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UNITED NATIONS CONFERENCE ON NEW AND RENEWABLE SOURCES OF ENERGY
Technical Panel on Geothermal Energy
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DRAFT FINAL REPORT

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I. INTRODUCTION

A. Purpose of the report

1. The Technical Panel on Geothermal Energy of the United Nations Conference on New and Renewable Sources of Energy met twice, from 10 to 14 December 1979 in New York, and from 3 to 7 November 1980 at Geneva, respectively.

2. The Panel consisted of 11 members selected by the Secretary-General of the United Nations from among the candidates designated by Governments (see annex I). Its terms of reference were set forth in annex II of document A/34/585 and were based on General Assembly resolution 33/148 of 20 December 1978. They were subsequently expressed in more specific terms at the second session of the Preparatory Committee, held at Geneva from 14 to 25 July 1980, in particular by decision 5 (II) (A/35/43 (Part II)) dealing with the "reports of the technical panels" and decision 2 (II) dealing with the "*ad hoc* groups of experts".

3. The documentation used for preparing this report, including the interim report of the Technical Panel on Geothermal Energy, established at the end of its first session, appears in annex II.

4. Annex III provides a bibliography of the existing studies on geothermal energy, in accordance with the request made in decision 5 (II).

5. This report, the report of the seven other technical panels and the reports of the consultants on peat and energy from draught animals, will serve as a basis for the six *ad hoc* groups of experts established to study financing, the exchange of information, research and development and the transfer of technology, education and training, rural energy, including the use of energy in agriculture, industrial questions, including the use of energy in transport and related sectors. The reports of all the technical panels, *ad hoc* groups of experts and individual consultants will be used for preparing the over-all report required under decision 5 (II).

B. General characteristics of geothermal energy

6. Geothermal energy is generated by the diffusion of the globe's internal heat through the earth's crust. It is this heat which the different procedures for harnessing geothermal energy propose to use.

7. The energy flux passing through the earth's surface has an average magnitude of 50 to 100 kW/km^2. It may show major local anomalies.

8. A thermal gradient exists between the deep zones of the earth, at a temperature much higher than 1,000°C, and the surface of the earth. The average value of this gradient is 25°C/km in the continental zones.

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9. The temperature gradients and thermal fluxes are greatest in well-defined zones, representing approximately 10 per cent of the emerged land. These zones are characterized by considerable seismic activity and by volcanic activity. They are organized in belts, such as the "Pacific fire belt", and correspond to the limits of the continental plates.

10. Geothermal energy is continuously generated by the flow of heat from the earth's core. It is therefore a renewable form of energy. Except for geothermal energy from the highly active magmatic zones, however, the flow which is harnessed is usually greater than the input flow of heat. The heat stored in the subsoil is then used. This kind of operation must therefore be regarded as the utilization of a finite reservoir, i.e. utilization for a limited period of time followed by a variable period required to replenish the reservoir.

11. At the present stage of technology, a drilling depth of 3,000 m is considered the economic maximum for the harnessing of geothermal energy. The potential available about the year 2000 should, on the other hand, include all the target areas situated at depths of less than 5,000 m. An over-all estimate of geothermal energy resources yields the figure of $14.5 \cdot 10^{25}$J for emerged lands as a whole ($4 \cdot 10^{13}$GWh) at the beginning of the third millennium.

12. The harnessing of geothermal energy requires the heat available in the earth's crust to be brought to the surface, so that it can be utilized there. This has several implications. The first is that geothermal energy must be obtained by drilling. The second is that it must be carried by a heat-transfer fluid. Different uses will be conceivable, depending on the thermodynamic level of this fluid at the wellhead.

13. The usual practice followed in classifying the different categories of geothermal resources is to distinguish three different thermodynamic levels: the low level, at temperatures under 100°C; the intermediate level, between 100 and 150°C; and lastly, the high level, above 150°C.

14. The geothermal energy sources most easily harnessed, and therefore called "conventional sources", are the high-temperature fields associated with recent volcanic activity, the low-temperature fields also associated with recent volcanic activity and, lastly, the low-temperature fields found in the deep zones of sedimentary basins.

15. Other potentially abundant sources are known but are not being harnessed for the time being, and their development raises technical problems not all of which have yet been solved.

16. Hot and dry rock masses contain a large quantity of sensible heat. The absence of natural porosity, and hence of water, which under normal circumstances acts as a heat-transfer fluid, means that the potential energy cannot be easily recovered. The harnessing of these resources therefore requires a prior mastery of the techniques of fracturing and maintenance of improved permeabilities. This problem is all the more important to solve because porosity usually diminishes with depth (20 per cent at the surface and 2 per cent at 5,000 m) and because the most energy-productive and thermodynamic levels are precisely those situated at the greatest depths.

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17. The high-pressure zones are frequently found in sedimentary formations. These are lenses of pervious porous formations isolated between two strata of impervious formations and contain fluids brought to abnormally high pressures and temperatures as compared with the usual conditions. The magnitude of these resources is not well known, and they create difficult technological problems.

18. Still other sources are conceivable, such as the magmas closest to the surface of the ground or, at the other extreme, fields dependent on a very deep convective current of water.

19. Geothermal energy, like water power, must be used where it is available. It cannot be transported except in the form of a derived energy, and such transport is costly. This situation almost always prevents a geothermal facility from being sited elsewhere than in the vicinity of the user(s). The presence of a market in the immediate vicinity of the geothermal resource is a decisive factor in determining its economic viability.

20. Moreover, for a given market, geothermal energy is in competition with other sources of energy. The decision to harness it must be based on economic criteria. Most of the cost of geothermal energy consists of fixed costs, i.e. financing expenses and capital amortization. The economic viability of geothermal energy is therefore very sensitive to the cost of financing, and the more the facilities are regularly used at values close to their maximum capacity, the more viable they will be.

21. Exploration for geothermal energy, however, also bears some resemblance to exploration for oil. In both cases, heavy investments in drilling are required. But if deep drillings do not reveal the existence of conditions necessary for the economic harnessing of geothermal energy, the investments will have to be written off as a loss. This is a risk which not all decision-makers can take, unless they have specific guarantees or insurance.

C. Historical background of the utilization of geothermal energy

22. Man's use of geothermal energy goes far back in history. In the earliest times, hot springs were used as baths for near-by populations. At the present time thermal facilities dating back several thousands of years are still in operation. In some regions, the inhabitants cook their food by dipping it directly into springs of boiling water.

23. Natural hot-water springs have also been used in Europe since the Middle Ages to provide household hot water and to help to heat houses.

24. It was not until the beginning of this century that the first attempts were made to produce electricity from geothermal energy. It was at Larderello in Italy that the first experimental power station was built in 1904 using the steam emerging from fissures in the earth. The first full-size power station was completed in 1913 in Italy. Thereafter a number of countries, including the United States of America, Indonesia and Japan, followed that example during the 1920s and tried to produce electricity from geothermal energy.

25. Many countries subsequently tried to develop this type of application of geothermal energy, and in 1976 the installed power capacity from geothermal sources was 1.6 GW.

26. The rise in the price of petroleum following the 1973 crisis led to reconsideration of existing sources of energy. In the case of geothermal energy, interest in electricity production and in non-electrical uses increased.

27. In several countries schemes were carried out to exploit low-temperature geothermal sources. There are now complexes having between 2,000 and 3,000 housing units and their common facilities whose energy supply for domestic heating and hot water comes from bore-holes sited in the grounds of the complex. Geothermal energy is largely replacing domestic fuel oil, gas or electricity for these uses, resulting in substantial savings for the consumers.

28. Agriculture has long been availing itself of geothermal energy as a supplementary heat source for greenhouses in some especially favourable cases. This application of low-temperature geothermal energy is spreading outside the regions in which it started and making headway in other sectors of agriculture: heating of cultivation beds for mushrooms, air supply for stables, fish farming, drying of organic matter, fermentation.

29. Agricultural and food industries need higher temperatures and utilize intermediate- or high-temperature geothermal energy. Temperatures of 120°C are required for dehydrating syrups and sugar crystallization. Accelerated drying of agricultural produce requires temperatures of 140°C, and the drying of wood and paper pulp still higher temperatures.

30. Industry could use geothermal energy instead of all the low-energy fluids it now uses for heating purposes. As it is, geothermal energy is hardly used except for dehydration processes (prefabricated fine-aggregate cement mortar parts, diatomaceous earth, concentration of saline solutions).

31. Between 70°C and 180°C geothermal energy can also be used for refrigeration or ice-making in an ammonia absorption cycle. Other cycles are also feasible for this application.

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II. GEOTHERMAL ENERGY SYSTEMS LIKELY TO BE SIGNIFICANT IN THE NEXT 10 TO 20 YEARS

A. Low-temperature geothermal energy

32. Low-temperature energy is the most widely accessible of all geothermal resources. There is no country, however small, without some potential. Monaco's potential - and it has the smallest geothermal reserves in the world - amounts to 1 thermal GW for 50 years. Unfortunately, not all of that energy is accessible and only a fraction of it can be extracted. If we take:

A = the area whose potential is to be estimated

h = depth

Cv = equals specific heat per unit volume of subsoil

Th = temperature at depth h

To = temperature at ground level

Q = geothermal energy

then the geothermal energy stored between depths h_1 and h_2 will be equal to

$$Q_{1,2} = A. \int_{h_1}^{h_2} Cv\ (h).\ (Th - To)\ dh$$

This is the formula to be used to estimate resources <u>in situ</u>, whatever their thermodynamic level.

33. In order to ascertain the volume of energy actually available to the user, several output coefficients must be introduced in order to take account of reservoir exit temperature (Lr), losses through reduced pressure, friction or leakage during production (Lp) and surface losses between the wellhead and the point at which the geothermal energy will be used (Lu). Available energy (Qa) will therefore be:

$$Qa = Lr.\ Lp.\ Lu.Q$$

34. The factor Lr allows for the fact that the reservoir temperature drops during production and that once a certain temperature threshold is reached, exploitation is no longer economic and must be halted. If T_1 is the initial reservoir temperature, T_2 exit temperature and To surface temperature, we have:

$$Lr = \frac{T_1 - T_2}{T_1 - To}$$

35. The factor Lp can be determined only by experience in each specific case. It takes into account the internal characteristics of the reservoir, the thermal conductivity properties over distance in the geological horizon that is being

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exploited, the flow characteristics of geothermal fluids within the rock formation and the inevitable exchanges between hot fluids and the earth surrounding the bore-hole as the fluids rise to the wellhead. Available data for Lp give values ranging between 0.01 and 0.8. The average is 0.3.

36. The factor Lu represents heat loss during transport within the delivery system and also incorporates the output of the primary exchanger through which the geothermal fluid flows. That factor varies according to the distance between the geothermal bore-hole and the point of use and according to the process for recovering the energy from the geothermal fluid.

37. Exploration for a low energy geothermal deposit not associated with vulcanism is very similar to oil exploration. The purpose is to find an underlying stratum formed of pervious rocks, filled with water and situated at such a depth that the geothermal gradient requires it to have a temperature above a specified threshold prescribed by technical and economic considerations.

38. Remote sensing has nothing specific to offer in surveys having these objectives, since there are no indications at ground level. Familiarity with the geology of the region, in contrast, makes it possible to locate basin boundaries and predict the extent and depth of zones favourable for prospecting. Unlike hydrocarbons, geothermal deposits of the type being considered are generally large in extent (several hundreds km^2) and have characteristics which vary relatively little within a given deposit. Again, unlike hydrogeology, which requires maximum content of dissolved salts, geothermal energy is compatible with solutions having a very high content of minerals. The effect of these concentrations is not neutral, however, and they affect the cost of the energy finally produced.

39. Once the summary of the geological characteristics of the basin has identified the objectives, scientific intuition must be corroborated by drilling. Only by drilling is it possible to ascertain exact temperature values and the flow volume and composition of the fluids. It is at this point that the main risk of loss occurs. If the measured parameters do not justify the conclusion that exploitation of the deposits is economic, exploration must be continued at other points in the basin. One drilling failure is never wholly useless, inasmuch as it adds to general knowledge of the subsoil. The financial loss it represents, on the other hand, can be prohibitive in a developing economy.

40. In the majority of cases, however, geothermal exploration is not the first exploration effort in a given basin. In general, petroleum exploration has usually preceded it in drilling. That drilling will have produced measurements of porosity, permeability, temperature and fluid composition for the whole of the area involved. Accordingly, the basic data are usually available. However, in the absence of legislation providing otherwise, that information is a trade secret and can be obtained only by purchasing documents that are useful to the oil company concerned and are in its possession. Where the law so provides, that information is communicated to the Government, which publishes it as soon as collected. Such legislation is very helpful in reducing the cost of low-temperature geothermal exploration in sedimentary formations. The success rate of geothermal drilling in a well-surveyed zone is about 0.9 to 1.

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41. The basic plant for this type of geothermal production consists of two bore-holes, one producing and the other reinjecting, and a set of exchangers. The geothermal fluid, having given up its heat, is reinjected through the second bore-hole in order to recharge the aquifer, so that no equipment needs to be provided for the treatment of effluent.

42. The cost of low-energy geothermal production is made up largely of capital costs. For example, the geothermal plant installed in the Paris basin required the following investment:

	$US
Feasibility studies	60,000
Bore-holes (2), 2,000 m	3,000,000
Titanium exchangers	500,000
Reinjection pump and piping	250,000
TOTAL	3,810,000

It is interesting to note that this geothermal plant was intended to supply domestic heat and hot water for communities having about 3,000 housing units each. The cost of the distribution system and of adapting boilers amounted, depending on circumstances, to between $US 1.2 million and $US 2.5 million.

43. Low-energy geothermal production relies on modern, highly specialized technology which is accessible only to institutions with sizable technical and financial capacity. It is accordingly a relatively unfamiliar form of energy, the more so because it is not associated in the public mind with any spectacular phenomenon, unlike the geothermal energy associated with vulcanism. On the other hand, it is a "soft" form of energy. It lacks the quality of uncontrollable brute force customarily associated with other sources of energy. It is, therefore, a reassuring form of energy and for that reason is well accepted or even preferred to competing sources.

44. The impact of the use of low-temperature geothermal energy on the environment is small but not negligible. The most important type of potential pollution is water pollution. Geothermal fluids are normally water with some content of mineral salts. These salts are almost always chlorides, sulphates and carbonates, the chief cations being Na, Ca, K and Mg. Silica is often associated with them. None of these chemical substances creates a toxic hazard, but when concentrated they may have dangerous effects on fauna and flora - should the geothermal fluids be discharged directly into a river, for instance - by raising the osmotic pressure of the environment. In a less visible form, the risk of polluting subsurface ground-water must also be given serious thought. If the casing of geothermal bore-holes is badly installed, the danger of connecting the geothermal aquifer with a fresh-water horizon, and thus of the latter being polluted by the former, arises. Normally this risk is obviated by taking special care with casing and cementing.

45. Visual pollution is insignificant. Equipment such as reinjection pumps, exchangers and pumps for the secondary thermal fluid distribution requires no arrangements different from those applicable to comparable industrial installations. At ground level the bore-holes themselves take the form of a cemented trough from which there emerges a short "Christmas tree" connected by piping to the building containing the equipment described above. The trough and the wellhead take up no more than the 400 m^2 needed for maintenance operations on the bore-hole. In order to save space, the extraction and reinjection bore-holes are generally placed side by side and staggered so as to leave a minimum distance between the zone where the geothermal aquifer is recharged with cold fluid and the point at which hot fluid is pumped.

46. It is not unusual for gases to be associated with the pumped fluids. These gases may cause air pollution if the gas is hydrogen sulphide or methane. The quantities involved are usually very small, and in most cases prevailing standards permit direct discharge into the atmosphere. In some cases a flare or a gas scrubber may be required.

47. There is no significant thermal pollution. The whole design of the installation is intended to keep losses to a minimum, so as to recover the maximum of the heat contained in the geothermal fluid. Neither is there any subsidence. The depth at which the fluids are pumped, at least 1,500 m, causes a slight fall in hydrostatic pressure at the level of the geothermal aquifer, but the lithostatic pressure is such that decompression phenomena are imperceptible and cause no measurable sinking of the soil in a vertical line through the geothermal deposit being exploited. There is likewise no noise pollution except when the well is being sunk, when drilling machinery working around the clock causes noise levels of 80-90 dBA.

48. Geothermal energy has the advantage of needing no storage. The geological horizon from which the fluids are pumped itself provides heat storage. The energy is permanently available, and production may be interrupted at any time and for any period without affecting subsequent production in any way. But fixed production costs still represent the bulk of the cost of such energy. For a suitable return on investment, facilities must operate as close as possible to their maximum production capacity in the first few years of operation, at least until the original capital costs have been amortized. Production is characterized by both great technical flexibility and high economic rigidity.

49. The scale of application of low-temperature geothermal energy is restricted by maximum well output. The flow rate is of the order of 200 to 500 m^3/hour per well, corresponding to a thermal power output of about 10 MW, which means that a maximum of 3,000 housing units, including shared supply facilities, can be served by a single installation. For larger complexes, the basic module must be repeated at a sufficient distance from the first to avoid the risk of interference between the two systems. On the other hand, there is no technical lower limit to the thermal power taken from a low-temperature geothermal installation. Low-temperature geothermal energy should increase in economic value in comparison with the cost of alternative energy sources.

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B. High-temperature geothermal energy

50. As distinct from low-temperature geothermal energy, which is designed only to use the sensible heat of geothermal fluids for purely thermal applications, high-temperature geothermal installations seek to derive mechanical or electrical energy from the enthalpy of the geothermal fluid. The amount of mechanical energy recoverable is limited by the second law of thermodynamics. A new output parameter must be added to those already mentioned for low-temperature geothermal energy. Using the same notation, with Fm denoting the new parameter that specifies the maximum fraction of the available energy which can be transformed into mechanical energy and Ln denoting natural logarithms:

$$Fm = 1 - \frac{To(LnT_1 - LnT_2)}{T_1 - T_2}$$

The available mechanical energy would thus be:

$$Qma = Fr.Fp.Fu.Fm.Q$$

51. From the technical point of view, the only well-developed method for converting heat into mechanical energy is the use of a gas to do work. In high-temperature geothermal energy the gas used is natural water vapour. The method is a fairly crude one and has the following characteristics.

52. The steam content of the geothermal fluid should be as high as possible. The temperature of the fluid, depending on the method used (exhaust direct to the atmosphere or condensing of the steam), should be significantly higher than its dew point at atmospheric pressure. A temperature of 150°C is recognized as the minimum.

53. In continental areas, this temperature value is found only at depths below 5,000 m. The amount of fluid, which depends on porosity, is relatively small, and ground permeability is seldom good. The conditions for finding high-temperature geothermal sites in such areas are therefore seldom met. On the other hand, at the belt zones of continental plates distinguished by seismic and volcanic activity, such temperatures are often found much closer to the surface because of the combined effect of a stronger geothermal flux and a higher geothermal gradient.

54. A location so close to the surface means that geothermal indicators may be present at the surface. These may be known to the people in the areas in which they appear. Systematic prospecting is also possible. Every thermal anomaly is a stronger emitter of infra-red waves than the land around it, and aerial photography in a suitable range of wavelengths can be used to prepare a map which is an important first element in prospecting rationally for high-temperature geothermal sites. The maximum resolution of currently available satellite-mounted remote-sensing systems in the infra-red range is not sufficiently high to make a satisfactory contribution to geothermal prospecting.

55. Bore-holes for high-temperature geothermal applications require a technology different in certain respects from that used by the oil industry. They are generally

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drilled in volcanic areas and reach relatively small depths. The ground penetrated is heterogeneous, soft regions alternating with very hard basalt layers. The rock cuttings removed by the drill are particularly abrasive. Moreover, the frequent occurrence of highly pervious zones with no strong hydrostatic pressure poses tricky problems for the circulation of the drilling mud. The temperatures associated with the small depths give rise to a difficulty of another kind. To ensure that the drilling takes place in safety, the well must be equipped with a blow-out preventer capable of withstanding an eruption of geothermal fluids. By definition, however, such fluids are at high temperatures and pressures. In oil drilling, the casing is normally anchored in the ground firmly enough to withstand such conditions by the cemented length, since the temperature levels in question occur only at depths of several thousand metres. In geothermal bore-holes the depths are of the order of 600 to 900 m, and the shorter cemented length must be compensated by increased vigilance.

56. On the basis of the experience gained in high-temperature geothermal fields, over-all capital costs lie within the following range:

	Cost, $US/kW	
	Lower value	Upper value
Exploration	7	19
Fluids production	150	500
Separation and collecting network	30	240
Electric power station . . .	400	750
Effluent treatment and disposal	30	200
	617	1,709

57. The cost of the energy itself lies between 0.015 and 0.043 $US/kWh if one makes the following additional assumptions:

(a) Cost of well amortized over 15 years, and cost of the power station over 30 years;

(b) Interest rate of 12 per cent;

(c) Variable annual operating and maintenance expenses amounting to 1.5 per cent of fixed capital investment;

(d) Average annual load factor of 85 per cent.

58. Introducing high-temperature geothermal energy into everyday life has never been a problem. For one thing, high-temperature geothermal energy is not associated with major concentrations of people; for another, experience shows that it is generally well accepted by the inhabitants of the areas in which the units are installed. It

is not found in conjunction with major concentrations of people, inasmuch as high-temperature geothermal energy tends to occur in areas of instability in the earth's crust. The regional population density may be high, because volcanic soils are generally fertile and attract a substantial farming population, but this population is widely scattered. The risk of a major disaster, such as a severe seismic shock, lava flows, ash fall-out or volcanic explosions, prevents the construction of towns of any importance. Moreover, experience in Italy with the Larderello site, in a rural area, has shown that the existence of a full-scale geothermal industry, with the inevitable high-tension power lines that spread over the agricultural countryside, did not impede traditional activities and was well accepted by the local population. The results of this experiment appear to be representative of the general attitudes of those involved towards high-temperature geothermal plants as a part of their daily lives, and hence it can be extrapolated to the areas where future installations may be built.

59. The environmental impact of high-temperature geothermal energy is somewhat greater than that of the low-temperature variety. The first effect on the environment is noise. In addition to the high sound levels produced by drilling equipment during the sinking of the wells, there is a free release of steam into the air during tests. Such supersonic emissions create noise reaching intensities of 125 dBA, making it necessary to provide special protection for personnel working in the vicinity. Moreover, a field of economic magnitude will include several producing wells. Lastly, to clean the well and the below-ground steam-collection area properly, it is normal to allow a well to vent at full capacity for several weeks. This creates a serious nuisance for local residents.

60. A well generally emits from 100 to 500 tons of steam per hour, accompanied by a greater or lesser amount of liquid water. This effluent very often contains a certain amount of boron, arsenic or even mercury, resulting in a long-term toxic danger because these elements can be assimilated and not eliminated by higher organisms. It may be economical in some cases to separate out these chemical substances for commercial purposes (boron, potassium, lithium). In most cases, the fluids emitted must be reinjected after recovery of the electrical energy. It may happen, on the other hand, that the steam is very pure and there is no need to heat the effluents, which may then be simply discharged into the river.

61. There is some thermal pollution to be overcome, owing to the generation of electricity. If the steam is released after simple depressurization, the resulting very hot water can affect life in the natural environment downstream from the power station. If, on the contrary, the power station has a condenser unit with an air-cooled closed cooling system, it may produce fogs, with varying effects on the environment, particularly in cold climates, where ice may accumulate on trees and break branches or form a glaze on adjacent roads.

62. Aesthetic deterioration of the sites at which such units are installed is inevitable. However, it is no greater than in the case of any other industrial installation. The high-tension lines joining the geothermal power station to the rest of the grid are no more unsightly than those running from a hydro-electric dam. In each instance, the cost of preserving the site must be carefully calculated and compared with the expected benefits to the community; the one should not necessarily rule out the other.

63. Since high-temperature geothermal energy utilizes relatively shallow reservoirs situated in unconsolidated blocks of land, it may result in subsidence of the soil by several centimetres over areas of varying size. Generally speaking, the consequences are minimal because of the absence of infrastructure and of population concentrations at the surface. However, the subsidence may affect the installations themselves and should be taken into account.

64. In general, in high-temperature geothermal energy, as in other types, there is no storage problem.

65. The scale of utilization may be small or large. In non-electrical uses, such as rapid drying, what is needed is intensity rather than power. In other words, the temperature level is more important than the amount of steam produced. A single production bore-hole may then suffice. On the other hand, electrical uses are limited only by the capacity of the field, the size of the market to be supplied and the budget available. Other things being equal, it is better to connect the largest possible number of wells to the electric power station in order to take advantage of the benefits of scale for output and investment costs. The largest geothermal electric power station currently installed has a power of 800 MW.

C. Intermediate-temperature geothermal energy

66. Intermediate-temperature geothermal energy covers the area between low and high temperatures, i.e. the range between 100 and 150°C. The enthalpy of the geothermal fluids is not sufficient for the production of electricity by direct use of the steam. Moreover, they consist of a liquid-gas mixture, which complicates their handling. Nevertheless, they contain a substantial amount of energy.

67. The agro-food industries are the principal consumers of this type of geothermal energy in connexion with the processing of wool, the more or less rapid drying of vegetable products (seaweed, hay, cereals), sugar refining and tinned foods. Small-scale industry employs it for evaporating saline solutions or drying prefabricated concrete slabs.

68. Intermediate-temperature geothermal sites have no specific characteristics and are generally to be found in association with volcanic phenomena. They can most frequently be regarded as the upper sections of high-temperature sites. They are exploited as such when there is no need for a higher thermodynamic energy level. The wells are then drilled to a lesser depth, the temperatures and pressures are somewhat lower than for high-temperature geothermal energy, and therefore the investment cost is also lower.

69. The geothermal fluids are used in their existing state. In general, the steam, which is the product utilized in the drying process, must be separated from the hot water. The latter and the steam condensates may require treatment following utilization but before being returned to the environment or may have to be reinjected. Economic considerations will dictate the solution chosen.

70. The socio-cultural and environmental problems posed by intermediate-temperature geothermal energy are the same as those arising from high-temperature geothermal energy.

71. The scale of utilization may be small or large. In favourable conditions, quite small installations producing only a few tons of steam per hour can be economic. At the other end of the range, intermediate-temperature geothermal installations rarely consume more than a few hundred tons of steam per hour.

D. Binary-cycle geothermal systems

72. Conventional intermediate-temperature geothermal systems, that is to say, those in which the steam produced is used directly, do not utilize the available thermal energy to maximum advantage, since a substantial portion of the hot fluids is flushed away as unused water. Furthermore, they are limited to thermal applications and cannot be used to obtain mechanical and electrical energy.

73. With the introduction of a secondary cycle, the greater part of the energy available in the geothermal fluid can be transferred to another chemical substance with physical properties which make it possible to recover mechanical energy. The products used are natural or halogenated hydrocarbons butane, hexane, freons.

74. The primary loop includes a producing well which carries the geothermal fluid to an evaporator. A second bore-hole reinjects the cooled fluids in order to resupply the geothermal aquifer with water. In the evaporator, the primary fluid is put into contact with the secondary fluid through metal walls. Calories are thus transferred from the first fluid to the second. The effect of this transfer is to convert the secondary fluid from the liquid to the vapour phase and to subheat it slightly. The gaseous secondary fluid is then conveyed to a turbine connected to an in-line alternator. There the gas is depressurized, the corresponding work is converted to electrical energy, and then the depressurized gas is cooled in a small cooling tower before returning to the evaporator and thus closing the secondary loop.

75. This type of installation is well suited to the power range from 10 kW to several hundred kW and can be used to obtain electricity at a reasonable price, at temperatures of 80°C or higher. It is not yet widely used but appears to offer interesting possibilities in the case of isolated human communities. However, elaborate equipment is required, even though it is sturdy, and maintenance calls for a minimum of technical training on the part of the operating and maintenance staff; there have been difficulties in this area.

76. Environmental problems are reduced to a minimum because of the reinjection of the geothermal fluids, eliminating water and air pollution. Noise may be a problem during drilling but is limited. Plant layout can be made pleasing to the eye, especially since the equipment occupies only a limited space. On the other hand, the electricity is usually distributed by means of overhead wires, and such lines, a symbol of development, mar the appearance of old cities. That, however, is not a problem limited to binary-cycle geothermal energy but relates rather to the availability of cheaper electricity.

E. Geothermal energy from hot dry rock

77. All the types of geothermal energy described above require a geothermal fluid to carry the calories from the geothermal reservoir to the surface. In nature, however, it is found that there are numerous hot rock masses that contain substantial quantities of geothermal energy which cannot be extracted simply because of the absence of heat-transfer fluids and of natural passages through which such fluids could circulate. The total potential is substantial because of the abundance of this type of rock at deep levels, where temperatures are highest.

78. The principle underlying the development of this resource involves circulating within the hot dry rock a heat-transfer fluid that will deliver the heat to the equipment which will use it at ground level. For the operation to be economically feasible, it is essential that the régime of transfer of the geothermal energy to the fluid should be regular and that the thermal drainage system should apply to the whole of the rock mass without exception.

79. Several methods for ensuring the quality of this transfer may be considered. The first requires a subterranean explosion which will induce isotropic fracture of the rock and permit intimate contact between the heat-transfer fluid and the rock throughout the entire volume mechanically affected by the explosion. This is the surest method. However, it requires considerable explosive power to fracture a sufficient volume of rock. Moreover, a highly concentrated explosive charge is required, and the economic implications of such an operation remain problematical.

80. Other, less ambitious methods seek to establish limited contact between the heat-transfer fluid and the hot rock. They rely on the natural thermal conductivity of the rock to make the first heat transfer to the single collection zone. The latter may, for example, be a circular fissure of large diameter, produced by hydraulic fracturation. The heat-transfer fluid circulates in it between an injection well and a producing well which both cross the flat gap between the separated rock masses. The fissure plays the role of a natural heat exchanger between the hot dry rock and the heat-transfer fluid.

81. Experimental results to date do not justify a favourable answer regarding the economic character of this geothermal resource, but it is unquestionably available.

82. If this type of geothermal energy should be brought into production, the related subcultural factors would probably be analogous to those in the case of high-temperature geothermal energy. The same would be true of environmental factors.

83. On the other hand, it is too early to estimate the range of power within which its use could be economic, since no data are available in this field.

F. Geothermal energy from geopressurized zones

84. The presence within normal sedimentary series of geological strata with marked temperature and pressure anomalies has long been observed in drilling for oil. This generally results when a pervious porous horizon is wedged between two impervious layers at a great depth. The pressure of the intergranular fluids tends to pass from hydrostatic to lithostatic pressure. Little is known, however, regarding the reason for temperatures which are higher than those that might be expected from the regional gradient.

85. There is not enough information in this area to regard this type of geothermal energy as an available resource in the short term. No rule which would make systematic prospecting feasible has yet been found. The extent, and therefore the unit energy capacity, of each of these confined zones remains unknown.

86. The socio-cultural or environmental factors involved should not be different from those encountered with other types of geothermal energy at a comparable power level.

87. The range of applications of this potential resource cannot be estimated because of a lack of relevant economic data.

G. Geothermal energy from magmas

88. Maximum goethermal flows occur in the neighbourhood of magma chambers which give rise to volcanoes. Estimates show that the energy present in volcanoes is of the same order of magnitude as the total known world reserves of fossil fuels.

89. Exploitation of these resources requires tapping the magma at a depth of several thousand metres below the volcano and extracting the energy present in it. There is no technology available at present that can handle this problem. Geothermal energy from magmas, failing some exceedingly unlikely technological advance, will certainly not be among the forms of energy available at the beginning of the third millenium.

90. The environmental impact of this type of geothermal power remains in the realm of speculation. It is possible that the withdrawal of a substantial amount of energy in the plate boundary zones where the magmas are situated could affect the major balances of the planet. Extensive theoretical studies will therefore be necessary before projects can be developed in this field.

III. PRINCIPAL CONSTRAINTS ON THE DEVELOPMENT AND USE OF THESE GEOTHERMAL ENERGY SYSTEMS

A. Flow of information

91. There is an abundance of information available on geothermal energy, but it is not always in the public domain or available in every user's mother tongue.

92. The problems with regard to the dissemination of scientific information are not peculiar to geothermal energy but are the same as those occurring in other disciplines in the case of published documents having a very limited circulation.

93. On the other hand, there is one specific subject area in which information is withheld at source, namely, information on subsoil geology. Such data are the first requirement for getting a project under way. The data frequently exist, having been obtained from earlier drilling for oil within the area in which prospecting is planned. Usually, however, the data remain confidential and are made available only against substantial payment. Paying up is less costly than it would be to duplicate the work. Nevertheless, it represents a heavy burden in the initial phase of geothermal operations, and to decide against geothermal prospecting for purely financial reasons may well deprive a country of new energy resources.

94. The dissemination of technical information is rarely a specifically geothermal problem. In most respects, geothermal work is a special variant of a technology which has already been extensively developed. There are few regular technical publications which treat geothermal energy separately and thus present in concentrated form the information which the geothermal specialist requires.

B. Financial constraints

95. Geothermal exploration, like all subsurface ventures, involves risk. Investment in pilot wells is high and success is never guaranteed. Traditionally, this risk is not covered by insurance. As in the case of the oil industry, the entrepreneur absorbs the entire prospecting risk. This situation is understandable in the case of the oil companies, which can spread their risks over a large number of concessions in different countries. When geothermal prospecting is to be undertaken by a developing country or even by a single entrepreneur, the risk of loss may be too great to justify taking the decision to start exploration. The geothermal potential then remains unexplored.

96. In other phases of the exploitation of geothermal resources the financial constraints are less specific. The dominant constraint is one common to all new sources of energy destined for remote areas. Inasmuch as in much of the economic activity of the regions concerned, production for own consumption and barter are predominant, the monetary system is ill-adapted to amortize a substantial debt. The principle of sound management that investment should be repaid from the services which it produces is thus a limiting factor. It should also be noted that a community employing elaborate technological equipment for the first time will be subjected to new economic constraints which may prove traumatic and cause loss of confidence in the new aid.

C. Research and development - transfer of technology

97. Generally speaking, the difficulties affecting geothermal energy in this sphere are not specific and occur in all other technical fields. They relate in particular to:

(a) Access to technical information concerning technologies available on the market;

(b) Access to operating procedure diagrams and "know-how";

(c) Access to expert technical advice during the initial phase of the programme;

(d) Effective inspection of deliveries of imported equipment;

(e) The services of advisers for the preparation of a preliminary estimate of the country's geothermal potential.

98. There are, however, difficulties which are specific to geothermal energy and which bear on all the technical aspects involved. Those requiring the most extensive improvements include:

(a) Geophysical methods for locating geothermal reservoirs;

(b) Simplification of drilling operations so as to reduce costs;

(c) Elimination of noise and other kinds of pollution;

(d) Determination of the optimum binary cycles according to the type of geothermal energy used.

99. It is highly probable that research and development in the field of geothermal energy will continue to be pursued primarily in countries which have long experience in the utilization of such energy. Nevertheless, transfer of technology is needed even in this area. The developing countries should have:

(a) Research and development facilities to adapt equipment designed abroad to local conditions and to start local production;

(b) Technical reference norms which local producers of equipment can use as a basis for their ideas.

D. Education and training

100. In many countries the introduction of the geothermal industry is hampered by the lack of certain technical skills, several of which are not specific to geothermal energy. This shortage of technicians takes two forms. The main difficulty usually stems from poor maintenance of equipment and from the fact that

it is often impossible to solve the less common technical problems at the local level. The result is a rapid drop in efficiency, deterioration of the equipment and a sharp increase in the cost of the energy finally produced.

101. The second form relates to the establishment of geothermal facilities. Far fewer people are needed, and as soon as one geothermal site has been equipped, the team can move on to a new location. In some cases one team may be enough for a particular country. However, the staff must be highly specialized and the necessary training usually cannot be provided locally because there is no market to justify special training for this particular form of energy and the technologies related to it.

E. Infrastructure

102. There is often an economic threshold to low-temperature geothermal energy which corresponds to urban or village communities with several thousand inhabitants. When the population is scattered, as it is in some predominantly agricultural countries, this may make it impossible to introduce low-temperature geothermal energy because the length of the connexions required would make the investment cost prohibitive.

103. In high-temperature situations, the use of geothermal energy is justified if the power station supplies a single major consumer or if it is hooked up to the national electricity grid. In many cases, the geothermal site is far removed from industrial zones. The solution may sometimes be found in establishing a major consumer on the site itself, but in most cases this is impossible owing to the additional infrastructure costs it would involve (roads and railways, housing, communal facilities) and the resulting additional production costs, which would wipe out - or more than wipe out - any competitive edge obtained by the use of geothermal energy. Another solution would be to hook up the power station to the national grid. This is easy to do in an industrialized country; on the other hand, it is more difficult when a country's electricity development is only entering the interconnexion stage. The introduction of electricity produced from geothermal sources may cause planners to rethink the sequence of investments and to reorient regional development.

104. Geothermal energy requires a general infrastructure. It can produce the results expected of it only if it is supported by appropriate networks of services: maintenance, spare parts, repairs and the like. This is actually a general constraint, but is is important to bear in mind its implications for geothermal energy when efforts are made to remedy the constraint at the national level.

F. Institutions

105. The main group of institutional constraints affecting geothermal energy is of a legal and administrative nature. The status of geothermal energy is rarely spelled out clearly in legislation. When the problem arises, the law governing geothermal energy is generally made a part of the law governing mining activities.

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Depending on how the latter law is conceived (whether the ownership of land implies ownership of the subsoil or whether, on the contrary, the State retains ownership and control of the wealth of the subsoil and can award concessions for its exploitation), the development of geothermal resources will be faster or slower. The parcelling of mining rights is an obstacle to small-scale geological synthesis. Private mangement of geothermal resources, on the other hand, often leads to speedier exploitation. At the same time, when the State or local community is in charge of operations, considerable financial resources are guaranteed and this makes it possible to have technical work of high quality.

106. The very special position of geothermal energy makes it somewhat difficult to classify, so that it may be made subordinate to different administrative departments. When a decision must be taken quickly whether to use conventional energy or geothermal energy for a particular purpose, the delays and the complexity of the procedure for issuing the geothermal authorization may discourage the decision-maker from using the source of energy which would be generally more satisfactory.

IV. MEASURES THAT CAN BE TAKEN TO OVERCOME THE CONSTRAINTS LIMITING GEOTHERMAL ENERGY

A. Flow of information

(1) 107. The most important step is to ensure that all available raw geological and geophysical information concerning the subsoil which might affect geothermal energy - stratigraphy, lithography, porosity, nature of the fluids and temperature - is accessible. Those who obtain such data should systematically transmit them to a specialized public body responsible for storing them, for making sure that they are communicated to qualified persons and for preserving the confidentiality of any information protected by law.

(2) 108. An international documentation centre on geothermal energy would be useful, but the dissemination of the data to users would pose serious problems. Only through the spread of geothermal energy leading to the issuing of specialized publications in several languages can this form of energy and the techniques it requires become a part of modern technology.

B. Financial constraints

(3) 109. Geothermal energy should be given a special status by energy-importing countries as a way of economizing in the field of foreign trade. Investment incentives in that area could be planned. They could take the form of loans at preferential rates, insurance for exploration, the assigning of priority for the supply of equipment available only in small quantities, or special tax treatment.

(4) 110. In some countries geothermal energy may be introduced through technical assistance from abroad. In order to be complete, such assistance should be accompanied by financial facilities for the first operations until it has been demonstrated that an operation is economic and profitable, so that national investors can take over from the aid organization.

(5) 111. Another type of international assistance could be the creation of insurance for geothermal-energy exploration. An international body such as the International Development Association could provide insurance against the risk of geothermal research, providing for an additional amount to be reimbursed by successful operators, so as to recover the costs of unsuccessful drilling operations.

C. Research and development - Transfer of technology

(6) 112. Efforts should concentrate primarily on adapting existing technology to regional conditions. In particular, local industry should be helped to supply an increasing proportion of the equipment and services. Civil engineering works, buildings and electricity and water supply systems should be the first operations to be carried out locally. The next phase in the transfer of technology should be drilling operations. It is more difficult to specify targets for subsequent operations.

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(7) 113. However, considerable work can be undertaken outside the purely technical field. Making the population aware of the depletion of economically viable sources of conventional energy, familiarizing them with geothermal energy, identifying energy uses in which conventional fuels could be replaced by geothermal energy, inventorying instances in which geothermal energy could provide the solution to hitherto unmet needs - all this calls for interdisciplinary studies, to be conducted in conjunction with the administration, local communities, universities and industry.

(8) 114. High-level scientific and technical problems remain unresolved and require international efforts. Geothermal energy is very often not competitive because of the high chemical activity of the fluids involved. In order to prevent unduly rapid corrosion and scaling, titanium exchangers sometimes have to be installed. Titanium cannot be considered for very large-scale applications if they are to be economic. New alloys which can perform satisfactorily in the special physical and chemical environment of geothermal energy must be developed.

D. Education and training

(9) 115. There are a number of training centres for the higher staff levels of the geothermal industry. Ideally, more students from a wider range of countries should be able to receive such training, with particular emphasis on technical training and the physical conduct of operations.

(10) 116. However, existing centres are often very far away from these students' native countries, and their environment is sometimes quite different from the conditions prevailing in the areas in which geothermal energy is to be introduced when the students have completed their training. It would therefore be useful to open new training centres in major regions which do not yet have one.

E. Infrastructure

(11) 117. Priority must be given to including geothermal energy in the economic and social development plan from the earliest stages of plan preparation. A country's need for geothermal energy and the contribution that it can make to the national energy balance must be taken into account very early on, in order to ensure that development of geothermal energy is not hampered by infrastructural constraints.

(12) 118. Priority should be given, as far as possible, to consumers in sparsely populated areas who require geothermal energy for non-electrical uses because it is in these circumstances that investment is minimized and return maximized. Industries which are potential customers for geothermal energy should, moreover, be sited as close to the prospective geothermal areas as safety considerations allow.

F. Institutions

(13) 119. It is imperative for every country to have a geothermal-energy code governing the ownership of geothermal resources, conditions for their use, the charges payable by users and their fiscal régime. Otherwise there is a danger that legal uncertainty will discourage private entrepreneurs from embarking on geothermal exploration because they cannot be sure of making a profit and being rewarded for taking the risk. A model set of regulations could be drafted at the regional or international level.

(14) 120. At the same time, the scope of State supervision of geothermal resources must be clarified. A sound course is to confer technical responsibility for monitoring the geothermal industry on a single technical ministry. This does not, of course, preclude the other ministries (Finance, Foreign Affairs and the like) from assuming their respective responsibilities.

V. PROPOSED ACTION

121. The proposed measures have been set out in the table below according to the level - international, regional or national - at which they are to be taken. The figures refer back to the 14 measures identified above in the order in which they are described.

	International	Regional	National
Information flow	2	2	1
Financial constraints	4 - 5	-	3
Research and development - transfer of technology	8	6	6 - 7
Education and training	9	10	-
Infrastructure	-	-	11 - 12
Institutions	13	13	13 - 14

A. At the international and regional levels

122. At the international level the proposed measures can be divided into three categories, depending on whether they relate to:

(a) Financial constraints (4, 5);

(b) Organization of the geothermal industry (13);

(c) Necessary know-how (2, 8, 9).

Existing institutions, both multilateral and bilateral, are equal to the task of dealing with the problems posed. These measures must be taken as early as the exploration phase in the case of guarantees (5) and at the development phase in the case of financing (4).

123. On the other hand, there is at present no institution capable of dealing with the other measures. An international agency (or regional agencies) is essential for data collection and dissemination (2), training more geothermal experts (9) and conducting or commissioning studies on key areas of geothermal energy (8). Such an agency could be entrusted with the all-important task of working out a general geothermal energy code (13).

124. At the regional level, priority must be given to information (2) and training (10). This level is particularly useful because it is possible here to combine the efforts carried out by countries individually while at the same time preserving a degree of unity as regards the types of problem encountered. Solutions

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worked out in this framework can probably be applied more easily and more rapidly to countries in the region than those worked out in a far broader framework embracing all possible situations. Regional bodies could put the finishing touches to the legal principles on geothermal energy drafted at the more general level by adding the clarifications and corrections warranted by each region's particular situation.

B. At the country level

125. The main effort must be concentrated on the country level because, in the final analysis, it is in that framework that geothermal resources are developed naturally. Moreover, it is at that level that most constraints are encountered.

126. The constraints which must be removed first are those that prevent prospecting from being undertaken. Accordingly the institutional measures (13 and 14) must be adopted first. At the same time, all due attention must be given to the inclusion of geothermal energy in the country's economic fabric. Infrastructural measures (11 and 12) are therefore equally pressing. Lastly, and this relates to measure 13, the dissemination of geological data (1) is a prerequisite for economic exploration.

127. Second priority goes to financial constraints. Tax relief measures (3) will be a prerequisite for a speedy start in the development of geothermal resources.

128. These resources may be developed initially with external technical assistance, but efforts must be made as soon as possible to replace foreign capital goods and services gradually with locally produced equivalents. That is the aim of measures 6 and 7.
