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Training Needs in Geothermal Energy

Report of the Workshop

Laugarvatn, Iceland, July 1978

THE UNITED NATIONS UNIVERSITY

From the CHARTER OF THE UNITED NATIONS UNIVERSITY

ARTICLE I

Purposes and structure

1. The United Nations University shall be an international community of scholars, engaged in research, post-graduate training and dissemination of knowledge in furtherance of the purposes and principles of the Charter of the United Nations. In achieving its stated objectives, it shall function under the joint sponsorship of the United Nations and the United Nations Educational, Scientific and Cultural Organization (hereinafter referred to as UNESCO), through a central programming and co-ordinating body and a network of research and post-graduate training centres and programmes located in the developed and developing countries.

2. The University shall devote its work to research into the pressing global problems of human survival, development and welfare that are the concern of the United Nations and its agencies, with due attention to the social sciences and the humanities as well as natural sciences, pure and applied.

3. The research programmes of the institutions of the University shall include, among other subjects, coexistence between peoples having different cultures, languages and social systems; peaceful relations between States and the maintenance of peace and security; human rights; economic and social change and development; the environment and the proper use of resources; basic scientific research and the application of the results of science and technology in the interests of development; and universal human value related to the improvement of the quality of life.

4. The University shall disseminate the knowledge gained in its activities to the United Nations and its agencies, to scholars and to the public, in order to increase dynamic interaction in the world-wide community of learning and research.

5. The University and all those who work in it shall act in accordance with the spirit of the provisions of the Charter of the United Nations and the Constitution of UNESCO and with the fundamental principles of contemporary international law.

6. The University shall have as a central objective of its research and training centres and programmes the continuing growth of vigorous academic and scientific communities everywhere and particularly in the developing countries, devoted to their vital needs in the fields of learning and resrarch within the framework of the aims assigned to those centres and programmes in the present Charter. It shall endeavour to alleviate the intellectual isolation of persons in such communities in the developing countries which might otherwise become a reason for their moving to developed countries.

7. In its post-graduate training the University shall assist scholars, especially young scholars, to participate in research in order to increase their capability to contribute to the extension, application and diffusion of knowledge. The University may also undertake the training of persons who will serve in international or national technical assistance programmes, particularly in regard to an interdisciplinary approach to the problems with which they will be called upon to deal.

ARTICLE II

Academic freedom and autonomy

1. The University shall enjoy autonomy within the framework of the United Nations. It shall also enjoy the academic freedom required for the achievement of its objectives, with particular reference to the choice of subjects and methods of research and training, the selection of persons and institutions to share in its tasks, and freedom of expression. The University shall decide freely on the use of the financial resources allocated for the execution of its functions. . . .

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TRAINING NEEDS IN GEOTHERMAL ENERGY

REPORT OF THE WORKSHOP
LAUGARVATN, ICELAND, JULY 1978

THE UNITED NATIONS UNIVERSITY

NRR-3/UNUP-17

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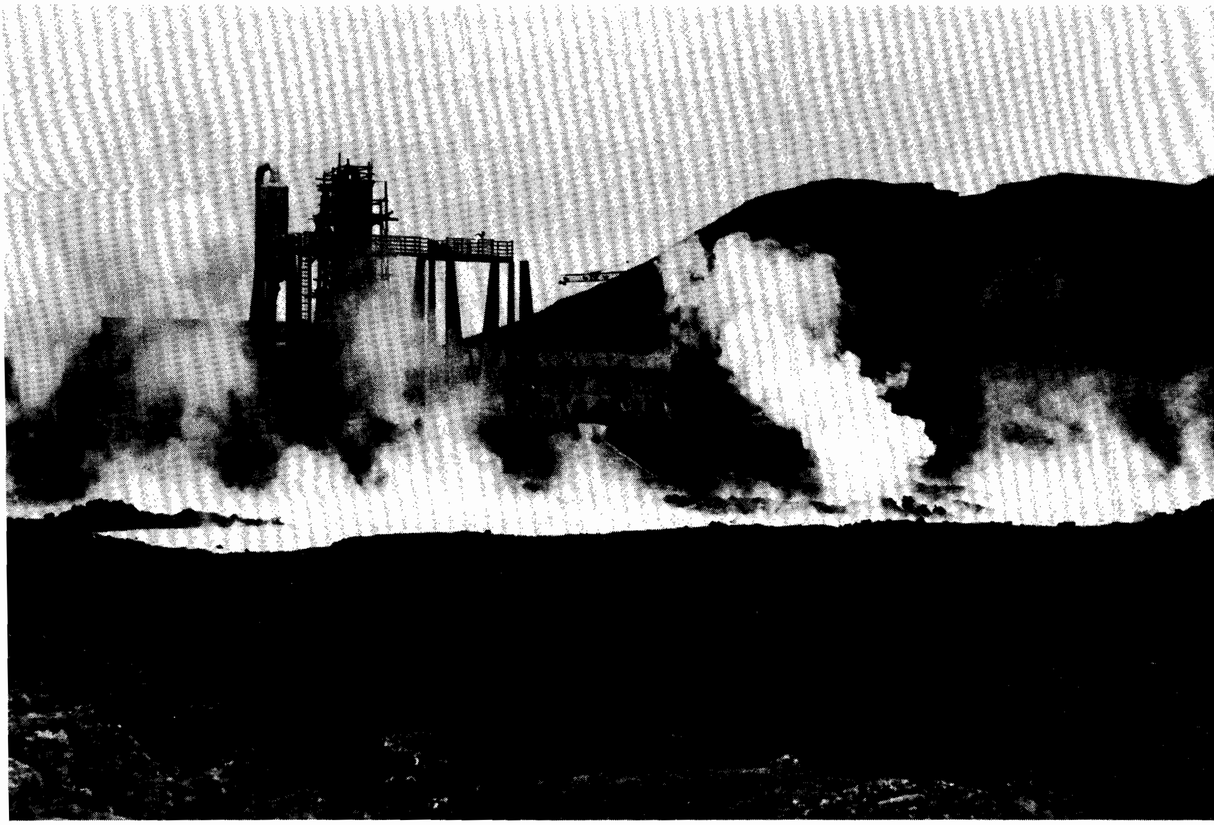
FOREWORD

In its efforts to provide internationally co-ordinated advanced training to strengthen scientific resources in critical areas, particularly in developing countries, the United Nations University decided to give consideration to the training of specialists in geothermal energy. In line with the University's policy of consulting with scientists and experts as well as with other UN organizations and specialized agencies, a meeting was convened at Laugarvatn, Iceland, in July 1978. This meeting considered the international geothermal energy training presently available and adopted recommendations for UN University activities in this field.

This report both summarizes that meeting and provides information on such training programmes that should prove useful to those national planners responsible for energy resources.

James M. Hester
Rector
The United Nations University



PREFACE

The Programme on the Use and Management of Natural Resources was chosen as one of the three programme areas of the United Nations University by the UNU Council at its fourth session in January 1975. From among ten priority areas identified by an Expert Panel at a meeting convened at the UNU Headquarters in December 1975, energy for rural communities was selected as the topic of a sub-programme.

While the main thrust of the Sub-programme on Energy for Rural Communities is on decentralized and renewable energy sources for rural areas in developing countries, it is recognized that developing countries should be encouraged to judiciously exploit any energy resources with which they are endowed that are environmentally and economically sound – even site-specific non-renewable resources such as geothermal energy. Logically, any increase in the availability of a non-polluting centralized energy source capable of producing electricity which can be conducted to major urban areas reduces a nation's dependence on expensive imported fossil fuels and, furthermore, reduces its dependence on the current major source of energy for rural communities – firewood.

Since geothermal energy is an environmentally and economically sound energy source capable of providing a significant amount of the energy needs of some developing countries, the Natural Resources Programme has initiated activity in this field. The need for international geothermal energy training programmes is emphasised by the recent increase in research in geothermal energy throughout the world. Research is now under way in: Algeria, Argentina, Bolivia, Bulgaria, Canada, Czechoslovakia, Chile, Costa Rica, Ethiopia, Greece, Guatemala, Honduras, Indonesia, India, Iran, Israel, Jordan, Kenya, Mozambique, Nicaragua, Panama, Peru, Poland, Portugal (Azores), Romania, Spain (Canary Islands), Uganda and Yugoslavia. Research is also expected to commence in the near future in: Austria, Burundi, United Republic of Cameroon, Chad, Colombia, Ecuador, Haiti, Jamaica, Madagascar, Malawi, Malaysia, Mali, Morocco, Nepal, Pakistan, United Republic of Tanzania, Tunisia, Zaíre and Zambia. Extensive research projects have been undertaken to increase production in China, El Salvador, France (Guadeloupe), Hungary, Iceland, Italy, Japan, Mexico, New Zealand, Philippines, Turkey, USA and USSR which are already utilizing geothermal energy for electricity production and other applications.

This report is a summary of the proceedings of a workshop convened by the Programme on the Use and Management of Natural Resources of the United Nations University to discuss a proposal made by the Government of Iceland to conduct, with UNU support, advanced, practical training in geothermal energy for persons from developing countries. The objective of the workshop was to determine the need for the proposed training course and ensure that it would not duplicate courses already available. For this purpose, invitations were sent to experts in geothermal energy who were knowledgeable about current training facilities and development activities, to individuals from selected developing countries that are developing their geothermal energy resources, and to representatives of the UN agencies that sponsor training courses. Participants also included the staff of Orkustofnun (National Energy Authority of Iceland), which was the host organization, scientists from the University of Iceland, and many interested observers from the government of the host country.

The workshop on which this report is based was organized with the able efforts of Dr. Gudmundur Pálmason, to whom a debt of gratitude is acknowledged.

Following the workshop, a series of site visits were made to the terrains and installations listed below where future UNU Fellows may receive a part of their training in the exploration, development and application of geothermal energy:
– Reykjavík Municipal District Heating Service,
– Thingvellir rift zone,
– Geysir geothermal field,
– State Horticultural College, Hveragerdi,
– Tungulax Fish Hatchery, Hveragerdi,
– Krisuvík high-temperature field,
– Svartsengi high-temperature field and heating plant for the Sudurnes Regional Heating,
– Námafjall geothermal field and diatomite factory, and
– Krafla geothermal field and power plant.

Grateful acknowledgements are extended to the Ministry of Foreign Affairs of the Government of Iceland, to the Reykjavík Municipal District Heating Service, to the State Horticultural College, to the Sudurnes Regional Heating, to the Krafla Geothermal Project Executive Committee, and to Orkustofnun for the receptions they held for the participants of the workshop.

For reasons of space, it has been necessary to present all contributions in summarized form. However, the participant on whose contribution each summarized section is based is identified in a footnote. Only the text of the opening address of the Minister of Culture and Education is presented, translated from the Icelandic in its entirety, in Appendix I. A list of the participants at the workshop can be found in Appendix II.

Walther Manshard
Vice-Rector
Programme on the Use and Management
of Natural Resources

I. IMPORTANCE OF GEOTHERMAL ENERGY IN ICELAND*

The Energy Situation

The importance of geothermal energy in Iceland can be understood from a description of the overall supply and a brief description of the government energy advisory and research organization, Orkustofnun, the National Energy Authority.

The total use of energy in Iceland in 1976, the latest year for which complete statistics are available, amounted to 1,460 kilotons oil equivalent, i.e., an amount of energy equivalent to the consumption of 1,460 kilotons of oil. Actually only slightly more than 600,000 tons or about 42 per cent of this figure was oil. The total amount of energy delivered to the ultimate consumers was 13.37 terawatt-hours. While these figures may appear low in comparison with those of larger countries, on a *per capita* basis, Iceland is among the countries with the highest energy consumption.

Table 1 shows a breakdown of the total energy use in 1976 by sources: geothermal energy, hydropower and petroleum products. The first two are indigenous, while the third is foreign. All fossil fuels used in Iceland are imported as petroleum products since there is no importation of either coal or crude oil, and Iceland has no nuclear power plants. This table clearly shows the difference in the relative importance of each source depending on whether it is reckoned as an equivalent fuel input into the nation's energy system or as energy delivered to the consumer. However, regardless of the mode of presentation, it is clear that geothermal energy plays a substantial role in the country's energy supply. Even the lower figure, 17.8, is much higher than for any other country in the world. Thus, geothermal energy is more important to Iceland than to any other country.

Table 2 shows a breakdown of the total use by main consumption sectors. The two largest are space heating and industry. The main reason for the size of the space heating sector is, of course, the country's climate, which necessitates heating throughout the year.

*From an Address by Jakob Björnsson, Director-General of the National Energy Authority.

TABLE 1 TOTAL ENERGY USE BY SOURCES (per cent)

	Equivalent fuel input	Energy delivered to consumers
Geothermal energy	17.8	32.2
Hydropower	40.4	15.8
Petroleum products	41.8	52.0

TABLE 2 TOTAL ENERGY USE BY CONSUMPTION SECTORS (per cent)

	Equivalent fuel input	Energy delivered to consumers
Space heating	29.0	41.4
Other residential and commercial uses	7.9	3.2
Industry	39.5	26.2
Fishing	8.2	10.2
Transportation	15.4	19.0

TABLE 3 SPACE HEATING BY SOURCES (per cent)

	Equivalent fuel input	Energy delivered to consumers
Geothermal energy	53.4	69.8
Hydropower	17.7	4.9
Petroleum products	28.9	25.3

TABLE 4 GEOTHERMAL ENERGY USES BY CONSUMPTION SECTORS (per cent)

	Equivalent fuel input	Energy delivered to consumers
Space heating	86.9	89.9
Other residential and community uses	0.4	0.1
Industry	12.7	10.0
Fishing	0	0
Transportation	0	0

Because of the importance of space heating and, in particular, because of the role played by geothermal energy, a closer examination of space heating is shown in Table 3. From the relative contribution to space heating of the three energy sources shown in the table, it is obvious that geothermal energy plays the dominant role. At the end of 1976, furthermore, 59 per cent of the population of Iceland had access to geothermal energy for this purpose. Ultimately, it is planned that around 80 per cent of the population will be able to use this method of heating in their homes.

Table 4 indicates the uses to which geothermal energy is put in Iceland, with the overwhelming part going to space heating and a minor part to industrial uses, including greenhouses. Under industrial consumption are counted two plants that use geothermal steam and hot water, respectively, for drying: a diatomite plant at Námafjall and a seaweed plant at Reykhólar. Both are unique in the sense that they appear to be the only plants of their kind in the world that use geothermal energy.

Iceland possesses energy sources that are large in proportion to present consumtpion, but of very limited variety. For practical purposes, only two sources are indigenous to Iceland: geothermal energy and hydropower. No economic fossil fuel deposits have been found and there is no uranium.

The amount of economically exploitable hydropower is estimated at 28 terawatt-hours per year. Of this, about three terawatt-hours per year or 10.7 per cent will have been developed by the end of 1978.

In the case of geothermal energy, the size of the resource is less known. Furthermore, the amount of usable energy from geothermal sources is highly dependent on the mode of use. For instance, when used for space heating, about 90 per cent of the energy taken from the ground may be utilized, provided the return water is reinjected. When used for production of electricity, on the other hand, a corresponding percentage would be about 15 per cent even with reinjection. However, reinjection is not used in Iceland solely for economic considerations: reinjection is too expensive. From the standpoint of conservation of resources, however, it would be desirable. For practical purposes, assuming the present "mix" of uses, geothermal energy is at least as large a resource as hydropower, and may even be larger. Also, only a minor part has been put to use so far, as in the case of hydropower.

The geothermal sources are closely associated with the country's volcanism. Iceland is among the countries with the greatest volcanic activity. The volcanism is confined to the volcanic zone stretching from southwest to northeast and coincides with the Mid-Atlantic Rift Zone which crosses Iceland. It is estimated that about 90 per cent or more of the geothermal energy potential is located in high-temperature geothermal fields within the volcanic zone. A high-temperature field is an area where the temperature of the rock at a depth of one kilometre exceeds 150–200°C, while a field with a temperature below about 150° is a low-temperature field. Low-temperature fields are extensive on both sides of the volcanic zone and adjacent to it. Some low-temperature areas are found away from this zone, but they generally have lower temperatures.

Even though the low-temperature areas constitute only a minor part of the potential, to date they have been the major source of production of geothermal energy in Iceland for several reasons. The temperature is often ideally suited to space heating, the main application. The hot water is often so pure that it can be supplied directly to consumers without the use of heat exchangers, which simplifies operations. Only four high-temperature areas have been partially developed to date: the Hveragerdi field for space heating and greenhouses; the Svartsengi field for space heating and power production, the Námafjall field for industrial purposes, power production and space heating; and the Krafla field, which is in the course of development, for power production alone. Geothermal energy provided 0.8 per cent of the electricity produced in 1976 but its position will probably be between 10 and 15 per cent by the middle of the next decade. However, electric power is overwhelmingly derived from hydropower, and will remain so for a long time to come.

Iceland possesses domestic energy sources that have been utilized only to a minor degree, yet, at the same time, the country imports a substantial part of its needs in the form of petroleum products. The rapidly rising cost of oil, balance of payments considerations, and the question of security of oil supply have made the replacement of imported oil by domestic energy a major component of Icelandic energy policy. However, the economics for such replacement vary tremendously among consumption sectors. For instance, mainly for technical reasons, neither geothermal energy nor hydropower contribute to use in mobile applications such as in fishing or transportation. For the industrial sector, the prospects are more promising, although the applications at present are somewhat limited for technical and economical reasons. The sector with the greatest replacement potential is space heating. Here geothermal energy is both technically and economically superior to oil, provided a source can be found close to the consumption area, since this form of energy cannot be transmitted economically over great distances. In fact, by the middle of the next decade, it is expected that oil will have largely disappeared from the space heating sector and will have been replaced by geothermal heat wherever sources exist and by hydropower and geothermal generated electricity elsewhere.

If means can be found to convert geothermal energy or hydropower economically into easily transportable liquid or gaseous fuels, the picture will change radically, presenting the possibility of energy self-sufficiency. However, no such means is in sight.

The National Energy Authority – Orkustofnun

The National Energy Authority is the government advisory and research organization in the field of energy. In addition to advising the government and carrying out investigations and research into the nation's energy resources, it collects and publishes energy statistics and initiates and co-ordinates energy forecasting. Furthermore, it is responsible for supervising the safety inspection of electrical apparatus and installations and carrying out investigations in economic geology.

By far the greatest part of the National Energy Authority's money and manpower is tied up in the study of energy resources, and the Authority's two major divisions are devoted to hydropower and geothermal energy resources. The Geothermal Division employs at present about 50 persons, of whom 37 are professional engineers, geologists, geophysicists, geochemists, mathematicians, etc. In addition, a number of undergraduate students are normally employed in fieldwork during the summer months. In fact, many of the specialists now working with the Geothermal Division began their careers in this way and thus became intimately acquainted with the practical side of geothermal energy work before becoming professionals.

Obviously the ultimate test of all methods of geothermal prospecting is drilling. Drilling is undertaken in Iceland by one company, the State Drilling Contractors under the Ministry of Industry. The minister of industry has assigned to the National Energy Authority the task of supervising the operations of the State Drilling Contractors. Thus, there is a close and extremely valuable liaison between the staff of the Geothermal Division and the drilling personnel.

A number of employees of the Geothermal Division and the State Drilling Contractors have become internationally known and have been called upon by the United Nations as advisors and supervisors for geothermal energy projects in 13 countries.

The National Energy Authority, with few exceptions, neither constructs nor operates energy production facilities. Most geothermal production and distribution plants in Iceland, especially district heating systems, are owned by municipalities. A municipality wishing to develop a geothermal field for space heating purposes normally approaches the Geothermal Division for information and advice. If the Division considers the field to be sufficiently promising, it recommends to the municipality that drilling be undertaken, whereupon the latter contracts the drilling work to the State Drilling Contractors. The Geothermal Division serves as a consultant to the municipality during and after the drilling operations and evaluates the results.

Drilling costs are borne by the municipality, which may turn for financial aid to the Energy Fund, a government agency financed from the state budget with a parliament-appointed council. At present, the Energy Fund grants loans for geothermal drilling amounting to 60 per cent of the drilling costs. If a new field turns out to be non-productive, the loan is converted to a grant and need not be repaid. Loans for increased production from fields that have already been developed must be repaid in all cases.

II. CURRENT ACTIVITIES IN GEOTHERMAL ENERGY SPONSORED BY THE UNITED NATIONS AND UNESCO

United Nations*

The United Nations Centre for Natural Resources, Energy and Transport (CNRET) is the substantive office of the UN Office of Technical Co-operation, which is the executing agency for the UN Development Programme (UNDP). The activities of CNRET relate only to exploration and the development of geothermal fields in developing countries. Programmes amounting to US$12 million have been administered by CNRET through funds provided by UNDP over the last ten to twelve years. UNDP is also funding the geothermal engineering course to begin in February 1979 at the University of Auckland, New Zealand (for details see section III). In view of the lack of funds in many developing countries, as well as the lack of skilled manpower which must be contracted from abroad, the critical need for practical training of geothermal energy explorers and drillers is felt in the CNRET projects.

At present CNRET is assisting exploration projects in India, Jordan, Madagascar, Ethiopia and Kenya. One of the main activities of an Interregional Project for Central America is the organization of training seminars on project planning, exploration and drilling. Also CNRET has sent consultants to Romania to advise on geothermal well pumping. Fellowships have been established in all the projects.

Two requests are presently being processed by CNRET: a project in Mexico to increase research capability in remote-sensing geophysics, drilling technology and reservoir engineering, and the continuation of a World Bank-initiated exploration project in Honduras. CNRET anticipates an additional request for assistance in developing the geothermal resources of Djibouti.

* From a presentation by James R. McNitt, Senior Advisor to the UN Centre for Natural Resources, Energy and Transport.

United Nations Educational, Scientific and Cultural Organization (UNESCO)*

In 1968, UNESCO took the initiative in convening a meeting of experts on training in geothermal energy. This meeting produced a document entitled "Report on Meeting of Experts on Training in Geothermal Energy" (SC/CS/250/3, UNESCO, Paris, 25 October 1968) and, as a result, annual training courses at Pisa, Italy and Kyushu University, Japan (for details see section III) were established. UNESCO support for these two training courses continues up to the present time.

In 1973, UNESCO published a valuabie book entitled *Geothermal Energy,* consisting of articles by leading authorities on the various aspects of the exploration and utilization of geothermal sources.

At the request of Member States, UNESCO has organized consultant missions to advise on general aspects of geothermal energy in Indonesia, United Republic of Cameroon and, presently, in the Democratic People's Republic of Korea.

Interest at UNESCO in supporting training activities in geothermal energy will continue and the Organization is prepared to co-operate with the UN University, as well as with the other interested members of the United Nations system, in developing a more comprehensive and systematic approach to this problem, which is now of some urgency to many developing countries.

* From a presentation by E. Michael Fournier d'Albe, Director of the Earth Sciences Division of UNESCO.

III. CURRENT INTERNATIONAL GEOTHERMAL ENERGY TRAINING PROGRAMMES SUPPORTED BY THE UN SYSTEM

International Post-Graduate Course in Geothermics*

This was the first course to be established following the recommendations of the Meeting of Experts on Training in Geothermal Energy convened by UNESCO in Paris in 1968. The course was launched in Pisa, Italy, in 1970 at the International Institute for Geothermal Research, an institute of the Consiglio Nazionale delle Ricerche dealing with basic research in geothermics. UNESCO, the Ministero degli Affari Esteri and the Consiglio Nazionale delle Ricerche, provided support for the course in the form of scholarships and financial contributions. The Ente Nazionale per l'Energia Elettrica has assisted in the practical phase of the course.

From 1970 to 1976 the course was divided into two main parts, one theoretical, lasting five months, and the other practical for a period of four months. In 1977 and 1978, however, the course was reduced to only five months in order to accommodate the request of students who, for professional reasons, were unable to leave their posts for a longer period. This reduction was accomplished by condensing the theoretical part to about three months and the practical part to about two months.

The theoretical course was presented by Italian and foreign experts while the practical side of the course, which was tailored to the requirements and interests of each participant, was held in the Instituto Internazionale per le Ricerche Geotermiche, at university institutes, in scientific laboratories and in public and private institutions specializing in the research, exploration and exploitation activities in geothermal fields.

The course, which can accommodate a maximum of 15 participants, is open to citizens of Member States of UNESCO who possess a degree, or equivalent academic qualification, in geology, physics, chemistry or engineering. The candidates are selected accord-

* From a presentation by Raffaele Cataldi of the Centro di Ricerca Geotermica of the Italian Ente Nazionale per l'Energia Elettrica, and relevant documents.

ing to the status or the possibility of development of geothermal projects in their countries, and on the basis of their curriculum vitae and information provided by the UNESCO national commissions and the embassies of the Government of Italy. Admission to the course is awarded preferably to employees of state bodies, societies and organizations that are currently conducting or initiating basic research or projects for the exploitation of geothermal energy.

A total of 95 persons from 38 countries have participated in the course since its inception, of whom 60–70 per cent are believed to be still active in the field.

Problems that have arisen have been due to different standards of preparation among the participants, different interests depending on the stage of development of geothermal activity in the country of each participant, and frequently an inadequate knowledge of English.

Starting in 1979, with additional support from the UN Development Programme, the course will be directed mainly toward the exploration of geothermal fields including geological, geophysical and geochemical methods, with an outline of some of the problems inherent to drilling, modelling and reservoir physics. Participation is therefore restricted to individuals who intend working in exploration. The course will last ten months, four of which will be devoted to theoretical preparation and six to practical application on projects already under way. Admission will alternate between citizens of Latin American countries, with the lectures being given in Spanish or Italian, beginning in 1979, and citizens of other UNESCO Member States with lectures conducted in English. A decision will be made later as to whether the structure and content of the course will be modified to extend the training to the problems of exploitation of fields and the utilization of geothermal fluids.

The programme for the theoretical part of the course is as follows.

(a) Introductory outline (Duration: 1 week):
including such subjects as heat flow, hydrology, examples of geothermal fields, concepts of cover, reservoirs, heat sources, and uses of geothermal energy.

(b) Hydrogeology (Duration: 1 week):
general problems of hydrogeology, especially as they relate to geothermal environments.

(c) Geological methods (Duration: 3 weeks):
mainly concerned with such questions as volcanology, reservoir problems, petrography, geochemistry of rocks, heat sources, photointerpretation, especially with reference to and comparison between geothermal fields.

(d) Geochemical methods (Duration: 4 weeks):
physicochemical aspects of geothermal fluids, interpretation of chemical and isotopic data, analysis of hydrothermal alteration, and statistical studies of geothermal fields.

(e) Geophysical methods (Duration: 3 weeks):
methods of determining structural models including application of various geophysical techniques, data processing, interpretation of data, etc. as they apply to different active tectonic structures; methods for reconstructing the thermal regions including application of soundings, borehole gradient data, infrared spectrometry and seismic and microseismic noise; application of various prospecting methods to different kinds of geothermal areas.

(f) Summary (Duration: 1 week):
multidisciplinary discussion of the foregoing and introduction to the area selected for a co-ordinated excursion.

Before beginning the practical part of the course, a three to four-week excursion is made to an area of geothermal interest. The remaining six months is devoted to participation in operational projects suitable to the general objective of developing capacities for exploration in geothermal areas. Students successfully completing the course receive a certificate.

International Group Training Course in Geothermal Energy*

Following a recommendation of the Meeting of Experts on Training in Geothermal Energy at UNESCO headquarters in 1968, the International Group Training Course in Geothermal Energy was established in 1970 at Kyushu University in Fukuoka, Japan, by the Japan International Cooperation Agency of the Government of Japan and with the support of UNESCO. The course given in English is offered to young researchers from developing countries who hold a university degree or its equivalent in earth sciences or engineering, and who are nominated by their governments.

Since its foundation the course has been completed by 108 persons from 24 countries, most of whom have remained active in various aspects of geothermal operation or administration.

The 12-week course is divided into 183 hours of lectures, seven days for fieldwork, 9.5 days for field trips and a one-day study tour. The lectures, seminars and laboratory sessions cover such topics as geothermal geology, volcanology, including a study of the volcanoes and hot springs around Mt. Aso, structural geology hydrothermal and stable isotope geochemistry, heat and thermodynamics, geothermal hydrology, geophysical exploration, including geothermal measurements, reservoir physics drilling, well-head technology and techniques, power plant engineering, corrosion fundamentals and details of the development of the Otake and Hatchobaru geothermal fields. The lectures are given by specialists in the various subjects.

* From a presentation by Seibe Onodera, the leader of this course and Professor of Exploratory Geophysics, Department of Mining, Faculty of Engineering, Kyushu University, and pertinent documents.

All students are requested to provide an evaluation of the course. Successful completion is marked by the presentation of a certificate.

Under serious consideration is a plan to extend the course to six months, the first three of which would be essentially the same as the present course. Those students successfully completing the first half would be eligible to continue for the second three-month period, during which time they would undertake directed specialized studies. The specialties offered include geothermal geology, power plant engineering, geophysical exploration, hydrothermal chemistry and production engineering.

Kyushu University hopes to establish a geothermal research centre which could provide training in research in geothermal techniques and applications.

Diploma Course in Energy Technology (Geothermal)*

Commencing in 1979, the University of Auckland's Geothermal Institute will offer a post-graduate course of training in geothermal energy technology lasting one academic year or about ten months. The course is financed jointly by the United Nations Development Programme and the Government of New Zealand.

Applicants must possess a bachelor's degree or its equivalent in science or engineering. A good command of English is essential. Of the twenty places that are open annually, three are reserved for citizens of New Zealand and the remainder for individuals from developing countries selected by the UN Development Programme.

All students will attend a common core of classes, interspersed with either of two series of more detailed lectures, one designed for engineers and the other for earth scientists. Classroom instruction will be supplemented with practical laboratory sessions and fieldwork in geothermal regions.

The programme of the course is as follows.

(a) General topics for engineers and earth scientists (Duration: about 2 months): scope of geothermal projects, basic facts of geothermal systems, introduction to geothermal exploration and technology, down-hole measurements, introductory reservoir engineering, introduction to chemistry of thermal fluids and to corrosion problems, well-siting and costs, and case histories.

(b) Technology for engineers (Duration: about 4 months): drilling technology, completion tests, reservoir engineering pre-feasibility studies, corrosion, fluid collection and transmission, power plant design, geothermal plants, and legal aspects.

(c) Technology for earth scientists (Duration: about 4 months):

* From a presentation by Richard S. Bolton of the New Zealand Ministry of Works and Development, and relevant documents.

petrology, logging of drill holes, field geology and mapping, geochemistry, geophysics, and thermal potential.

The basic lecturing and laboratory staff is supplied by the university, supplemented by other lecturers from government agencies and private industries involved in geothermal investigations. The programme will allow for extra work on a selected topic either alone or under tutorial supervision. The final examinations for this diploma will consist of written papers and a report on a practical project.
The course will be reviewed after the first two years and perhaps extended to students from industrialized countries.

Bilateral Courses

In addition to the UN-sponsored courses described above, geothermal training is available on a bilateral basis in several countries, notably the USA, France, New Zealand and Hungary. Information on the government-sponsored programmes in the latter two nations is of interest.

New Zealand *

In addition to the diploma course, and separate from it, informal on-the-job training is offered by the Ministry of Works and Development and the Department of Scientific and Industrial Research. An average of about six students per year are trained for two to six months. This training is usually on a bilateral basis, although, in some instances, the UNDP arranges to provide funds for the trainee.

Hungary **

A course is offered in the field of geothermics at the Technical University at Miskolc. The source of heat exploited in Hungarian geothermal fields is a closed sedimentary basin that provides thermal water for heating at temperatures from 60–100°C. The technical needs for development in this geological environment have generated a rather different training course, which is given as part of the university curriculum. Of the twelve students accepted each year for this one-year course, occasional students come from other countries. The course, given in Hungarian, covers terrestrial heat and crustal evolution, measurement of terrestrial heat flow, geothermal energy systems, geothermal conditions in the Pannonian basin, geothermal energy production, development methods, and applications of geothermal energy.

* From a presentation by Richard S. Bolton of the New Zealand Ministry of Works and Development.

** From a presentation by Boldizśar Tibor, Professor of Geophysics at the Hungarian Technical University, Miskolc.

IV. GEOTHERMAL ENERGY TRAINING NEEDS IN SELECTED DEVELOPING COUNTRIES

Central America*

Systematic exploration of geothermal energy in Central America began in El Salvador in 1966 with a project supported by the UN Special Fund (later the UN Development Programme) and executed by the United Nations. This project was concluded by a feasibility study in 1971 on the basis of which the Government of El Salvador decided to construct a geothermal power station at Ahuachapán. The first 30-MW unit was operational in 1975, followed by a second unit of the same size in 1976, and a third 35-MW unit is presently under construction. The exploration was carried out by international experts in co-operation with local professionals who received training on the job and under fellowships abroad. In this way a nucleus of local specialists in geothermal techniques was formed, which has since been able to expand and carry out the geothermal development in the country with minimal outside assistance. This was one of the most important achievements of the UN project.

Increases in petroleum prices have had serious economic repercussions in all the Central American countries, most of which were highly dependent on petroleum imports for electric power generation (generally 50–80 per cent). This and the successful results in Ahuachapán led to the initiation of geothermal exploration and development in all other countries of the region including Panama. The construction of the first 35-MW geothermal power station in Nicaragua is now under way and other countries are planning similar projects. It has been estimated that Central America will have about 450–500 MW of geothermal power in production before 2000.

Manpower and training requirements

A principal limiting factor in the utilization of the region's geothermal potential is the

* From a presentation by Sveinn S. Einarsson, Senior Geothermal Expert of the Central American Energy Programme, UN Office of Technical Co-operation.

shortage of specialized personnel to explore and develop the geothermal resources. All of the countries of the region with the exception of El Salvador have tried to solve this problem temporarily by entrusting exploration and development work to various extents to commercial consulting firms. Experience has shown, however, that (a) it is difficult to find fully competent consulting firms, (b) the required time is longer and the costs are considerably higher than expected, and (c) the training of local professionals has generally been neglected.

A new regional project, the Central American Energy Programme, is being organized with a view to assisting the countries of the region in rationalizing their supply and use of energy, so that they can reduce their dependence on imported hydrocarbons. This comprehensive project is supported by UNDP and executed by the United Nations. As part of the preparatory activities of this project a survey of the status of geothermal development in the region was made in July 1977 indicating that at that time 30N–35 local professionals were working full-time in geothermal activities. Future projections indicate that this number will have to be increased to 75–80 by 1980, and 110–120 by 1985, which is indicative of the requirements for training of new personnel in the area over the next seven years.

Regional training seminars

As a temporary measure, the organization of short intensive training seminars was proposed within the region, using international experts as instructors. This proposal was approved by the UNDP/UNOTC and a ten-day seminar on geothermal contract drilling and geological monitoring was held in Managua at the end of 1977, with participation from all the Central American countries, Mexico and some countries of South America. The UNDP provided instructors, paid the international travel for the Central American trainees and contributed towards their daily subsistence. The results of the seminar proved very encouraging.

It is now hoped that the Central American Energy Programme will become operational in late 1978. At the invitation of the Government of El Salvador and with the consent of all other governments concerned, a series of regional training seminars is now planned under this project. The tentative programme is as follows.

Seminar 1: Basic planning and methodology in the development and exploration of geothermal energy; general orientation.

Seminar 2: Geological, geochemical and geophysical exploration techniques for preliminary evaluation of geothermal potential preceding exploration drilling.

Seminar 3: Geothermal drilling technology; hydrological, chemical, physical, and geological monitoring of drilling; well logging; and production testing.

Seminar 4: Reservoir engineering and testing and estimation of energy resources.

Seminar 5: Feasibility studies, plant design and construction, environmental aspects and exploitation.

The first two seminars are planned for November–December 1978, and March 1979 respectively, and it is expected that the others will follow in due course. All the seminars will consist partly of theoretical lectures and practical field work and will be held in El Salvador with local support from the Comision Ejecutiva Hidroelectrica de Rio Lempa (CEL), the national power company. These seminars are primarily intended for professionals who are already active in geothermal development work in their respective countries and who can remain absent from their projects for only a limited time. Each seminar will last two to four weeks and, thus, this series of seminars is complimentary to the more formal and longer training courses held in Italy, Japan, New Zealand and that proposed in Iceland. The latter courses are of fundamental importance in assisting the developing countries in producing new personnel. The instructors for the Energy Programme will be specialists from El Salvador, as well as international experts specially recruited for the task by the United Nations.

El Salvador*

The present geothermal programmes in El Salvador comprise two main activities; management of the Ahuachapán geothermal field and exploration and development of new geothermal fields in the eastern part of the country. The first geothermal power unit at Ahuachapán was commissioned in May 1975 and it is expected that the total capacity of the plant will reach 95 MW in January 1980. The Berlin, Chinameca and San Vincente geothermal fields are now being studied, with very promising conditions for electric power production already encountered in the Berlin field.

On a national basis the composition of the total electric power generation capacity in 1977 is as shown in Table 5. However, because of sustained operation of the geothermal plant, 32.3 per cent of the total electric power actually generated in the country in that year was produced by geothermal energy. Since geothermal power plants are substitutes for thermal plants which operate on imported fuel oil, the annual savings in imports at the price level of 1976 amounts to more than US$10 million, which is of great significance for the balance of payments of the country.

Because El Salvador has no petroleum resources, and consequently must rely on imports, and because the nation's hydropower resources are limited and will soon be fully exploited, the government has decided to accelerate and intensify the development of new and promising geothermal fields. On this basis, the present manpower needs of the Department of Geothermal Resources of CEL are personnel for:

(a) the Exploitation Section, responsible for the operation and management of the Ahuachapán field, including the reinjection programme;
(b) the Exploration Section, responsible for the development of the new fields at Berlin, Chinameca and San Vicente;

* From a presentation by Gustavo Cuéllar, Superintendent of the Department of Geothermal Resources of the El Salvador Comision Ejecutiva Hidroelectrica del Rio Lempa.

TABLE 5 COMPOSITION OF THE INSTALLED CAPACITY FOR ELECTRIC POWER GENERATION IN EL SALVADOR IN 1977

	MW	%
Hydropower	232	55.2
Geothermal power	60	14.3
Conventional thermal power	128	30.5

(c) the Chemical Section, in charge of all analytical work and solutions to chemical engineering problems; and

(d) the Geothermal Laboratories, responsible for petrographic work, measurements of physical properties of rock, and calibration of equipment.

Furthermore, specialized personnel in reservoir engineering are now being trained.

At present the Department of Geothermal Resources employs 20 full-time geologists, geochemists, geophysicists, chemists, mechanical engineers, etc., about one-half of whom are conversant in English. About 6 of these professionals have had ten years experiences, another 6 about five years and the remainder from one to three years. Many of these specialists were trained under the UN exploration project in 1967–68, and received fellowships to Mexico, New Zealand, Iceland, Italy, Japan, and the USA.

Later, CEL began taking advantage of the training courses in Italy and Japan and now sends professionals who have recently joined the Comision to the courses in order to provide them with a general background in geothermal methodology. The development of geothermal energy utilization in El Salvador has now reached a stage where more emphasis is placed on specialization of the staff which is in charge of the various activities.

While El Salvador has benefitted from the general orientation given by the courses in Japan and Italy, it is felt that the more practical and specialized courses for personnel with experience, which will be offered by the new UN University-sponsored training facilities in Iceland, will be complimentary. Since companies cannot release personnel for extended periods, the availability of courses of relatively short duration, four to six months, is important. The immediate training needs of El Salvador are in the areas of geophysical exploration, drilling technology, geochemistry, and reservoir engineering.

Kenya*

The present project for the exploration of geothermal steam for electricity commenced in October 1970 under the joint auspices of UNDP and the East African Power and Light

* From a presentation by Sebastian Bwire-Ojiambo, Geothermal Project Geologist with the Kenya Power Company, Ltd.

Co., Ltd., the latter acting as the Government of Kenya's counterpart to UNDP. During the period between 1970 and 1973, hydrogeological and geochemical surveys were carried out in the Rift Valley between Mt. Suswa and Lake Baringo. Geological and geophysical surveys were carried out in three of the most promising areas, namely Olkaria, Eburu and Lake Bogoria.

At the end of 1972, after a technical review meeting between UNDP experts and the staff of the East African Power & Light Co., Ltd., it was decided to start exploration drilling at Olkaria with production-size wells. Drilling commenced in 1973 under a UNDP contract and by 1976 three successful wells had been drilled. A feasibility study carried out under a UN contract and an engineering report under a Kenya Power Company, Ltd. contract showed that the area was promising enough to warrant an initial 15-MW power plant by 1981 followed by another 15-MW unit in 1983.

In July 1977, the project was taken over by the Kenya Power Company, Ltd. (KPC), a national company, to facilitate obtaining financial assistance from international bodies under government guarantees. The KPC has thus embarked on a programme of drilling to provide enough steam for the first 30 MW since early June 1978. The purchase of a track-mounted drilling rig is contemplated to augment the present trailer-mounted rig in order to increase the drilling rate and obtain the required steam, enabling the power stations to be constructed on time. Acquisition of a new rig would require more trained Kenyan manpower.

Over the 8 years that the project has existed, a total of eight Kenyans have attended various courses in New Zealand, Japan and Italy in geothermal exploration and development, four at professional level and four at technician level. Of the four professionals trained, only one of whom has continued with the project, two were geologists, one a geophysicist and one a geochemist.

At the present manpower level, it is obvious that a great many specialists and technicians are required to develop the project and that even more will be required in the near future. A detailed list of these requirements and a breakdown of the present manpower resources are found in Table 6.

The present international training courses in geothermal development in Italy and Japan and the proposed post-graduate level diploma course in New Zealand, as well as the bilateral training facilities offered by the New Zealand government, are useful for professionally trained personnel who require more special training in their particular disciplines to increase their effectiveness in geothermal work. However, there are no international courses catering to the technician and artisan-level trainees, including the operations staff which assists the drillers. The United Nations University could be of great assistance in organizing the planning, co-ordination and execution of such courses at an international level, possibly in conjunction with rig and compressor manufacturers and with

TABLE 6 MANPOWER REQUIREMENTS IN GEOTHERMAL ENERGY FOR KENYA

	Number now required	Number required by 1980	Number now available
Generation engineer	1	1	–
Drilling engineer	1	1	1
Geothermal scientist	1	1	–
Geologists	1	2	1
Geophysicist	1	1	–
Geochemist	1	1	–
Measurement engineer	1	1	–
Measurement technician	1	1	1
Technician drillers	4	8	3
Compressor operators	4	8	3
Artisan drillers	4	8	3
Power station engineer	1	1	–
Scientific assistants	8	10	7
Rig maintenance technician.	1	1	1
Drilling supervisor	1	1	–
TOTAL	31	46	20

international training schools in petroleum drilling and production. The KPC has tried as much as possible to train such personnel on the job and through the available training facilities at the company's training school, as well as at government vocational training institutions. However, these means are limited and courses lasting for two or three months abroad would be of great benefit to such operations staff.

India*

Regarding the geothermal energy situation in India, nearly all electrical energy is derived from fuels or hydroelectricity. Thus, it is not expected that more than six trainees per year would be sent from India. Many of these candidates would require training in short-term specialized aspects of exploration. Since all geothermal development in India lies with the Geological Survey, successful trainees wishing to apply their knowledge could seek employment only within that agency.

* From a presentation by Murali Sabnavis, Reader in Geophysics at the Department of Geophysics, Osmania University, Hyderabad, India.

Philippines*

The exploration for geothermal areas in the Philippines was initiated by the Commission on Volcanology in 1962. Five years later, a small demonstration geothermal power plant was placed in operation in a remote area in the town of Tiwi, Albay, southern Luzon. By 1970, the government took the big step of developing and exploiting the field under the National Power Corporation, which resulted in full-scale geothermal exploration and drilling activities in the Tiwi area. In 1976, the Philippine National Oil Company organized the Energy Development Corporation to explore and develop two resource areas in the Visayas in central Philippines and one promising field on the island of Mindanao. At present there are six geothermal fields in the country in various stages of exploration and development. The most advanced is the Tiwi project, which has a total productivity of 178 MW. The country expects to operate the first 55-MW unit at Tiwi by December 1978. A second unit of the same capacity will be on stream by March 1979.

At the Makiling-Banahaw project near Manila, the National Power Corporation has found a potential 108 MW and the first 55-MW plant will start operating by March 1979. A second unit is expected to be operational in June of the same year. In central Philippines, feasibility studies of the Tonyonan geothermal field have just been completed with the first 37.5-MW plant to be commissioned in November 1980. Exploratory drilling is in progress in the provinces of Negros and Davao del Norte. By 1985 it is hoped that about 1,320 MW will be produced, which would be about 18 per cent of national requirements for electricity.

The Philippines sends young geologists and engineers regularly to New Zealand under an aid agreement. The training covers a period of three months and involves thorough exposure to the technology most suitable to the individual and the preferential needs of the trainee's sponsoring organization. The programme calls for individual training wherein discussions are carried out informally with emphasis on participation in actual field operations. This training, as stipulated in the aid programme, is limited to Energy Development Corporation personnel. Another venue is the Japan group training course, which is used by other agencies of the government. In this course, many topics are compressed into a short period of lectures and field and observation trips.

The Energy Development Corporation, a government entity, and so far the sole organization in the country actively engaged in geothermal exploration and development, maintains a training programme formally through organized lectures and technical sessions. At the job sites, the exercises become an almost continuous and painstaking process of learning, especially for those who are just starting out.

* From a presentation by Bernardo S. Tolentino of the Energy Development Corporation of the Philippine National Oil Company.

What the Philippines may consider desirable at this point in time is a two-pronged programme, including, first, a training package that is short and more practical in approach than those available in any of the leading countries engaged in geothermal exploration development and utilization. This arrangement would give more weight to actual participation in field operation to effect a fast transfer of technology within a reasonable span of time. For this type of training, it is felt that three to four months is appropriate. This time constant is necessary since at the present pace the Philippines cannot afford to send personnel for lengthy training abroad. Secondly, training that will develop top calibre expertise through formal education, experiments, and actual practice within a period of about one year is needed. This may be considered a degree course in geothermal energy exploration, development and utilization. In our opinion, such training would be most beneficial in subjects like reservoir physics and reservoir engineering.

Specifically, immediate training needs in geothermal energy in the Philippines may be broken down as follows.

(a) Geology:
a 4-month course on alteration and clay mineralogy, alteration chemistry, mineral geothermometry and the nature of circulation losses.

(b) Geochemistry:
a 4-month course on gas, isotope and general reservoir chemistry and hydrogeochemical patterns.

(c) Geophysics:
a 4-month field and lecture course on new and refined techniques in resistivity surveying and the interpretation of Schlumberger traverse and sounding surveys and geophysical modelling.

(d) Reservoir geology and physics:
12- to 18-month course of classroom lectures, experiments and field measurements and investigations with emphasis on calculation and interpretation, concepts and modelling.

(e) Well measurements:
a 4-month course in instrumentation, techniques, procedures, calculation, evaluation and presentation of results.

(f) Drilling engineering:
a 6-month course in engineering practices in geothermal drilling with emphasis on monitoring of bore situation while drilling is in progress, preventive measures, mud technology and other problems.

At present there are fewer than 30 specialists in the country, all fully occupied, so that advantage must be taken of any training opportunities available.

V. FACILITIES AVAILABLE IN ICELAND FOR GEOTHERMAL ENERGY TRAINING*

National Energy Authority

In accordance with the Energy Act of 1967, the National Energy Authority (NEA) advises the Government of Iceland on energy matters and operates under the auspices of the Ministry of Industry.

The NEA has eight main divisions, three of which are directly concerned with the exploration, production drilling, and utilization of geothermal energy. These divisions are the Geothermal Division, the State Drilling Contractors, and the State Geothermal Heat Supply. These three divisions are closely associated and cover the entire field from geothermal exploration to exploitation. The exploration involves a combination of geological, geophysical and geochemical methods, and is succeeded by exploratory drilling, production drilling, well logging, reservoir engineering, corrosion testing and in some cases feasibility studies. The NEA, therefore, offers a good opportunity for visiting scientists to obtain an overall view of the exploration, production and utilization of geothermal energy.

The full-time staff of the Geothermal Division is composed of over 50 geoscientists, engineers, and technicians, of whom 14 possess Ph.D. qualifications. The staff is divided into sections as follows.
Management (director, 4 clerical staff)
Regional and local geological surveys (6 geologists)
Petrology and geological logging of drillholes (5 geologists and 5 technicians)
Geophysical exploration surveys (5 geophysicists, 2 electrical engineers and 1 technician)
Geophysical logging of drillholes (3 geophysicists and 2 technicians)
Water chemistry (6 geochemists and 1 assistant)

* From documents prepared by the National Energy Authority and the University of Iceland accompanying the "Proposal for UNU Training Programme in Geothermal Energy Exploration and Production" submitted to the United Nations University by the Government of Iceland.

Reservoir hydrology and modelling (1 geological engineer and 1 hydrologist)
Data processing (2 mathematicians)
Scaling and corrosion (2 chemical engineers)
Production engineering (3 mechanical engineers and 2 technicians)

During the field season from June to September, some 30 science students are hired to work in exploration teams for geological and geophysical exploration surveys . The production engineers work mostly for the State Geothermal Heat Supply, which has no other permanent staff.
The Geothermal Division operates two laboratories:

(a) a geophysical laboratory for the development and maintenance of geophysical instrumentation for surface and borehole surveys, using two trucks for the logging of boreholes (temperature, pressure and resistivity logs, as well as down-hole water samples); and
(b) a chemical and petrological laboratory for standard water and gas analysis and with equipment for making thin sections, mineral separation, X-ray diffraction and porosity determination. (Access to X-ray fluoresence equipment and an electron microprobe is secured at other institutions in Reykjavík. Corrosion tests are made in the geothermal fields.)

Geothermal exploration involves a combination of many methods, including geological mapping, structural analysis, electrical resistivity surveys (Schlumberger and dipole-dipole methods), ground-magnetic and aeromagnetic surveys, and, in some cases, gravity and seismic surveys. Water and gas are analysed in order to extract information on underground temperatures and water flow. For each main exploration project, working groups are set up consisting of scientists representing the various disciplines.

Geothermal energy in Iceland has mainly been utilized in the form of space heating using water at temperatures up to 150°C. In some cases the thermal water is free flowing, but most of the municipal heating services use submergible turbine pumps creating drawdown in the reservoirs of more than 100 m at peak periods. The utilization of high enthalpy fluids for power production, industrial processing, and space heating is increasing rapidly. The highest temperature so far measured in an Icelandic steam field is 345°C. Most of the geothermal areas that have been explored are characterized by relatively fresh water, although brines and carbonate waters have also been encountered.

The State Drilling Contractors executes all geothermal drilling in Iceland, with a full-time staff of about 15 personnel excluding the drilling crews. There are five rotary drilling rigs in operation with depth capacities of 3,600, 2,000, 1,500, 1,000 and 600 m, and a number of smaller rigs. Continuous coring is limited to very shallow wells, although cuttings are sampled routinely. Drilling is usually done using water as the flushing medium, with the help of drilling mud when necessary. Most wells are tested and stimulated by means of high-pressure water pumps and injection packers at the completion of drilling.

Although three divisions of the NEA are directly concerned with geothermal research and utilization, two other NEA divisions participate, to a limited extent, in some geothermal projects. These are the Electric Power Division and the Economic Geology Division with staffs of about 30 and 10 scientists and technicians, respectively. The former division is divided into four sections: the Engineering Geology Department, Hydrological Department, Hydraulic Laboratory and Geodetic Survey Department. The Economic Geology Division is mainly concerned with the search for potable water. Experts from these two divisions co-operate in some geothermal projects with the Geothermal Division, especially with regard to the disposal of waste water, regional hydrological conditions and reservoir engineering and simulation.

The NEA possesses a library containing approximately 7,000 titles and subscribes to about 200 scientific and engineering journals.

The activities of the NEA touch on every step from the planning of an exploration programme to the completion of a production well containing a harnessable fluid. It should be borne in mind, however, that the geology of Iceland consists entirely of volcanic rocks, and many of the exploration and development methods used by the NEA are designed for geothermal exploitation in volcanic areas, and may, therefore, not be directly applicable in countries where the geothermal activity is in structurally different environments and associated with metamorphic or sedimentary strata. As a result, it might be desirable in some cases to arrange for part of a training programme to be carried out jointly with geothermal institutions in countries whose geological conditions differ from those in Iceland.

The idea of a geothermal training programme for foreign scientists at the NEA of Iceland is not altogether new, since over the last decade there have been scientists from El Salvador and Turkey who came as UN Fellows and remained for periods of about one month, in addition to a large number of other foreign visitors on shorter study trips.

Geothermal experts from the National Energy Authority have in the past been consultants, generally on behalf of the UN, to geothermal projects in numerous countries including Costa Rica, El Salvador, France, Indonesia (Sulawesi), Kenya, Mali, Nicaragua, Philippines, Tanzania, Turkey and Zambia, and in the West Indies.

University of Iceland

The following facilities of the University of Iceland are prepared to participate in a geothermal energy training programme: the Science Institute, the Nordic Volcanological Institute, the Engineering Institute and the University Computer Centre.

The Science Institute has a staff of 26 faculty members and 20 research associates, five divisions for mathermatics, physics, chemistry, geosciences and computer science. Eleven of the staff members have been involved in geothermal research or related work.

The Science Institute works in close co-operation with the Nordic Volcanological Institute which is associated with the university. This institute has three permanent research positions for research fellows from the Nordic countries. Two of the permanent staff have long experience in geothermal research.

Research subjects of these institutions include volcanology, experimental petrology, thermal water and gas geochemistry, isotope geology and geochemistry, seismology, paleomagnetism and aeromagnetic surveys, ground water hydrology and reservoir mechanics and simulation. These institutes possess conventional laboratories for mineralogy and chemical analysis of rocks, fluids and gases, tritium and radon analysis, X-ray diffractometry, X-ray fluoresence spectrometry, mass spectometry of hydrogen and oxygen isotopes and for electron microprobe investigations. Instrumentation for geophysical exploration and monitoring work includes a network of microearthquake recording stations supplemented by portable instruments, tilt-meters and a laser geodimeter. Both institutes have electronic laboratories for the development of instruments.

The Engineering Institute is staffed by Engineering Faculty members, totalling 16 professors and associate professors. Of these, 6 have been directly involved in geothermal engineering work including drilling technology, two-phase fluid mechanics and applications of geothermal energy in industry, power production and central heating systems. The Engineering Institute operates teaching and research laboratory facilities in the following fields: thermofluids and power engineering, applied mechanics, soil mechanics, automatic control, electrical machinery, telecommunications.

The University Computer Centre operates IBM 360/30 and PDP 11/34 computers together with a Calcomp 836 plotter. In addition, the centre is linked to the State Computing Centre IBM 370/145 computer through an on-line terminal.

The Faculty of Engineering and Science offers a number of courses related to geothermal research and engineering which could be of interest to participants in a training programme. Several foreign students specializing in this field have already attended these courses although no formal study programme has yet been established.

Geothermal experts from the university have in the past been consultants generally on behalf of the United Nations in geothermal projects in several countries, including El Salvador, Nicaragua and Kenya.

VI. PROPOSED ICELANDIC GEOTHERMAL TRAINING PROGRAMME*

In March 1978, the Government of Iceland sent a proposal to the United Nations University for the establishment of a training programme in the field of geothermal energy, intended for Fellows selected from various countries under the sponsorship of the UN University.

It is intended that the training programme will be executed by the Geothermal Division of the National Energy Authority (NEA), but will also be closely linked with the University of Iceland. Supervisors and instructors will be drawn from the staffs of both institutions and an attempt will be made to integrate the training programme into the geothermal exploration and utilization projects that are in progress in Iceland at the time of training.

The aim of the programme is to provide practical training that will enable successful participants to return to their countries and work independently in their chosen field. No attempt will be made to train an individual in all fields of geothermal studies, which would require several years, but instead emphasis will be placed on the practical aspects of training in selected fields. A sound background is required to take full advantage of this rather specialized practical training. No attempt will be made to duplicate the geothermal training courses that already exist in Italy and Japan, and the one planned to start in 1979 in New Zealand. These courses give an overall view of geothermal exploration and development and deal with the theoretical aspects of geothermics.
The Icelandic course will be built on the knowledge acquired from these courses or through practical experience gained by working in geothermal activities. Participants are expected to have had basic university training in science and engineering and preferably some practical experience in the field of geothermal energy in their home countries. In ideal cases, practical and project-oriented training in Iceland could begin after comple-

* From the document "UNU Geothermal Training Programme in Iceland" presented by Ingvar Birgir Fridleifsson of the Geothermal Division of the National Energy Authority.

tion of the rather theoretical courses in one of the international geothermal schools. This would require close co-operation and co-ordination of the various training courses sponsored by the United Nations.

The curriculum presented here for a possible geothermal training programme in Iceland was designed by a working group consisting of: Ingvar Birgir Fridleifsson of the NEA, Chairman; Stefán Arnórsson of the NEA; Sveinbjörn Björnsson of the University of Iceland; Jón Steinar Gudmundsson of the NEA; Ísleifur Jónsson of the State Drilling Contractors; Jón Jónsson of the NEA; Thorbjörn Karlsson of the University of Iceland; and Valgardur Stefánsson of the NEA. Other specialists were also consulted with regard to specialized fields of training.

A chart of the curriculum is shown in Table 7. In general, all participants in the geothermal training programme are expected to attend an introductory lecture course, which will last for four weeks. There will be 3 morning lectures five days per week and the afternoons will be used for background reading and seminars. Included will be short excursions to geothermal fields under exploitation near Reykjavík.

The introductory lecture course will be composed of lectures on a wide range of topics related to geothermal energy, including geothermal energy around the world; geology, geophysics, and chemistry of thermal fluids in geothermal exploration; drilling, borehole geology and geophysics; safety aspects of geothermal drilling; well testing and reservoir engineering; utilization of geothermal resources; environmental factors; planning and execution of geothermal projects; and case histories of selected geothermal projects around the world. The purpose of this lecture course is to provide general background knowledge concerning most aspects of geothermal energy. The emphasis of the lectures will be global rather than limited to Iceland. An important aim of the course is to generate an appreciation of the interrelationship between the various disciplines necessary in geothermal projects from the first to the last stages. At the conclusion of the introductory lecture course, a supervisor will be appointed for each participant and the details of the participant's training programme formulated.

An essential feature of the geothermal training programme is to provide participants with sufficient understanding and practical experience to permit the independent execution of projects within a selected discipline in their home countries. This is an ambitious goal and requires dividing the training programme into several courses. of Each of the participants is expected to follow mainly one of the eight courses of training, although, very often, they may wish to participate in selected parts of other courses. The courses range from 22 to 32 weeks in duration, including the introductory lecture course and field excursions. If a participant follows more than one course, the training period becomes correspondingly longer. The training programme is intended to be adaptable to the needs of each individual.

The details of the curriculum are described below.

TABLE 7 UNU TRAINING PROGRAMME IN GEOTHERMAL ENERGY IN ICELAND

Week	Geological Exploration	Borehole Geology	Geophysical Exploration	Borehole Geophysics	Reservoir Engineering	Chemistry of Thermal Fluids	Geothermal Utilisation	Drilling Technology	Week
1	Introductory lecture course on all aspects of geothermal energy and short field excursions								1
2									2
3									3
4									4
5	Field Geology R	Drilling P	Heat flow PF	Logging & well testing PR		Chemistry & LR		Introduction R	5
6	" R	Petrological RP	" FI	PR		chemical thermodynamics LR		" R	6
7	Maps & Photos P	logging RP	Magnetics P	RI		" LR		Medium size rig P	7
8	Structure Anal. P	" P	& tectonic F	Well completion & stimulation PF		Sampling RP		" P	8
9	Hydrogeology RP	" P	structure I	PF		Deposition LR		" P	9
10	FP Field excursions	Field excursions	Field excursions	Field excursions	Field excursions	Field excursions	Field excursions	Field excursions	10
11	FP "	"	"	"	"	"	"	"	11
12	Mapping P	Petrological PI	DC-Resistivity P	P-T-Ωm- LR	Reservoir LR	Sampling & RP	Fluid flow LR	Produc. size rig P	12
13	Field work in F	logging PI	soundings F	Caliper logs LR	properties & LR	analysis P	Collection & LR	" P	13
14	deeply eroded F	Report PI	" I	LR	well performance LR	P	disposal LR	" P	14
15	volcanic strata F	Alteration RP	Project PI	Field work F	LR	Geothermometers RP	Corrosion LR	Prep.& planning LR	15
16	F	" RP	" P	F	Well testing F	" P	Deposition LR	Selec. equipm. RP	16
17	Field work F	" RP	" F	Logging PR	Well testing PR	" P	Reservoir LR	Techniques R	17
18	in recent F	X-ray RP	Report I	Project PR	Project PR	W/R Interact. RP	Plants LR	" R	18
19	volcanic fields F	" RP	" F	" F	" P	" LR	" LR	Completion P	19
20	F	Report IP	" I	" F	" F	" P	" LR	Practices P	20
21	Report PI	"	Special methods P	Report I	Report I	" P	Project P	Management RP	21
22	" PI	Clay minerals RP	(Electrical or F	I	I	Project P	" P	" RP	22
23	" I	P	gravity & seismic)	I	I	" P	"		23
24	"	Aquifers	F		Modelling RL	" P	" P		24
25		Geological P	I		& RL	" P	" P		25
26		modelling I	I		assessment RL	" PI	" PI		26
27					of a PI	" PI	" PI		27
28					reservoir PI	" PI	" PI		28
29					I	" PI	" PI		29
30					I	Report I	Report I		30
31					I	" I	" I		31
32					I	" I	" I		32

F = Field work
I = Interpretation
L = Lecture
P = Practical exercises
R = Reading & seminars

Geological Exploration

This course offers practical training in basic geological mapping which is commonly the first step in the geothermal exploration of an area. In addition to making a geological map, participants will analyse the structure of an area with regard to siting drill holes and will be trained in mapping surface geothermal manifestations. The fieldwork will be conducted partly in deeply dissected strata, where the "roots of volcanoes" can be inspected, and partly in active volcanic fields. The training will be conducted in the laboratory for five weeks, in the field for eight weeks and, after the fieldwork, in the laboratory for four more weeks. In addition, the geologists will be expected to participate in excursions to the main geothermal fields in southern, western and northern Iceland.

Week	*Subject*
5–6	Field geology: Supervised background reading on the geology of Iceland with respect to the geological conditions in geothermal areas; case histories from other countries will be studied for comparison.
7–8	Training in the use of aerial photographs, stereoscopes, and calculation of map scales: Training in the use of maps, transfer from aerial photos to maps, enlargement of maps, etc.; training in transferring geological data such as compass readings onto aerial photos and maps, correction of magnetic declination, etc.; drawing of fault and dyke maps from aerial photos, and production of rose diagrams; and structure analysis from aerial photos and geological maps.
9	Hydrogeology: Training in basic concepts.
10–11	Field excursions to the main geothermal fields in Iceland.
12	Geological mapping: Basic concepts; measurements of dip and strike and division of strata into mappable units; and recognition of the main rock types in Icelandic strata and identification of main secondary minerals in hand specimens. This training will be conducted in the lab and on short excursions from Reykjavík.
13–16	Geological mapping in dissected Tertiary and Quaternary strata: The tracing of dykes and the production of a ground magnetic map; and distribution of geothermal manifestations mapped and correlated to geological structures.
17–20	Geological mapping of a geothermal area in an active volcanic rift zone. This includes inspections of the various volcanic rocks in unaltered form, and the study of the various volcanic structures. Methods include shallow temperature surveys in thermal fields. Classification of thermal activity will be covered.
21–24	Report: Geological maps and descriptions will be prepared mainly during the field season as the work proceeds. When the fieldwork has been completed the participants will write reports on their respective areas, including comparison of their data with data from other disciplines such as geochemistry and geophysics. Whenever possible, geological, geophysical and geochemical surveys will be conducted at the same time in the same area.

Borehole Geology

In this course the Fellows will be trained in making geological logs from drill cuttings. They will be introduced to alteration studies and their use in geothermal exploration. They will also be trained in providing geological advice regarding production drilling in geothermal areas, such as decisions on depths of casings and the positioning of injection packers. They will be trained in the recording of aquifers with temperature logs and hydrological methods, and in making geological models of geothermal reservoirs from their own data and data from other disciplines. The training will mostly be conducted in the laboratory with a short visit to a drilling rig.

Week	*Subject*
5	Drilling: General orientation and the function of the geologist at the drilling site. One day will be spent on a drill rig. The topics will cover sampling, correction of sample depths, registration of circulation losses, calculation of penetration rate, preparation of samples, logging, and a brief orientation in well testing. A manual will be provided covering this first week of orientation.
6–9	Petrological logging, Part I: Supervised study of drill-hole data from selected areas, including a study of drill-hole data from type localities; stratigraphic sections and corresponding samples of drill cuttings; and thin sections and reports on mineralogical and petrological investigations in the respective areas.
10–11	Field excursions to the main geothermal fields in Iceland.
12–14	Petrological logging, Part II: The participants will log a drill hole independently and make a standard stratigraphic section. In subsequent studies the participants' own drill holes will be used for exercises. Included in this training will be the selection of depths for casings and sites for the emplacement of injection packers on a petrological basis.
15–17	Alteration: Supervised reading on hydrothermal alteration and the use of alteration studies in geothermal exploration, including practical training in the selection of samples for mineralogical studies.
18–21	X-ray techniques: Theoretical introduction and practical training in running X-ray equipment; and the preparation of samples and the interpretation of films and diagrams. In the course of the training, some samples from the participants' drill holes will be analysed and identified.
22–23	Clay minerology: Introduction including some practice in clay mineral identification. Guidance for further study will be given.
24–26	Aquifers and geological modelling: Training in recording aquifers from temperature logs and hydrological data; and training in making geological models of geothermal reservoirs from borehole logs and data from other disciplines.

Geophysical Exploration

This course requires a solid, prior knowledge of geology, geophysics, physics or engineering. Emphasis is placed on project-oriented training from which the basic knowledge and preliminary experience required to conduct geophysical surveys of geothermal fields is acquired. The essentials of heat-flow studies, ground magnetic surveys and their relation to tectonic structure, DC-resistivity depth soundings and profiling will be covered. During the last six weeks a selection can be made among (a) further training in electrical survey methods such as dipole, MT, EM, AMT and SP, (b) training in gravity surveys and seismic refraction work, and (c) training in seismology with emphasis on microearthquakes and ground noise studies.

Week	*Subject*
5–6	Heat flow: Shallow temperature surveys in geothermal areas; temperature surveys in geothermal wells; heat conductivity of rocks; thermal gradients; and heat output of springs and fumaroles.
7–9	Magnetic surveys and tectonic structure: Surveys of magnetic field anomalies due to faults, dykes and intrusive bodies; methods of interpretation; and rock magnetism and thermal alteration.
10–11	Field excursions to the main geothermal fields in Iceland.
12–14	DC-resistivity mapping of geothermal fields: Schlumberger depth soundings; resistivity profiling; introduction to survey methods, instruments and methods of interpretation; and case histories and background reading.
15–17	Resistivity mapping of geothermal area.
18–20	Interpretation of data gathered during fieldwork; and report of results.
21–27	Option 1 — Specialization in electrical methods: Introduction to dipole-dipole, magnetotelluric, electromagnetic, audiomagnetotelluric and self-potential survey methods, and instrumentation and interpretation: Three weeks of fieldwork followed by interpretation and report.
	Option 2 — Introduction to gravity and seismic refraction surveys: Methods and instrumentation; mapping of gravity anomalies due to tectonic structures and their relation to geothermal activity; mass balance and changes in the gravity field; and seismic refraction survey in a geothermal area.
	Option 3 — Introduction to the study of microearthquakes and seismic ground noise in geothermal fields: Methods, instrumentation and interpretation; operation of portable seismometers in a geothermal fields; and location of earthquakes and sources of ground noise: Interpretation and report.

Borehole Geophysics

The training will cover the essentials of geophysical measurements in boreholes used for geothermal investigations, with the main emphasis on pressure and temperature measurements, but including resistivity, SP, caliper, porosity and density logs. The purpose of this course is to provide practical experience for the planning and execution of the measurements necessary to obtain adequate information on: geological structure, the location of aquifers, hydrological characteristics, chemical composition of deep water, well performance and modelling of geothermal systems. To achieve this, the course is divided in two parts. The first 8 weeks consist of practical and theoretical instruction in various methods. The last 7 weeks are devoted to the design, execution and interpretation of the results of a logging project under the supervision of an instructor. After 23 weeks, it should be possible to extend the course to some specialized field of logging.

Week	*Subject*
5–7	Down-hole measurements and flow-rate measurements from wells: Practical exercises in measurements and interpretation of data. Pressure, temperature, differential temperature, self-potential, resistivity and caliper logs will be treated.
8–9	Well completion and stimulation: The purpose of completion tests, location of aquifers, selection of sites for injection packers, well transmissivity and well stimulation; and practical training in pump or injection testing.
10–11	Field excursions to the main geothermal fields in Iceland.
12–14	Practical training in the interpretation of pressure, temperature, and resistivity logs using case histories.
15–16	Practical training in performing down-hole measurements.
17–18	Design of a logging project for selected fields or a single well. The design proposal should include the purpose as well as economical considerations of the project.
19–20	Execution of the proposed logging project in the field.
21–23	Interpretation and preparation of a report on the logging project.

Reservoir Engineering

The purpose of this course is to provide practical training in the reservoir engineering methods required to obtain information on the hydrological characteristics of a geothermal reservoir, and to use this information to assess and study the feasibility of a reservoir. The course will cover both surface and down-hole measurements and the interpretation of well tests. Seven weeks will be devoted to the design, execution and interpretation of an individual project.

Week	*Subject*
5–7	Down-hole measurements and flow-rate from wells: Practical exercises in measurements and interpretation of data. Pressure, temperature, differential temperature, self-potential, resistivity, and caliper logs will be treated.
8–9	Well completion and stimulation: The purpose of completion tests, location of aquifers, selection of sites for injection packers, well transmissivity and well stimulation; and practical training in pump or injection testing.
10–11	Excursions to the main geothermal fields in Iceland.
12–13	Reservoir properties: Supervised reading and seminars on the properties of fluid flow in pipes and porous media; and properties of fluids and rocks.
14–15	Well performance: Analysis of injection tests, draw-down tests and pressure build-up; and Theis, Jacob and Horner methods.
16	Practical training in the performance of well testing.
17–18	Construction of a well-testing project for a selected reservoir or a single well.
19–20	Execution of the well-testing project in the field.
21–23	Interpretation of the results obtained in the well-testing project and preparation of a report on the results.
24	Orientation concerning parameters used in modelling geothermal systems, including case histories.
25	Simulation of simple geothermal systems.
26	Supervised reading and seminars on different approaches to the assessment of geothermal reservoirs (Bodvarsson, NZ, Muffler-Cataldi and LBL methods), including case histories.
27–28	Practical training in the assessment of a geothermal reservoir.
29–30	Feasibility study of a geothermal field.

Chemistry of Geothermal Fluids

The objective of training in this field is to provide insight into the role of thermal fluid chemistry in geothermal exploration and exploitation, including sampling, analysis of major constituents and interpretation of the results. Towards the end of the training period, a special exercise on a geochemical problem will be undertaken and a final report prepared.

Week	*Subject*
5–7	Chemistry and chemical thermodynamics: Lectures, tutorials and supervised reading in the chemistry and chemical thermodynamics of geothermal fluids with emphasis on the physico-chemical changes occuring during the flow of fluids up boreholes and in pipes and equipment.
8	Sampling: Lectures and practical exercises on sampling techniques and methods of analysis of major components. The subject will be dealt with sufficiently to provide an understanding of sampling and analysis, but not necessarily enough to permit independent work.
9	Deposition: Additional chemistry and chemical thermodynamics as related to various deposition problems and the distribution of gases between phases.
10–11	Field excursions to geothermal areas.
12–14	Sampling and analysis of geothermal fluids: Practical exercises with training limited to major gas components and major dissolved solids using conventional methods that do not require high-quality laboratory facilities.
15–17	Tutorials and training in topics related to the applicability of chemical geothermometers and the use of geothermal fluid chemistry to obtain indirect information on underground flow of hot water and flashing.
18–21	Influence of mineral equilibria on fluid chemistry: Training in evaluation with special emphasis on studies of water and gas chemistry in geothermal exploration. Evaluation and presentation of data which have a bearing on design assumptions for geothermal utilization will also be included. This involves the gas content of geothermal steam and various corrosion, deposition and environmental problems.
22–32	Execution of a practical project which illustrates the role of thermal water chemistry in one of the following topics: surface exploration, exploratory drilling, assessment of reservoir characteristics, or monitoring well-discharge chemistry in areas under exploitation. This project can be based on data from the participant's country and co-ordinated with the analytical training during weeks 12–14. The project ends with a report.

Geothermal Utilization

The purpose of this course is to give advanced training in the use of geothermal resources. The course will deal with the mechanical and chemical engineering aspects of geothermal fluids in pipes, equipment and plants. The feasibility of projects and environmental factors will also be considered. The training will aim at providing sufficient experience and knowledge to understand the engineering required in geothermal utilization projects and in carrying out some of the tasks independently. A university degree in engineering is a prerequisite.

Week	*Subject*
5–7	Chemistry and chemical thermodynamics: Lectures, tutorials, and supervised reading in the chemistry and chemical thermodynamics of geothermal fluids with emphasis on the physico-chemical change occuring during the flow of fluids up boreholes and in pipes and equipment.
8	Sampling: Lectures and practical exercises on sampling techniques and methods of analysis of major constituents. The subject will be dealt with sufficiently to provide an understanding of sampling and analysis, but not necessarily enough training to permit independent work.
9	Deposition: Additional chemistry and chemical thermodynamics as related to various deposition problems and the distribution of gases between phases.
10–11	Field excursions to geothermal areas.
12	Fluid flow and heat transfer: Lectures, tutorials and supervised reading. Review of fundamentals as related to geothermal situations.
13–14	Collection, transmission and disposal of thermal fluids: Lectures, tutorials and supervised reading. Fundamentals of fluid flow and heat transfer applied to geothermal hardware; and thermal and mechanical design of piping systems, steam-water separators, pumps and silencers.
15–16	Corrosion, deposition and environmental impact: Lectures, tutorials, supervised reading and practical exercises. Fundamentals of corrosion and deposition in geothermal situations; training for corrosion and deposition tests and sampling of geothermal fluids; examination, measurements and interpretation of corrosion and deposition experiments; and fundamentals of the environmental impact of geothermal fluids.
17	Reservoir performance: Lectures, tutorials and supervised reading. Examination of the requirements for various uses and their relation to the performance of individual wells.
18–20	Geothermal plants: Lectures, tutorials and supervised reading. Engineering aspects of thermal, power and combined plants, turbines, power cycles, heat exchangers, cooling towers, condensers, ejectors, driers, etc.; and consideration of the feasibility of geothermal energy projects.
21–32	Practical exercises: Participation in several, or one, current projects of the National Energy Authority, the University of Iceland, engineering offices and major users of geothermal energy. The practical training ends with a general report.

Drilling Technology

The aim of this course is to provide engineers with the information and on-site training necessary to prepare them for work on their own as drilling supervisors. The course begins with two weeks of lectures and discussions on the technique and equipment used in drilling for hot water and steam, followed by six weeks of practical training on the drill site to provide a feeling for the real work involved in geothermal drilling. There are rigs of different sizes used for different drilling tasks and there will be an opportunity to observe equipment of different sizes in operation. After on-site training there will be seminars on the different equipment and methods in use and on the selection of equipment appropriate for each task. Successful completion of this training course will enable participants to plan and supervise geothermal drilling in their countries. The course is not training for the task of drilling itself but for the supervision of geothermal drilling.

Week	*Subject*
5–6	Introduction: Rotary drilling equipment, including special reference to hot water and steam drilling with discussions of case histories.
7–9	Training on a medium-size exploration drilling rig: The participants will become acquainted with equipment and its use during actual drilling in geothermal areas.
10–11	Field excursions to the main geothermal fields in Iceland.
12–14	Training on a production-size drilling rig.
15	Preparation and planning of a site: Training continued with supervised reading and seminars. Selection and preparation of drill sites, including access roads and water supply; design of a drilling programme; and cost estimation.
16	Selection of drilling equipment: Drill pipe, drill collars and rock bits; and safety equipment (blow-out preventers and alarm systems).
17–18	Drilling techniques: Drill collar weight and rotating speed; hydraulics in drilling; straight-hole and directional drilling; drilling in unconsolidated layers and prevention of cave-ins; fishing tools and their use; setting of casings and liners; cementing; and lost circulation and its role in estimating well output.
19–20	Well completion practices: Production tests by step injection; use of open hole packers and thermal fracturing; workovers; and well stimulation.
21–22	Drilling rig management and maintenance: Drilling contracts; and drilling with own equipment versus contracting drilling.

From 1979, training in geological exploration, borehole geology, geophysical exploration and chemistry of thermal fluids would be available. Preparation for the drilling technology and borehole physics courses would require one year or more and probably longer for the geothermal utilization and reservoir engineering courses. This is especially true of reservoir engineering, which has been developing in Iceland only over the last year or two.

It is expected that five participants can be accepted the first year, beginning in April, and that the capacity can grow to about ten within a few years. The language of instruction will be English.

It must be borne in mind that one of the limitations of operating a training course in Iceland is that the terrain is a result of the volcanic activity associated with the mid-Atlantic ridge, although the exploration and development methods are applicable to most other volcanic terrains. Thus, practical training in Iceland may not be applicable in countries where geothermal activity is in a structurally different environment. It might be desirable, in some cases, that part or all of a training course be carried out with geothermal institutions in countries with geological conditions different from those in Iceland. This would call for co-operation and co-ordination among the existing UN-sponsored geothermal schools as well as with geothermal institutions such as the Ente National per l'Energia Elettrica in Italy, the US Geological Survey in Menlo Park and corresponding institutions in Hungary and France.

VII. RECOMMENDATIONS OF THE WORKSHOP

Recommendations with Regard to Geothermal Exploration*

It is recognized that there are three kinds of formalized international geothermal training programmes:
(a) academic courses;
(b) short, comprehensive, group-oriented courses; and
(c) training concentrated on an individual and his speciality.
In addition, there are regional or topical seminars, on-the-job experience, and academic training leading to a degree in a traditional discipline.

The existing and proposed international geothermal training programmes show a healthy diversity in structure, scope, approach, duration and focus. This is valuable in allowing managers from developing countries to select the training that best fits the needs of their personnel and countries at a particular time. This also allows flexibility in the evolution of training programmes to meet changing conditions and requirements. Hence, a need is seen for all of the existing and proposed training programmes and support is recommended for their continuation.

There is need for co-ordination of these programmes in order to avoid gross duplication and conflicting methodologies, and to ensure maximum effectiveness. This co-ordination should be both among the programme directors and between the directors and managers from developing countries. Such co-ordination could follow various routes, including:
(a) the development of a common training manual;
(b) the exchange of text materials;
(c) visiting lecturers;

* The report of a working group organized under the chairmanship of L. J. Patrick Muffler of the US Geological Survey, Menlo Park, California, USA, to consider the question of geothermal energy training with regard to exploration, including such aspects as borehole geology, chemistry of thermal fluids and various types of geological environments.

(d) regional sharing of field training;
(e) the co-ordination of information to developing countries; and
(f) review and supervising activities.

It is recommended that this co-ordination be implemented by the creation of an international geothermal studies board, under the aegis of the appropriate agency of the United Nations, which would be composed of perhaps ten persons, including the leaders of the programmes in Japan, Italy, New Zealand and Iceland as well as managers from developing countries and which would meet perhaps once per year.

Recommendations Concerning Geothermal Development*

On the basis of the descriptions of courses offered, and training needs to be met, consideration was given to three questions.

First, while training at various levels is necessary, should the workshop concern itself with levels other than professional? The answer to this question is no, because the United Nations University's basic responsibility lies at the professional level. Nevertheless, it is agreed that training at technician and skilled or semi-skilled workman levels is necessary to provide adequate support to the professionals whose training is discussed at the workshop.

Apart from the matter of the Iceland course, what, in general, can the UN University's role in geothermal training be? Briefly, although it is hard to tell at this point, there is a possibility that it could perform a co-ordinating role among the various courses offered. This would not be undertaking anything in competition with the work of other UN agencies such as the seminar training being conducted in Central America.

Finally, and most importantly, does the Iceland course fill a gap in training already being offered? The consensus reached is that the course would, indeed, fill such a gap. However, there is some concern about the proposed length of the course, from 22 to 32 weeks; six months is considered to be the maximum length of time trainees can remain away from their jobs. On the other hand, there is the understanding that the course length in each of the disciplines is designed to be flexible and, indeed, would be tailored to the trainee taking the course.

Concerning the selection of trainees, it is considered desirable that preference be given to candidates from countries where geothermal exploration or development is already under way. It is also considered desirable that the trainees themselves have some experi-

* The report of a working group organized under the chairmanship of Richard S. Bolton of the New Zealand Ministry of Works and Development to consider the question of geothermal energy training with regard to its development and utilization, including such aspects as drilling technology, borehole geophysics, reservoir engineering, and utilization for energy production.

ence in their own discipline. Among other things, this would influence the structure of the course in which they participate.

The suggested method of selection is to send travelling selection board members to the various countries wishing to recommend candidates. Their function would be to assess both the need for training and the suitability of the candidates recommended for training. Later, they would also be expected to provide feedback on the effectiveness of the training.

Recommendations for Practical Training in Developing Countries*

Geothermal exploration and development activities require the participation of five types of workers whose contributions can be characterized according to function: data gatherers, data interpreters, equipment operators including drillers and mechanics, design engineers, and managers.

Present training courses train only data interpreters and design engineers but not the other three types of geothermal workers. Furthermore, the training which data interpreters receive in any one country is not adequate because geothermal reservoir conditions vary from field to field and a wide breadth of international experience is required to make correct interpretations of exploration data. Therefore, travelling fellowships should be given to trainees who will eventually be doing data interpretation.

Of the remaining three types of geothermal workers to be trained, managers cannot be produced by a short training course and a few years' experience but require many years of on-the-job experience. On the other hand, data gatherers and equipment operators are not specialized professionals but technicians, drillers and mechanics.

In many developing countries, due to the remoteness of geothermal sites that require the technology used to be serviceable locally and to the lack of available back-up technology, particularly of skills and spare parts, there is a more serious need for technicians, drillers and mechanics than for professionals. Professionals cannot function without technicians, drillers and mechanics. If these support personnel are expatriate, the costs are high because they are required for long periods. Professional data interpreters and design engineers are much less costly even if they are from abroad, because their tasks can be completed in short periods once the basic work has been prepared by the local technicians, drillers and mechanics. Thus, to concentrate on training specialized professionals tends to distort, not to solve, the problem of developing geothermal resources in developing countries in an economical way.

Unfortunately, the basic responsibility of the UN University lies at the professional level

* From a presentation by James R. McNitt, Senior Adviser to the UN Centre for Natural Resources, Energy and Transportation, and subsequent discussions by participants of the workshop.

and, therefore, the University can do little to correct this situation.

However, taking, for example, drillers, it is possible that the usual manner of drilling training is sufficient, provided geothermal energy development is under way and drilling becomes a continuous operation. It appears that assistant drillers can be trained rather easily and that they can develop with experience into drillers. For those countries which have not reached a level of continuous operation in their geothermal energy development projects, however, a desirable step would be the establishment of regional centres for technician training.

On the basis of the five functions of geothermal energy workers mentioned above, it is suggested that there are really only four main lines of training to consider among the eight lines proposed for the Iceland geothermal training programme: exploration covering geological exploration, geophysical exploration, borehole geology, and borehole geophysics; drilling; reservoir engineering; and utilization including the chemistry of thermal fluids. Assuming this concept to be valid, training following the eight lines may result in over-specialization. However, the ideal solution to this training problem must be compromised by the time available to the participants for training.

Recommendations for Co-ordination of Geothermal Training Programmes*

The importance of the proposal for co-ordination of the various geothermal training programmes is apparent from the wealth of information and ideas that were presented and discussed at the workshop itself. Serious consideration was given to the sponsoring and support of such co-ordination. No extra funds appear to be available at UNESCO or UNCNRET for this activity. Furthermore, this is not the type of activity normally funded by UNDP. Such co-ordination is, however, within the scope of activities of the United Nations University in that it would make a significant contribution to the post-graduate training required in many developing countries for the management of a natural resource – geothermal energy. In view of the institutional and financial capabilities of the UN University in this area, it is proposed that the University be designated the co-ordinating agency.

* From a presentation by James M. Harrison, Consultant to the UN University.

VIII. CONCLUSIONS OF THE WORKSHOP

A. It is recognized that the United Nations system supports, or proposes to support, three types of formalized international geothermal training programmes:

1. a diploma course at the University of Auckland, Auckland, New Zealand, sponsored by UNDP;
2. comprehensive, group-oriented courses at Kyushu University, Fukuoka, Japan, and at the International Institute for Geothermal Research, Pisa, Italy, both sponsored by UNESCO; and
3. a proposed course developed for individuals in appropriate specialities at the National Energy Authority, in co-operation with the University of Iceland, Reykjavik, Iceland, to be sponsored by the UN University.

Less formal activities, also providing important training, are recognized but were not considered in detail:

1. regional and topical seminars, and
2. on-the-job experience.

After consideration of the existing courses and that proposed by Iceland, it is concluded that they cover reasonably well the diversity of general and specialized requirements for training at the professional level. The Iceland course is regarded as an important addition to the existing programmes. It is urged, especially by participants from recipient countries, that the Iceland training programme for individuals be as short and flexible as possible while still adequately improving the knowledge and skills of trainees. It is felt that preference should be given to candidates from those developing countries where geothermal exploration or development is under way, and to those who already have some practical experience in their own discipline.

B. It is recognized that training for professionals cannot be effectively utilized unless a cadre of skilled technicians exists to carry out the activities in the home country.

While the UN University does not have responsibility for technician traning, it is strongly recommended that a way be found to plan and execute training programmes aimed specifically at technicians and skilled workers so that the recipient countries can develop as quickly as practical the full spectrum of capabilities needed for geothermal exploration and development.

C. It is recognized that some means should be provided for co-ordinating existing training programmes and for recommending new and modified programmes. To this end, it is recommended that the UN University establish an international geothermal studies board to provide a forum for the exchange of information on existing and proposed courses. This board would help to ensure that:

1. the courses meet the needs of the recipients;
2. the candidates from recipient countries are informed about all the courses and can apply for those most suitable to their needs;
3. courses of training for technicians and skilled workers are available, or the needs for such courses are made known to the appropriate agencies;
4. suitable training manuals are prepared;
5. there are exchanges of text material, lecturers and students;
6. all course directors are aware of the latest techniques and technology; and
7. the total spectrum of activities is evaluated to determine whether the courses meet the needs of recipient countries, and whether recipient countries take advantage of the new knowledge and skills acquired by students returning from such courses.

It is suggested that the board be composed of 10—12 members including the director of each course, a representative of each sponsoring agency, and representatives of selected recipient countries and, as appropriate, of agencies or countries not directly involved in the formal training programmes. This board could meet at intervals of perhaps 12—24 months to review the world situation with regard to training in the exploration and development of geothermal energy, and to make recommendations to the appropriate agencies on needs for the future.

APPENDIX I: OPENING ADDRESS

MR. VILHJÁLMUR HJÁLMARSSON
MINISTER OF CULTURE AND EDUCATION OF ICELAND

Ladies and Gentlemen,

On behalf of the Icelandic government, I welcome you all to the workshop that is now beginning here at Laugarvatn. A special welcome is extended to the representatives of the United Nations, UNESCO and the United Nations University and to other participants from abroad, some of whom have come a very long way to deal with matters we consider of great importance.

The United Nations University has been assigned an important task with bearing on human welfare, not the least of which is helping to solve practical problems relating to developing countries. Iceland supported the idea of the establishment of the University early on and expressed interest in participating in its activities. In view of this, the Icelandic government decided in March of this year to submit to the United Nations University a proposal setting down suggestions for a training programme for United Nations University Fellows. This programme would consist of training in the exploration and development of geothermal energy. The main reasons for this proposal are that we believe that through such co-operation, Iceland has an opportunity to make a contribution to international progress in an important area where we think we may have something to offer, although financial considerations obviously impose certain limitations on our activities in this field as they do in other fields. At the same time, we realize that our own research would benefit through contact with specialists from abroad which would follow from such co-operation. It is our hope that this conference will contribute to a clarification of how this co-operation can be effectively arranged.

Iceland has often been called a country of contrasts, especially when one considers the unusual co-existence of fire and ice which has left its mark on the features of the country. In recent times, both of these elements have been harnessed as energy sources to a certain extent. In fact, use has been made to some extent of geothermal water throughout the 1,100-year history of the country. However, it is only recently that modern science and technology has made it possible to put this source of energy to extensive and diverse uses. We have already experienced the great value of this natural resource, and would like to be able to contribute to an increased knowledge of its utilization wherever favourable conditions exist. Therefore, we welcome the UN University's decision to organize the workshop during the next few days, and I express the hope that the outcome of its work will be successful.

APPENDIX II: LIST OF PARTICIPANTS

International

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