INTERNATIONAL ENERGY AGENCY

Geothermal Implementing Agreement (GIA) - Annual Report 2001

L. Rybach *(ETH Zurich/Switzerland; GIA Executive Committee Chairman in 2001)*
J. Garnish *(CEC Brussels/Belgium; GIA Executive Committee Secretary)*

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 was designed to operate for five years. The first phase ends on 6 March 2002; the prolongation of GIA for another five years has been approved by REWP and CERT in late 2001.

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.

A first Strategic Plan for the GIA was established in 1997 and reviewed subsequently by the REWP in 1998; the Discussant confirmed that the GIA activities are well on track. At the 6th ExCo meeting (Brussels, March 2001) the ExCo addressed a new Strategic Plan which is outlined in **ATTACHMENT 2**.

The GIA encompasses practically all kinds of geothermal technology: besides "traditional" uses like power generation and direct use of heat, new technologies (hot dry rock, deep resources) are also covered.

The present phase of the GIA (7 March 1997 – 6 March 2002) operates under the task-sharing mode of financing.

Task/Annexes

Currently there are three active Annexes that started in March 1997:

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

  The Work Plan of Annex I was designed for 4 years. Operating Agent is the Institute of Geological and Nuclear Sciences, Ltd. (New Zealand); Task Leader is T. Hunt (IGNS Wairakei).

- *Annex III: Hot Dry Rocks* (4 Subtasks)

  The Work Plan of Annex III was designed for 4 years. Operating Agent is the New Energy & Industrial Technology Development Organization (NEDO, Japan). Task Leader was M. Kuriyagawa (NIRE Tsukuba) until 31 March 2001; his successor is I. Matsunaga from the same Institution.

- *Annex IV: Deep Geothermal Resources* (3 Subtasks)

  The Work Plan of Annex IV was designed for 4 years. The Operating Agent during this period was NEDO (Japan). Task Leader was K. Kimbara (Geological Survey of Japan) from the beginning until February 2000 when M. Sasada (GSJ, Tsukuba - now AIST) took over. NEDO stood down as Operating Agent for this Annex at the end of 2001.

These three Annexes were prolonged for another four years by the GIA Executive Committee (ExCo) in 2001.

A new Annex has been started in 2001:

- *Annex VII: Advanced Geothermal Drilling Techniques* (3 Subtasks)

  The Work Plan of Annex VII is designed for 4 years. Operating Agent is Sandia National Laboratories (USA), Task Leader is J. Finger (Albuquerque)

Detailed Annual Reports of these, prepared by the Task Leaders, are given in **ATTACHMENTS 3** to **6.** The Annual Reports are organized in the following format:

- Introduction
- Work performed in 2001
- Work plan for 2002
- Output (publications).

During 2001, the Executive Committee has considered also the following additional Annexes:

- Annex V: Sustainability of Geothermal Energy Utilization
- Annex VI: Geothermal Power Generation Cycles
- Annex VIII: Direct Use of Geothermal Energy
- Annex IX: Geothermal Market Acceleration

The status of the preparations is different. Special emphasis was given to Annex IX (see below).

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 at present 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".

These will all contribute to the broader (but unstated) goal of encouraging the wider use of the geothermal energy option.

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.

The involvement of the Participants in the different Annexes is shown in Table 1 (below). 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 extend the GIA further the ExCo is investigating a possible participation of France and Sweden.

Non-Member Countries

Contacts to China, Turkey and the Philippines to join the GIA are sustained. In fact, Philippine scientists already participate actively in the work of Annex I and IV; their involvement has significantly broadened the range of data and experience available to the formal participants. Input from Turkey would have a similar effect in Annex I.

Table 1. Task participants as of February 2002

Participating country / organization	Annex I (Environment)	Annex III (Hot Dry Rock)	Annex IV (Deep resources)	Annex VII (Advanced drilling)
Australia		P	P	
CEC		P		P
Germany		P	P	
Greece	P			
Iceland	P, I			P
Italy	I	I	I	
Japan	P	P	P	P
Mexico	P		P	P
New Zealand	P, I		P, I	I
Switzerland		P		

United Kingdom		**I**		
USA	**P**	**P**	**P**	**P**

Key: P = publicly-funded research institute or university   I = industry

ExCo ACTIVITIES

Composition

There were no changes in composition in 2001 except that the UK representatives have exchanged roles: Andy Jupe is now the Member and Alan McGovern the Alternate.

Meetings

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

The ExCo had one Meeting in 2001: on 8 and 9 March in Brussels, Belgium, organized and hosted by ExCo Secretary John Garnish (CEC). At this Meeting

- The Executive Committee approved by unanimity an extension of the Geothermal Implementing Agreement with a new termination date of 31 March 2007.
- The Executive Committee approved by majority vote the extension of Annexes I, III, and IV (on Environmental Impacts, Hot Dry Rock and Deep Geothermal Resources respectively) with new termination dates of 31 March 2006.
- The Participants in Annex I (Environmental Impacts) and Annex IV (Deep Geothermal Resources) agreed unanimously that the entities designated by the US Contracting Party could participate in these Annexes .
- The Executive Committee agreed unanimously to the withdrawal of the Commission of the European Communities from participation in Annex IV on Deep Geothermal Resources.

A further ExCo meeting was organized to be held in Cuernavaca/Mexico on 12-13 November but it had to be cancelled due to the international political situation in the wake of the 11 September event.

Renewable Energy Working Party (REWP)

- On January 23-24, 2001 in Paris the GIA contributed through its ExCo Chairman to the REWP Cabinet meeting with Renewable Energy Implementing Agreement Chairmen on Renewable Energy Market Acceleration.
- A further GIA contribution was presented at the REWP meeting in Paris on 4 April 2001 by the ExCo Chairman.

These contributions were strongly assisted by the IEA Secretariat (Rick Seller, Laurent Dittrick, Johan Wide).

IEA Market Initiative

Special emphasis has been given in 2001 to the preparation of Annex IX (Geothermal Market Acceleration), especially in view of the well-initiated GIA/UNEP/GEF alliance (see below). A Draft Annex has been prepared by the USA Participant and it is now under consultation within the ExCo.

Alliance with World Bank / UNEP-Global Environment Facility (GEP)

On March 7, 2001 a well-attended co-ordination meeting was hosted by the European Commission in Brussels, jointly organized by GEF and GIA. It was decided that GIA and GEF will join forces in global geothermal market development and form a strategic partnership collaboration. In particular, the objectives and the follow-up agenda/schedule for the GIA-GEF Alliance were agreed. Details are recorded in the Minutes of the 6th ExCo meeting.

The alliance will undertake focused efforts in regions with high geothermal potential like Central & Latin America and Central and Eastern Europe, followed by selected developing countries.

The conditions of collaboration with GEF will be discussed case by case. Generally, for agreed actions GEF will provide 50 % of the project sum.

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 become clear that the increasing scope of activities under the GIA, and particularly the implementation of Annex IX, will require greater resources than can be supplied by the present ExCo Secretary. To carry out the proposed new tasks (e.g. GIA brochure, website, administration of Annex IX) will need a dedicated Secretariat and a Common GIA Fund. The ExCo has agreed to the principle of this enhanced activity and changed method of working, but details (e.g. level of funding) have yet to be agreed formally between the Participants. In any case, an enhanced working level of the ExCo will be inevitable in the planned new phase of GIA.

Dissemination of Results

The GIA follows the normal methods of disseminating research results: publications in scientific/ technical journals and Conference Proceedings. In addition, a draft GIA Website has been prepared by the UK Participant and is now under review within the ExCo.

PLANS FOR 2002

GIA

The GIA Strategic Plan needs to be further developed and expanded to include the definition of long-term goals and the means of their accomplishment by the GIA Participants.

The visibility of GIA work and results needs to be revised, improved and enhanced, especially to explain to non-experts the contributions GIA is making and the strategy for collaborative technology development, deployment, information dissemination, and market acceleration.

The new phase of GIA (2002-2007) might face some uncertainties. The first phase (1997-2002) has shown – and there are some signs for the immediate future too – that governmental funding of geothermal R&D at the national level can be unstable and unpredictable. Besides the year-to-year changes there are contrasting tendencies and trends: whereas in some countries the funding has decreased successively other countries are speeding up their geothermal efforts. These somewhat unclear perspectives call for a strong dedication and efforts in the next phase of GIA activities.

Annexes

For the corresponding plans of the individual Annexes see **ATTACHMENTS 3 – 6.**

Executive Committee

The ExCo will have to find a new Chairman as well as a Secretary for 2002 and beyond.

ATTACHMENT 1
Executive Committee

IEA Geothermal Implementing Agreement Executive Committee

(December 2001)

Country / Name	Delegate	Organization / address	e-mail / tel / Fax	Alternate	Address, etc. (where different)
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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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ATTACHMENT 2
Strategic Plan

International Energy Agency

Geothermal Implementing Agreement

Strategic Plan

Draft outline prepared by A Jelacic, USDOE (8 February 2001)

Contents

ATTACHMENT 3
Annex I report

IEA GIA Annex I

ENVIRONMENTAL IMPACTS OF GEOTHERMAL ENERGY DEVELOPMENT
2001 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.

At the Executive Committee Meeting held in September 2000 it was decided to continue operation of Task I for a further 4 years. At the start of 2001, six countries were formally participating in Annex I: Greece, Iceland, Japan, Mexico, New Zealand, and United States of America. One further country, Turkey, is expected to join soon.

The Operating Agent for Annex I is the Institute of Geological & Nuclear Sciences (IGNS), 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

ATTACHMENT 3
Annex I report

2. Work performed in 2001

2.1 General:

Few tangible results are available for this Task this year because a new phase of the Annex has been started and new projects needed to be organized. New projects underway or planned are given in Appendix 1.

With completion of the first phase of this Annex last year (2000) most of the results have been published or presented at conferences. However, some results of ongoing work have been published in 2001 (see Section 4., below).

Information about Annex I for an Internet website was prepared but is not yet complete.

Organization of a further Special Issue of *Geothermics* journal was begun, and one paper has already been submitted.

Milestones in Task I set for completion in 2001 were:

- *Complete setting up of a website on Internet to inform the general public about the aims of the Task and results obtained*. Material was prepared, but needs to be completed (photographs etc compiled and put in digital format).
- *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).* This will in part be achieved by the contribution from Greece, but further attempts to obtain research in these areas will be made.
- *Organize a Workshop or Session on Environmental Aspects of Geothermal Development (covering "work in progress / results achieved") at an international geothermal conference*. Not achieved.
- *Define longer-term R&D needs*. Not achieved.

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.

New projects 'have been organized which will examine the effects of geothermal developments on natural geothermal features in Iceland, Japan, New Zealand and United States of America.

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.

New projects have been organized which will examine the problems associated with disposal of waste geothermal fluids from existing geothermal developments in Iceland and Turkey. The effects of hydrogen sulfide gas emissions in Mexico will be investigated. A socio-economic study will be made of a geothermal development in Greece.

2.4 Sub Task C:

Methods of impact mitigation and Environmental Manual (Sub-Task Leader: not assigned).

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 the previous Sub-Task Leader (Dr Goff) for this project and so it will be remain in abeyance.

3. Work Plan for 2002

- Complete setting up of a website on Internet to inform the general public about the aims of the Task and results obtained.
- Continue collecting material for a further Special Issue of *Geothermics* journal.
- 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)

White, P.A., Hunt, T.M., 2000. Simple models for changes in spring flows at Wairakei. *Proceedings 22nd NZ Geothermal Workshop*: 203-208.

White, P.A., Hunt, T.M., 2001. Cessation of spring flow and spring feeder depths, Geyser Valley, Wairakei. *Proceedings 23rd NZ Geothermal Workshop*: 173-178.

ATTACHMENT 3
Annex I report

Appendix 1. Projects underway or planned.

Greece:

1. Socio-economic study of geothermal development on Milos, Greece (Karytsas, *CRES*)

Iceland:

1. Interpretation of TIR imagery over geothermal areas. (Arnason, Kristmannsdottir; Univ Iceland, Orkustofnun).
2. Changes to natural thermal features as a result of development. (Armannsson, Torfason, Kristmannsdottir; Orkustofnun).
3. Environmental effects of surface water disposal in Iceland. (Thorhallson, Kristmannsdottir; Orkustofnun).
4. Production-induced ground subsidence and gravity changes in Iceland. Eysteinsson, Kristmannsdottir; Orkustofnun).

Japan:

1. Documentation of hydrothermal eruptions (yet to be arranged)
2. Chemical changes in hot spring waters (yet to be arranged)

Mexico:

1. Chemical and isotopic monitoring of atmospheric sulfur associated with H2S emissions from geothermal systems in the Mexican Volcanic Belt. (Verma et al, IIE)

New Zealand:

1. Documentation of renewed hydrothermal activity in Rotorua. (Scott; IGNS)
2. Numerical modelling of production-induced changes to hot springs. (Hunt, White; IGNS)
3. Natural variations to geothermal features. (Bromley, IGNS)
4. Impacts of developments on thermophyllic vegetation (Sylvester, Waikato Univ)
5. Economic aspects of geothermal (White, IGNS)

Turkey:

1. Environmental changes at Kizildere field (Simsek, et al)
2. Balcova District heating scheme and its effects (Simsek, et al)

USA:

1. Modelling of the high-temperature geothermal system in Long Valley (Sorey, US Geological Survey)

ATTACHMENT 4
Annex III report

IEA GIA Annex III
HOT DRY ROCK
2001 ANNUAL REPORT
Prepared by Task Leader Dr. I. Matsunaga (AIST, 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 organization participating in Annex III are Australia, Germany, Japan, Switzerland, UK, USA and CEC.

The following four Subtasks are 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, AIST, Japan)

2. Work performed in 2001

2.1 Change Task Leader

On 31 March, 2001 Michio Kuriyagawa retired from National Institute for Resources and Environment and went to Argentina as a ODA project leader of Japan International Co-operation Agency. Isao Matsunaga of NIRE (now AIST) took over the task leadership.

ATTACHMENT 4
Annex III report

2.2 Subtask A - Hot Dry Rock Economic Model

Overview

The 3-year project to perform economic analyses of Enhanced Geothermal Systems (EGS), including Hot Dry Rock (HDR) systems, was successfully completed in July 2001. 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 was completed and posted on the Internet in April 1999, where the world geothermal community can easily download it for use. A group in Australia trying to launch a commercial project has recently used the model. This last year our research focused on an alternate path to economic development by investigating EGS systems as part of a sustainable development portfolio.

Work Performed in 2001

One of the goals of the Subtask was to evaluate the new economic model on actual geothermal projects. Shell Oil Company's Geothermal Energy Group agreed to collaborate in this effort. Ms. Esther Kim, graduate student at Massachusetts Institute of Technology, spent the month of January 2001 collaborating with Shell's Geothermal Group at the Shell International Exploration and Production's (SIEP) research center in Rijswijk, The Netherlands. The Geothermal Group is part of Shell Technology Ventures, a business group that brings new exploration- and production-related technologies to market. Upon her return, she did additional research and wrote her thesis on "The Economic Value of Sustainable Development as Applied to Enhanced Geothermal Power Generation." Her abstract follows:

> " Geothermal energy has many attractive benefits from a sustainable development perspective. In particular, enhanced or engineered geothermal systems (EGS) such as hot dry rock (HDR) have the potential to offer a clean, local, small-footprint, long-term source of energy without the associated carbon dioxide and other emissions of fossil-based energy. However, barriers such as high initial capital costs, resource risks, and drilling limitations (particularly in low-grade areas) pose a challenge to making engineered geothermal systems commercially viable.

> " Overcoming these barriers has, until now, involved the "technical push" approach of government research programs. However, investment into geothermal R&D, particularly from the public sector, has dropped considerably in recent years due to lack of incentives and availability of lower-cost alternatives, such as natural gas. One way to surmount these barriers is to consider the value that engineered geothermal systems can bring to an energy company through sustainable development – in other words, the "sustainable development pull" approach."

> " This thesis proposes a pathway based on sustainable development to encourage renewed geothermal progress. Through sustainable development, opportunities exist for geothermal power to become more attractive as an investment. An analysis of Royal Dutch/Shell Group and their geothermal strategy shows the potential for private-sector interest in geothermal power from a sustainable development perspective. As examples of revenue generation and cost savings through sustainable development, the market potential for geothermal power through green power marketing and carbon taxes in the U.S. is analyzed. Finally, policy measures are proposed to encourage the development of this pathway. These measures include incentives for sustainable development, help in reducing investment requirements for renewable deployment, and educational activities related to sustainable development."

ATTACHMENT 4
Annex III report

The Economic Model

In developing the EGS 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/

The EGS model allows the user to define the engineering and financial characteristics of a proposed project and the available geothermal resources, to determine resulting economics and to optimize the plant configuration. Elements of the model are:

- Resource Characterization - relating to the geology of the site and the maximum reservoir temperature that the drilling equipment, casing, and other equipment can withstand. Measured resource temperature gradients can be defined in segments by the user. The program calculates the maximum allowable well depth for the set of gradients depending on the engineering characteristics of the project.
- Reservoir Model - characterizing the conditions of the artificial reservoir created in the project, using one of three alternative thermal drawdown calculation models to simulate the reservoir performance. The three available reservoir models are based on (1) multiple parallel rock fractures, (2) volumetric block analysis using one-dimensional linear flow in a fractured geothermal reservoir, or (3) drawdown parameter method based on volumetric mass flow in an individual fracture. Other reservoir parameter options are fracture temperature profile, reservoir shape and the number of fractures, fracture separation, and overall reservoir volume.
- Financial Model – defining commercial project financing and operating assumptions. These include: two methods of evaluating the impact of time on the capital investments of the project. The first is using a simple fixed annual charge rate often used in the utility industry. The second method uses a levelized life-cycle cost model, which evaluates a much richer and more complex economic system. Other economic parameters that can be specified or evaluated are the plant capacity factor, interest rates, inflation rate, required internal rate of return on investments, project lifetime and other business parameters.
- Engineering Parameters – defining the planned EGS project in terms of well configuration, ratio of injection to the production wells, water loss rate, pump efficiency, injection temperature, production well temperature drop, water flow rate, injection well inside diameter (ID), production well ID, well deviation, and well depth.
- Project Optimization - variables that can be optimized by the model are:
  Well depth (m)
  Water flow rate per production well (kg/s)
  Effective heat transfer area per fracture (sq. m)
  Reservoir volume (cu. m)
  Fracture separation (m)
  Well separation (m)
  Number of fractures per well-pair
  Injection temperature
  Well deviation

- Reports - generated by the program - can be in tabular and graphic formats.

Case Studies

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).

The model was used most extensively in evaluating and planning the development of the commercial Hunter Valley project in Australia. Feasibility of this 50 MW project is currently being evaluated, but the usefulness of model has been demonstrated by these results.

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

Background

Two activities are reported here. The two activities, which were both completed in fiscal year 2001, were described as ongoing in the previous report (October 7th, 2000) to the GIA Executive Committee. Both were completed by Princeton Energy Resources International (Rockville, Maryland) under contract to the U.S. Department of Energy Idaho Operations Office.

The first, "Costs and Performance of EGS for Electric Power Generation", relates to Subtask A of Annex III (Hot Dry Rock) of the Geothermal Implementing Agreement. Subtask A is Hot Dry Rock Economic Models and is defined as follows:

> " The Participants shall evaluate the economics of HDR systems worldwide by modelling the major parameters that affect the economics of HDR development, considering sustainability aspects and including a review of environmental and institutional factors."

The second activity, "Promising Developments in Fracture Detection", relates to Subtask B of the same annex. Subtask B is the Application of Technology of Conventional Geothermal Energy to Hot Dry Rock Technology and is defined as follows:

> " 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."

Costs and Performance of EGS for Electric Power Generation

PERI examined the cost and performance of four EGS type cases typical of the sort of projects that industry might pursue. These cases 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 effort included a parametric analysis of the most important cost determinants for the appropriate EGS systems

For Case 1, the analysis determined that if a replacement well costs $2 million, then well stimulation would be preferred to drilling a new well if the stimulation has a probability of success of 0.85 or better.

For Case 2, the cost of power was determined for three levels of well cost ($3, $4, and $5 million) and four levels of new well failure rates ranging from 0 to 75%. The cost of power ranged from 5.3 cents/kWh for a $3 million dollar well cost and well failure rate of zero up to 28.2 cents/kWh for a $5 million dollar well cost and well failure rate of 75%.

For Case 3, well production rate was added as an additional variable to well failure rate and well cost. The analysis included three levels for each variable. For the well failure rate of 0.25, the cost of power varied from 6.3 to 19.6 cents per kWh. For the well failure rate of 0.50, the cost of power varied from 8.0 to 26.7 cents per kWh. For the well failure rate of 0.75, the cost of power varied from 13.2 to 47.9 cents per kWh.

Under Case 4, the cost of power for the hypothetical project varied from 10.3 cents per kWh (for a drilling failure rate of 0.25, well production rate of 300 klb/hr (38 kg/s), and well cost of $3 million) up to 51.9 cents per kWh (for a drilling failure rate of 0.75, well production rate of 100 klb/hr (13 kg/s), and well cost of $5 million). The primary difference between Cases 3 and 4 are that the stand alone project (Case 4) includes the cost of developing the field and plant whereas Case 3 includes only field development costs because it assumes a pre-existing power plant.

From the case studies it is concluded that EGS could be an economically feasible option for supplying additional fluid to increase generation at an existing facility. A stand-alone EGS application would not likely be economic considering current technology and market conditions. The key determinants for project viability are the well success rate, well cost, and well flow rate. Additional research is needed to reduce uncertainty in these parameters.

Promising Developments in Fracture Detection

PERI reviewed technical literature to determine if there are new advances or promising developments in fracture detection, which might be applicable to EGS. The review also included interviews with U.S. experts in the areas of fracture detection and rock mechanics.

The conclusions from the review included:

- Single well geophysical techniques are cutting edge and should be evaluated for their potential in geothermal reservoirs. It has been demonstrated, at least in oil and gas applications, that single well reflection surveys can provide useful information on vertical features a significant distance from the well. Single well seismic surveys hold great promise in characterizing fine scale reservoir heterogeneity.
- Geophysics experts Lou and Rial (1997)[1] stated that shear-wave splitting may provide a cost-effective tool to characterize crack patterns in hydrocarbon or geothermal reservoirs. Monitoring shear-wave splitting is an important means to determine the direction and evaluate the bulk density of subsurface fractures in hydrocarbon or geothermal reservoirs.

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[1] M. Lou and J.A. Rial, Characterization of geothermal reservoir crack patterns using shear-wave splitting; *Geophysics*; **62** (2); March-April 1997.

ATTACHMENT 4
Annex III report

2.4 Subtask C - Data Acquisition and Processing

The overall aim of this Subtask is to provide an information and data framework for the project planning and construction of a commercial HDR plant. The concept includes documenting the availability of special tools and services and assembling 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 world wide since the early 1970's.

Organizing and Archiving HDR project data

An initial concept for data archiving was developed between 1995 and1998 and a test application was set up for the former HDR project at Rosemanowes in Cornwall. The concept, known as the "HDR DataIndex" has now been successively extended and improved on the basis of external feedback and implemented for the European HDR R & D project at Soultz-sous-Forêts, in Alsace. During 2001 a version of the data index for the project at was completed.

This is now available on a CD available from the project management team at Soultz. In addition, the Fenton Hill data index in which the historical information from the project has been assembled is available on a CD from the US DoE.

The master "HDR DataIndex" application has been extended to include the following three features:

A. Details of measuring tools used to acquire data
B. Storage locations of digitally archived documents
C. 3 new auxiliary data input forms for entry and modification of the parameters for the above extensions A and B.

Indexing and archiving of project literature

So far 801 literature references with 380 abstracts have been collected and indexed in the Soultz data index, whereof 70 reports have been scanned and archived as pdf-files.

Presentation of data requirements for the generic project

One of the aims of Subtask C of Annex III is to produce a compendium of the types of data required during the planning, construction and operation and closure of a Hot Dry Rock / Enhanced Geothermal System reservoir and its energy conversion plant. As far as possible with today's level of knowledge it is intended to define which data are required at which time and which methods can be used to obtain them.

A study of data requirements has been undertaken over the past four years, running parallel to the project planning for the Swiss "Deep Heat Mining" HDR pilot plant. A method for organising and presenting the assembled data requirements for a theoretical, generic HDR reservoir and energy conversion plant has been sought, so that what might be simply a useful guideline or check list becomes in addition an accessible and useable tool. In 2001 work has started on this aspect of the task. As a result of these deliberations, it appears possible, but by no means certain, that this will lead to the creation of a further small relational database application eventually linked to a project planning tool.

Next steps in Annex III, Subtask C

Development continues of the generic HDR energy project and the assembly of data requirements during each phase. These data are required for organisation and planning, for the ordering of services and materials and for the construction of both reservoir and surface plant.

Effort is being concentrated towards the development of an appropriate form for presenting the results of studies into data needs, which have been made on the generic project during the past four years and are still continuing. Ideally the data requirements should be linked to a project network plan. During the next year, three main directions of work are planned. These are similar to those reported in the present document, and represent a continuation of the tasks started in 2001:

1. reworking and detailling the information packets, data items and methods listed here for the concept and exploration phases (and in part also the development phase).
2. extending the assembly of information necessary, the data needed to provide the information and the methods for obtaining them to later phases.
3. pre-planning the techniques for presentation and usage of the generic HDR project work.

2.5 Subtask D - Reservoir Evaluation

For making clear what kind of methods, techniques and tools are effective for reservoir evaluation, and then finally establishing the evaluation method that can be applied to develop a new HDR site, a questionnaire survey has been conducted using Internet. Although the effort continued during 2001, Subtask leader Tsutomu Yamaguchi was involved in a major re-organization of NIRE/AIST and this restricted his efforts in Subtask D activities. Limited activities in 2000 and 2001 are listed below.

(a) The questionnaire survey was open to the public on NEDO server from August 1st, 1999. The purpose of the Subtask D was announced at WGC 2000 in Morioka both at the poster session and the HDR presentation session on 5 June 2000. The items in the questionnaire were 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

(b) A total of 22 scientists/researchers had responded to the questionnaire until the end of 2001. The nationalities and number of respondents are as follows; Japan (17), Swiss (3), German (1) and France (1).

(c) After WGC 2000 meeting, only one respondent joined the questionnaire. Thus, almost all of the scientists/researchers that are related to Hot Dry Rock research work are thought already to have joined the questionnaire. Particularly from the Japanese HDR test sites such as Hijiori and Ogachi, enough information for category from 1 to 5 has been collected.

(d) It was decided that the Internet questionnaire should be closed at the end of 2001.

(e) Compilation of the answers is now in hand.

ATTACHMENT 4
Annex III report

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 the Germany activity report y Reinhard Jung (BGR).

2.6.1 Australian HDR Activities for 2001

1. Hunter Valley: Muswellbrook Site

Activities at the Hunter Valley project site south of Muswellbrook, New South Wales continued as 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.

Deep Borehole

A 2km deep exploration hole PPHR1 was drilled near the south western edge of the Muswellbrook geothermal anomaly defined in 2000. Rotary drilling of the outcropping Wittingham Coal Measures and the underlying upper marine sequence was followed by coring starting at 800 metres. The recovered core delineates the deeper sequences of this part of the Sydney Basin including the Greta Coal Measures, the lower marine sediments and more than 1km of altered basalts and basaltic andesites in the bottom of the hole. Radiometric age measurements of recovered zircons confirm a Lower Permian age for the volcanics.

Temperatures were logged several times in PPHR1 at times up to 4 months after drilling was completed. Temperature results were obtained using thermistor logging tools and independently using maximum temperature thermometers. Results indicate a geothermal gradient of at least 50ºC/km in the coal measures and ~36ºC in the basalts of this region near the western edge of the anomaly. Similar logging methods were also used to investigate the higher temperature gradients in the 840 metre deep borehole at the "Randwick Park" site to the south of PPHR1. Additional temperature logging is being carried out in both boreholes to further characterize the temperature distributions.

A report was prepared for the AGO detailing the findings to date.

Seismic Reflection Survey

A 19 km long seismic reflection survey using three 40 000 lb vibroseis trucks was completed in 2001 along a line which included the PPHR1 borehole. The survey used a 3.6 km split spread array to detect reflections down to ~5 seconds two-way-time. The results define the major structural trends in the survey area including the north-south trending Muswellbrook Anticline in the east and a general thinning of low thermal conductivity coal measures sequences to the west. The coal seams and interbedded clastic units in the upper parts of the section represent excellent reflectors as does the inter-bedded altered volcanic sequence intersected in the PPHR1 borehole.

The results of the seismic reflection survey, while not directly imaging a buried granite, suggest that if one exists it must be at least 5-6 km deep. Extrapolation of the recorded geothermal gradient in PPHR1 suggest that at this depth temperatures would be at least 200ºC.

2. Hunter Valley: Bulga Site

A new company has been established to pursue the commercial development of HDR in Australia. This company, Geodynamics Limited (http://www.geodynamics.com.au), has attracted initial investments from private and institutional investors. The Australian National University is currently the largest shareholder. Geodynamics has acquired an exploration lease for HDR energy at Bulga in the Hunter Valley. This lease is south east of and immediately adjoins the Pacific Power Muswellbrook Lease.

A seismic reflection survey using three 40 000 lb vibroseis trucks was conducted along a 9 km east-west line across the Bulga lease in 2001. Initial results suggest first that the thickness of low thermal conductivity coal measures rocks is greater at Bulga than is the case in the adjoining Muswellbrook lease. Second, the thickness of the underlying lower conductivity rocks appears to be smaller than was found on the Muswellbrook lease. These findings suggest that a possible buried granite at Bulga would be at shallower depths and hotter than is likely to be the case on the Muswellbrook lease. This suggests that Bulga may be more prospective for HDR initially. Work is continuing at this site.

3. Cooper Basin

Geodynamics Limited has been granted an exploration lease for geothermal energy over a 500km^2 area in the Cooper Basin in the vicinity of Innamincka in north-eastern South Australia. Details for this lease, known as Block B, can be found on the Geodynamics website.

Initial work is concentrating on a synthesis of the extensive body of exploration data already collected by the oil industry over Block B. This includes numerous seismic reflection surveys, deep drilling to basement and temperature, stress and pressure testing.

Targeted research for HDR on Block B is scheduled to commence in mid-2002.

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

1. European HDR-Project Soultz

The German Ministry for Economy and Technology (BMWi) continued its financial support of the European HDR-Project Soultz via its funding agency PTJ (Jülich). New contracts were signed for the project period 01.04.2001 – 01.03.2004 (Phase 1 of a Scientific-Pilot Plant). The German contribution amounts to about €8 million, which is about one third of the total budget of the project. The new project period is co-ordinated by an industrial consortium (GEIE). Seven German partners are contributing to the project in the fields of hydraulic-fracturing, hydraulic testing, geothermal measurements and modelling, geology and tectonics, stress measurements and high temperature metal packer development.

During the preceding exploration phase (01.04.1998 – 31.03.2001) one of the existing boreholes of the site was deepened to a depth of 5080 m and the feasibility of creating a HDR system at this depth was tested by performing a massive stimulation test.

The aim of the new project period is to drill two additional boreholes and to establish the world's largest and deepest HDR system by massive stimulation tests. The 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 about 500 m at depth. The system will be tested during circulation experiments. A total flowrate of 80 l/s is envisaged. This is equivalent to a total thermal power of 50 MW.

During 2001 the design of the new system, the planning of the boreholes and the preparation of the site were finished. The start of the drilling is planned for May 2002.

Internet

www.soultz .net

2. GeneSys-Project

The GeoCentre Hannover investigated the feasibility of the HDR-concept for recovering heat from tight sediments and applied for a project called "GeneSys" (Generated Geothermal Systems). The focus of the project is the direct use of Geothermal Energy. The basic concept is to create extended fracture systems in tight sediments by applying the water frac-technique successfully used in crystalline rocks. The GeoCentre Hannover plans to produce about 2 MW thermal power from a single well system for heating its own and some adjacent office buildings.

Internet

http://www.bgr.de/

3. Resources for Geothermal Power Production in Germany

The Office of Technology Assessment at the German Parliament (TAB) in Berlin started a study on estimating the resources for geothermal power production in Germany. The study will cover the geological potential, the technical concepts and components, and the implementation in the German energy market. The study will be published and presented in June 2002.

Internet

http://www.tab.fzk.de/

3. Work plan in 2002 and beyond

Annex III has been extended for four years.

3.1 Subtask A - Hot Dry Rock Economic Model

- This sub-task was completed in July 2001, and there are no plans for continuation.

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

- A work plan for **Subtask B** is under discussion between USDOE and a contractor.

3.3 Subtask C - Data Acquisition and Processing

- Effort will continue to be applied to 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. We hope to find further projects internationally adopting some form of archiving and documentation during this formative period of commercial HDR technology. A start will also be made towards the documentation of the Swiss Deep Heat Mining project in the same way during 2002 and 2003.

- Further progress will be made with the general bibliography of HDR / HWR until 2003. An alternative format will, in particular, be introduced in order to make the library visible to more people. Work has been started on creating a spreadsheet version in the much more widespread Microsoft Excel to supplement the original EndNote version.
- Making progress with the build-up of the data requirements for carrying through a generic project including organization and planning, with the ordering of services and materials and with constructing reservoir and surface plant.

3.4 Subtask D: Reservoir Evaluation

- Answers from respondents related to active HDR fields such as Soultz and Australia are still not sufficient. The efforts to collect the data in these fields must be continued not only by Internet questionnaire but through the personal communication.
- In order to refine and confirm the contents of answers, the answers from all respondents will be printed out and sent back to each respondent by mail. Answers for the questionnaires will be compiled and analyzed by the end of 2002.
- Subtask will distribute the results of questionnaire by a media of CD-ROM at the end of the task.

4. *Output (Publications)*

Durst, P. and F-D. Vuataz (2001): Geochemical modelling of the Soultz-sous Forets Hot Dry Rock system, brine rock interactions in a deep hot fractures granite reservoir. *Proceedings Twenty-Sixth Workshop on Geothermal Reservoir Engineering*, Stanford, California, January 29- February 1, p.232-238.

Durst, P. and F-D. Vuataz (2001): Fluid-rock interactions and geochemical modelling of the formation brine in the fissured reservoir of Soultz-sous-Forets HDR test site. Final report for Nº UE JOR3-CT98-0313, Centre of Hydrogeology, University of Neuchatel.

Kim, E. (2001): The Economic Value of Sustainable Development as Applied to Enhanced Geothermal Power Generation," M.I.T. Masters Thesis. May be downloaded at http://web.mit.edu/energylab/www/hjherzog/pdf/Esther_Kim_Thesis.pdf

Kitsou, Olga (2000): Power Generation from Geothermal Resources: Challenges and Opportunities," M.I.T Masters Thesis, (February 2000).

Kohl, T. and L. Rybach (2001) Assessment of HDR reservoir geometry by inverse modelling of non-laminar hydraulic flow. *Proceedings Twenty-Sixth Workshop on Geothermal Reservoir Engineering*, Stanford, California, January 29- February 1, p.259-265.

Matsunaga, I., H. Sugita, and H. Tao (2001): Tracer monitoring by a fiber-optic fluoremeter during a long-term circulation test at the Hijiori HDR site. *Proceedings Twenty-Sixth Workshop on Geothermal Reservoir Engineering*, Stanford, California, January 29- February 1, p.74-77.

Matsunaga, I. (2001): Preface for special report on Hot Dry Rock development. *J. Geothermal Research Society of Japan*, 23, 273-274 (in Japanese).

Oikawa, Y., N. Tenma, T. Yamaguchi, H. Karasawa, Y. Egawa, and T. Yamauchi (2001): Heat extraction experiment at Hijiori test site. *Proceedings Twenty-Sixth Workshop on Geothermal Reservoir Engineering*, Stanford, California, January 29- February 1, 255-258.

Oikawa, Y. and T. Tosha (2001) Outline of Hot Dry Rock development project at Hijiori site. *J. Geothermal Research Society of Japan,* 23, 275-282 (in Japanese).

Sato, Y. and T. Okabe (2001): A long term flow test at the Hijiori Hot Dry Rock test site. *J. Geothermal Research Society of Japan,* 23, 283-291 (in Japanese).

Tenma, N., T. Yamaguchi, Y. Oikawa, K. Tezuka, and G. Zyvoloski (2001): Estimation of the fluid flow in the multi-reservoir system at the Hijiori HDR test site. *J. Geothermal Research Society of Japan,* 23, 303-315 (in Japanese).

Tenma, N., T. Yamaguchi, K. Tezuka, Y. Oikawa, and G. Zyvoloski (2001): Comparison of heat extraction from production wells in the shallow and the deep reservoirs at the Hijiori HDR test site using FEHM code. *Proceedings Twenty-Sixth Workshop on Geothermal Reservoir Engineering,* Stanford, Calfornia, January 29- February 1, p.249-254.

Tenma, N., T. Yamaguchi, K. Tezuka, and Y. Oikawa (2001): Estimation of productivity from the shallow reservoir using by pressure monitoring data in SKG-2 at the Hijiori HDR test site. *Geothermal Resources Council Transaction*, 25, 199-202.

Yanagisawa, N., I. Matsunaga, H. Tao, and H. Sugita (2001): Evaluation by tracer experiments in the Hijiori HDR reservoir. *J. Geothermal Research Society of Japan,* 23, 293-301 (in Japanese).

ATTACHMENT 5
Annex IV Report

IEA GIA Annex IV :
DEEP GEOTHERMAL RESOURCES – 2000 ANNUAL REPORT
Prepared by Task Leader Dr. M. Sasada (AIST, Tsukuba, Japan)

1. Introduction

The task of Deep Geothermal Resources was started from 1997 originally as a four-year international collaborative program under the IEA Geothermal Implementing Agreement (GIA). The continuation of this Annex was decided by the Executive Committee (ExCo) in 2001. 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 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. In 2001 the five-year activities were integrated to publish in CD-ROM and NEDO completed its task as Operating Agent.

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 December 2001, four countries are participate 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 organizations in subtask B network, 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.

2. Work performed in 2001

2.1. General

The special issue of *Geothermics* was planned in 2000 for the publication of task products. Guest editors continued to edit the submitted manuscripts in 2001. However, there were insufficient manuscripts to make up a whole issue so it was decided to print the papers in a regular issue.

The five-year activities were integrated for publication on CD-ROM. It contains “Introduction”, “Definition”, “Participating Countries”, “Operating Agent(OA)”, “Term of Work”, “Task Leader”, “Subtasks”, “Performed Work”, “Database”, “Output”, “Conclusions”, and “Annual Report”. The database consists of literature on Drilling and Logging Technology (179), Material Evaluation (148), 4 technical workshops (65), and full papers of Country Report (4) and Annual Report (4).

2. 2. Subtask A

Final results of the subtask A "Exploration Technology and Reservoir Engineering" including collaborative research on exploration technology, geothermal modelling, geophysical, geological and geochemical explorations, and on reservoir engineering have been summarized into four papers. They will be printed in *Geothermics*. The data collection has also been stored in the CD-ROM.

2.3. Subtask B

The database for drilling knowledge and experience has been revised, and stored in the CD-ROM. A paper on drill bits was also submitted to *Geothermics*, and will be printed soon.

2.4. Subtask C

Further compilation of literature references concerned with chemistries and materials performance has been made to exchange experience on materials and chemistries. All the data collected through the subtask activities were stored in the CD-ROM.

3. Plans for 2002 and beyond

NEDO will step down the OA of this task in March, 2002. All the task activities under the OA of NEDO are being finalized. Plans for 2002 and beyond will be made by a new OA.

4. Publications (all in *Geothermics*)

Garcia, A., Arellano, V., Aragon, A., Barragan, R.M., Izquierdo, G., Pinzano, A. and Espinosa, G. "Natural-state temperature distribution in the Los Humeros, Mexico, geothermal field". (in press).

Garcia, A., Espinosa-Pardes, G. and Hermandez, I. "Study on the flow production characteristics of deep geothermal wells". (in press).

Gianelli, G. and Ruggieri, G. "Evidence of a contact metamorphic aureole with high-temperature metasomatism in the deepest part of the active geothermal field of Larderello". (in press).

Muraoka, H., Tateno, M. and Tosha, T "Brittle-plastic transition penetrated by the well WD-1A and deep geothermal resources in northeast Japan". (in press).

Ohno, T., Karasawa, H. and Kobayashi, H. "Cost reduction of polycrystalline diamond compact bits through improved durability". Vol.31, no.2 (2002) .

ATTACHMENT 6
Annex VII Report

IEA GIA Annex VII
ADVANCED GEOTHERMAL DRILLING TECHNOLOGIES
2001 ANNUAL REPORT
Prepared by Task Leader J.T. Finger (Sandia National Laboratories, Albuquerque)

1. Introduction

Drilling is an essential and expensive part of geothermal exploration, development, and utilization. Drilling, logging, and completing geothermal wells is expensive because of high temperatures and hard, fractured formations. The consequences of reducing cost are often impressive, because drilling and well completion can account for more than half of the capital cost for a geothermal power project.

Geothermal drilling cost reduction can take many forms, e.g., faster drilling rates, increased bit or tool life, less trouble (twist-offs, stuck pipe, etc.), higher per-well production through multi-laterals, and others. Activities in the Advanced Geothermal Drilling Technology Task will address all aspects of geothermal well construction, including:
1) develop a detailed understanding of worldwide geothermal drilling costs;
2) compile a directory of geothermal drilling practices and how they vary across the globe; and
3) develop improved drilling technology.

The objectives of the Advanced Geothermal Drilling Task are:
1. Quantitatively understand geothermal drilling costs from around the world and identify ways to reduce those costs, while maintaining or enhancing productivity.
2. Identify and develop new and improved technologies for significantly reducing the cost of geothermal well construction to lower the cost of electricity and/or heat produced with geothermal resources.
3. Inform the international geothermal community about these drilling technologies.
4. Provide a vehicle for international cooperation, field tests, etc. toward the development and demonstration of improved geothermal drilling technology.

2. Work performed in 2001

A preparatory meeting to develop work plans for the proposed Annex VII on Advanced Geothermal Drilling was held immediately before the 6th GIA Executive Committee meeting (Brussels, 8-9 March 2001). Attendees at the Annex VII meeting were: H. Gutierrez (CFE, Mexico), T. Wada (NEDO, Japan), S. Bjornsson (OS, Iceland), R. Baria (Soultz Project, EC), A. Jelacic (DOE, USA), and M. Prairie (Sandia Labs, USA).

Work plans approved by the participants include activities under the Annex subtasks on : documenting costs of drilling geothermal wells; producing a Handbook of best practices for geothermal drilling, both for electricity and for direct use; and organizing international collaboration for field tests of new drilling technology. Following presentation of this same material at the ExCo meeting, the Committee unanimously reconfirmed its decision to initiate a new Annex VII with Sandia National Laboratories as Operating Agent.

ATTACHMENT 6
Annex VII Report

A complete draft version of Annex VII was circulated in June 2001 to all ExCo members and parties identified as potential Participants. All comments and suggestions have been incorporated into a final draft, which will be submitted to the IEA Legal Department for review.

As of November 2001, the Participants planning to join in Annex VII are:

- Century Drilling Company (New Zealand)
- Comisión Federal de Electricidad (CFE, Mexico)
- The European Commission (EC)
- The New Energy and Industrial Technology Development Organization (NEDO, Japan)
- Orkustofnun (OS, Iceland)
- The United States Department of Energy (DOE, USA)

Except for Iceland, a formal confirmation of participation has been received from all these parties.

Following approval of the Annex Draft, the proposed work will comprise these Subtasks:

Subtask A: *Compile Geothermal Well Drilling Cost Information*
Subtask Leader: The New Energy and Industrial Technology Development Organization (NEDO), Japan.

This activity is a compilation of actual drilling costs associated with the development, construction and operation of geothermal wells. This cost data will be maintained in a single database, so that all participants can use it to identify key cost components that might be reduced by new technology or by different drilling practices. Data could include R&D cost, project cost, operation and maintenance cost, and overall cost of energy. It will include information on wells for both electricity and direct-use applications (including geothermal heat pumps), and will include information from 1990 to date.

Subtask B: *Geothermal Drilling Best Practices*
Co-Subtask Leaders: Comisión Federal de Electridad (CFE), Mexico (*Electricity*); Orkustofnun – Iceland (*Direct use*)

The Participants plan to identify and catalogue the technologies that have been most successful for drilling, logging and completing geothermal wells. Practices from the various Participants' countries will be compared and contrasted. This work will be published as a <u>Handbook on Geothermal Drilling: Best Practices</u> for use by the Participants. The study will include, but not be limited to: design criteria for the drilling and completion programs, drilling practices for cost avoidance, problem diagnosis and remediation during slimhole drilling, trouble avoidance, well testing, geophysical logging, and wellbore preservation.

Subtask C: *Advanced Drilling Collaboration*
Subtask Leader: Sandia National Laboratories – USA

The Participants will monitor and exchange information on drilling technology development and new applications in their respective countries. Meetings to share information will be conducted at least twice annually. The meetings will be used to identify activities and projects for collaboration, and then collaboration plans will be developed. For example, it is anticipated that Participants will identify opportunities to field test in one country a technology/system that is being developed in another participant's country.

3. Plans for 2002 and beyond

2002:

- Adopt final Subtasks, select research areas, and gain detailed commitments from Participants. Report to Executive Committee.
- Complete compilation of actual costs associated with the construction and operations of geothermal wells in different countries. Collect cost-model software.
- Develop first draft of Best Practices Handbook and circulate to Participants for comment and addition. Survey Participants and organize at least one Proof-of-Concept collaborative field test of advanced technology.
- Conduct workshop of Participants and make early presentations of results at GRC Annual Meeting. Report to Executive Committee.

2003:

- Analyze cost data to identify research areas with high payoff and broad applicability. Employ economic modelling to predict cost savings from using improved hard rock, high-temperature drill bits (PDC and roller-cone); lost circulation technology; high-temperature electronics; and high-temperature, acid-resistant cementing technology.
- Publish Best Practices Handbook..
- Conduct workshop of Participants in association with an important international geothermal or drilling meeting. Compile results to date for publication in a Special Issue of an international technical journal. Report to Executive Committee.

2004:

- Verify economic modelling through collaborative international field tests of advanced technology.
- Complete the compilation of cost data and make the database available to all Participants. Publish summary report of database analysis, with emphasis on identification of high-cost problems that should receive research focus.
- Conduct workshop of Participants and present results at GRC Annual Meeting or an international geothermal conference. Report to Executive Committee.

2005:

- Publish results of collaborative field test(s). Document performance of advanced technology and recommend next action.
- Conduct workshop of Participants. Compile results to date for publication in a Special Issue of an international technical journal. Form Committee of Participants to organize a Special Session for presentations of results at the World Geothermal Congress 2005. Final report to Executive Committee.

Publications –

There are no publications for this Annex in 2001