Ohaaki reservoir chemistry: insights into the nature and location of the heat source(s) *B.W. Christenson, E.K. Mroczek, M.K. Stewart, G. Lyon and B.M. Kennedy*
9:40	F6-3	Contact metamorphism in the Larderello geothermal system *G. Gianelli and G. Ruggieri*
10:00	FG-4	The deeper parts of the Geysers thermal system - implications for heat recovery *D. Nielson and J. Moore*
10:20	FG-5	A mathematical model coupling heat and mass flow and extension rate in the Taupo volcanic zone, New Zealand *G.J. Weir*

11:00 - 12:40	**Session F7: IEA Deep Geothermal Resources (2)**	**Room F**
	Chair: Hideo Kobayashi and H. Muraoka	

11:00	F7-1	Activity report on drilling and logging technology of IEA deep geothermal resources task *H. Kobayashi*
11:20	F7-2	Advanced drilling system for drilling geothermal wells - an estimate of cost savings *J. Rowley, S. Saito and R. Long*
11:40	F7-3	IEA deep geothermal resources subtask C: materials, progress with a database for materials performance in deep and acidic geothermal wells *N. Sanada, Y. Kurata, H. Nanjo, H. Kim, J. Ikeuchi and K.A. Lichti*
12:00	F7-4	The fluid geochemistry and reservoir model for the Kakkonda geothermal system, obtained by NEDO's deep-seated geothermal reservoir survey, Japan *K.Kasai,Y. Hishi, D. Fukuda, O. Kato, N. Doi, V. Akaku, T. Ominato and T. Tosha*
12:20	F7-5	Deep geothermal drilling, on the Reykjanes ridge - opportunity for international collaboration *G.O. Fridleifsson and A. Albertsson*

ATTACHMENT 5
Presentations at WGC2000

PRESENTATIONS IN POSTER SESSIONS

IEA Hot Dry Rock

PM-086 Steps towards a comprehensive thermo-hydraulic analysis of the HDR test site Soultz-sous-Forets
T. Kohl, D. Bächler and L. Rybach

PM-087 Progress of the task of HDR evaluation under IEA agreement
T. Yamaguchi, M. Kuriyagawa, I. Matsunaga, N. Tenma and H. Karasawa

PM-088 The European HDR programme: main targets and results of the deepening of the well GPK2 to 5000m
R. Baria, J. Baumgärtner, A. Gérard and J. Garnish

PM-089 Soultz-sous-forêts: main technical aspects of deepening the well GPK2
J. Baumgärtner, A. Gerard and R. Baria

PM-090 Geological structure around the Ogachi hot dry rock test site using seismic reflection and Csamt surveys
K. Suzulki and H. Kaieda

PM-091 A study of the pressure-flow response of the Hijiori reservoir at the Hijiori HDR test site
N. Tenma, T. Yamaguchi, K. Tezuka and H. Karasawa

PM-092 Study on surface area estimation of the Ogachi HDR reservoir by geochemical method
K. Kiho

PM-093 Stress stale at the Ogachi site
K. Shin, H. Ilo and Y. Oikawa

PM-094 Determination of stress state at the Hijiori HDR site from focal mechanisms
S. Sasaki and H. Kaieda

PM-095 Plugging method for HDR reservoir using hydrothermal processing of smectite clays to improve recovery efficiency
N. Hirano, S. Higashi and N. Yamasaki

PM-096 Analysis in preparation for Hijiori long term circulation test
T. Okabe, K. Kirihara, K. Hayashi, K. Karasawa, D. Swenson and R. Schroeder

IEA Deep Geothermal Resources

PM-104 A summary of results of the IEA task activities of deep geothermal resources
K. Kimbara, H. Muraoka, H. Kobayashi, N. Sanada, K. Fujimoto and K. Ohsato

PM-105 Recent results of “deep-seated geothermal resources survey“ project in the Kakkonda geothermal field, Japan
T. Tosha, K. Koide, T. Ohminato, K. Akaku and N. Doi