Article from:

Proceedings of the Fifth Annual Geothermal Conference and Workshop, June 23-25, 1981, San Diego, California. Palo Alto, California: Electric Power Research Institute, 1981.

2478

DEVELOPMENT OF GEOTHERMAL ENERGY FOR ELECTRICITY GENERATION IN ITALY

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1. Background

The exploitation of geothermal energy to generate electricity can be said to have begun in Italy in 1904 when about 15 kW were generated to illuminate the plants producing boric acid at Larderello. However, the first geothermoelectric power station began operating in 1913, with a capacity of 250 kW. From that moment on continuous research, drillings, new plants, and improved technology have, despite the halt enforced by the war years, led to the present installed capacity of 439,600 MW in the Larderello, Travale, and Mt. Amiata areas. These are, in fact, the only vapour-dominated geothermal fields that have been discovered so far in Italy.

2. Geothermal Fluid

The power stations operating nowadays are fed by about 200 wells spread over an immense area within the Larderello, Travale, and Mt. Amiata regions.

Each of these wells produces a fluid comprising for the most part steam and other constituents, the most predominant of which is CO_2 (see Fig.1).

These constituents often have a major influence on the choice of utilization plant; the content of uncondensable gases affects the choice of materials used and the decision to expand at less than atmospheric pressure or not.

Usually no serious corrosion problems arise when natural steam is superheated where there is no condensate phase, so that a carbon steel can be used satisfactorily. However, the fluid in some of the wells at Larderello contains rather abundant traces of the chlorine ion.

The chlorine content is generally below 10 ppm; in some wells it exceeds 50-100 ppm and may also vary suddenly with time.

The chlorine content has been shown to be particularly high in some of the more recently drilled deep wells that produce a high temperature fluid (≅ 250°C). This creates grave problems in transport and in the turbine whenever there is condensate present (insulation failures, on the contact points between pipelines and supports, etc.).

The corrosive properties of the endogenous fluids sometimes take their toll of even the best steels: corrosion has indeed been noted to develop even faster in some inox steels, appearing in the form of pitting.

The most effective means of fighting the chlorine ion would so far seem to be that of "cleaning" the steam with an alkaline solution (NaOH at 1.5%); a slightly higher dose of this solution than is really necessary for complete saturation is added to the steam; the fluid then passes through the separators to eliminate the liquid phase containing the chlorides. This treatment takes place before the steam enters the turbine so that there is obviously some loss in capacity. However, adequate compensation is made for this in the reduction in corrosion phenomena in the machinery.

Endogenous fluid temperature ranges between a minimum of 120-130°C and a maximum of about 250°C.

Fluid pressure on entering the power plants ranges from 2 to 11 ata. Well flow rate usually varies from a few tons per hour to about one hundred. The relationship between flow rate and production pressure is expressed by characteristic curves whose trends are shown in Figures 2 and 3. The characteristic curve is not constant with time, as flow rate and pressure both tend to decrease as production proceeds. The pressure and flow rate of each well in the network thus change with time.

Each characteristic curve obviously has a point at which the theoretical extractable capacity is maximum, all other conditions being equal. It would clearly be more economic to operate at this point, but, in practical terms, the operational flow rate and pressure are chosen on the basis of other factors, such as the existing network of steam pipilines, available machinery and also results of reservoir engineering studies.

3. Fluid Transport

The wells feeding the power plants are spread over a surface area of several square kilometres. They are connected to the utilization plants by a network of steam pipelines totalling about 120 km. The pipes, in welded steel, vary in diameter from 150 to 800 mm and are covered externally by a layer of insulating material (asbestos or rock wool) of about 80 mm thickness. A sheet of polyethyline is placed over the insulating material and the lot covered by thin (o.8-1 mm) sheets of aluminum as a final protection.

A double series of safety devices are fitted on the steam pipelines to avoid an excess buildup of pressures within the pipes should there be breakdowns in the utilization plants or erroneous handling of the valves. Automatic pressure control valves are fitted in the power plants and safety diaphragms all along the pipes, calibrated to the nominal pressure of the latter.

The pipes, which were at one time laid with bellows, now follow a zigzag route, so that the variation in length caused by thermal expansion is kept within the elastic deformation limits of the system and passed on to the cambers of each arch of pipeline. The increase in the length of the pipelines is thus negligible. The diameters are chosen so as to strike a happy medium between reduction in load loss and costs. Provision must also be made for the decline in produced fluid with time and an eventual insertion of new wells into the network. The steam velocity in the pipelines at Larderello ranges from 25 to 40 m/s. The average heat dispersion was calculated at 100 kcal/m^{2}h; the overall transmission coefficient ranges between 0.1 and 1 kcal/m^{2}h ^{o}C.

4. Utilization Plants

The choice of plant for generating electricity depends on the chemiophysical characteristics of the fluid and on the set of objectives.

At the moment the endogenous fluid is carried directly into the turbines as the indirect cycle plants have by now been completely abandoned. In these more complicated and expensive systems (Fig. 4), the fluid entering the turbine was a much cleaner steam than the endogenous fluid. Nowadays the materials and technologies are so far advanced as to permit the use of direct cycles.

The cycles used now to generate electricity from endogenous fluids are summarized in Fig. 5. Installed capacity in each unit ranges from about 900 kW to 26,000 kW (Fig. 6). The utilization coefficient of the plants, by which we mean the ratio of operational hours to the total number of hours in a year, is 96.43%. The ratio of energy produced to theoretical attainable energy with the present installed capacity is, on the other hand, much lower, as some units in the Larderello zone are not operating at full load.

In the simplest cycle the steam enters directly into the turbine and discharge is into the atmosphere.

The plant adopting this cycle has a specific consumption of 15-20 kg of endogenous fluid for each kWh. It is very cheap and easy to install. Running and maintenance costs are relatively small.

These plants are installed wherever the condensing plants are not economically feasible, i.e., where the fluid has a high content of un-uncondensable gases.

Plants of this type (1000 and 3500 kW) have also been installed in order to carry out long-term production tests for studying the characteristics of one or a group of wells. The 15,000 kW back-pressure unit operating in the Piancastagnaio plant at Mr. Amiata uses the above-described cycle: it has an impulse and reaction type turbine that permits shuttering of the inlet valves and can operate with a high efficiency at pressures between 5 and 11 ata with up to 20% gas percentage, by means of special bladed rings that can be inserted or removed depending on the fluid conditions of the moment.

The unit can adapt to varying inlet pressures and can, where necessary, be coupled to a second low-pressure unit and to the gas extractor-compressor; the plant can thus be converted to a condensing cycle.

The latter is, in fact, the most common cycle in the geothermoelectric power plants.

All the plants using this cycle (Fig. 7) are fitted with direct contact barometric type condensers and multi-stage gas compressors-extractors with intermediate coolers. The water is carried to the condenser by the difference in pressure while being pumped from the hot tank to the cooling towers. The pumps are usually of the vertical axis type with a submersed helical centrifugal rotor with blades that can vary in tilt to adjust the flow rate when a change of water level is desired.

In the Radicondolo 2 (Travale) and S. Martino power plants the pumps are the vertical axis type with submersed centrifugal rotor and control valve on the delivery side.

The circulation water is usually cooled in reinforced cement cooling towers of natural draught, with a Δt between 10 and 14^{o}C, as there is not enough cold water available.

In the Radicondoli 2 (Travale) power plant, which has an installed capacity of 30 MW and began service in 1980, the circulation water is cooled in much smaller induced draught towers.

New criteria have recently been adopted in the design of new power plants, as part of a program for amplifying and developing geothermal activity. The new plants will thus be designed and constructed with the following set objectives: speed and economy in construction, economy in running and size, great flexibility and reliability, simplicity.

Work has already begun on three new 8 MW power plants with a direct admission condensing cycle that were based on some of the above, unconventional criteria. The water will no longer be extracted from the condenser by way of a barometric pipe, as in other power plants, but using extraction pumps. Thus less civil engineering work will be required and the plant will be simpler.

In the future the power plants will be constructed very soon after the geothermal fluid is discovered, as highly flexible machinery and equipment (capable of operating in relatively wide ranges of flow rate and pressure) will enable the plants to be ordered before the fluid is even discovered. If kept in store they can be available at very short notice.

The turbine, alternator, condenser and main pump will be installed on the same level, thus eliminating a great deal of civil works; the power plants will be remote-controlled and able to start and stop automatically.

5. Resource Prospects for Electricity Generation

Estimates of the geothermal potential are based on conventional evaluation methodologies that begin by evaluating the total heat stored in the underground to a certain depth and end with an estimate of the conomically extractable quantities, i.e., the so-called "reserves". Estimates made in Italy refer to a depth of 3000 m and are based on methodologies elaborated jointly by ENEL and the DOE (USA).

The thermal energy in the underground down to this depth, throughout Italian territory, is of the order of 2250×10^9 TEP; the extractable energy is, however, merely a very small percentage of this figure.

The "reserves" in this country are estimated indeed at around 10 thousand million TEP. Much of this energy, however, cannot be extracted at temperatures above 130°C and, where electricity generation is concerned, would require a technology that has still to be tried and tested.

Where electricity generation is concerned, fluids corresponding to a geothermoelectric potential of about 100 GWa_e are estimated to be extractable from Italian territory, i.e., about 900 thousand million kWh. Assuming that these "reserves" were to be exhausted in a 50-year period, then theoretically 2000 MW_e could be installed.

When setting industrial objectives one must bear in mind factors such as the type of fluids, as this can create problems when utilizing the reserves; the maximum capacity attainable in Italy from the reserves should thus, in practical terms, be estimated at about one thousand MWe for 50 years (Fig. 8).

Note, however, that these reserves are distributed all over the country in a non-uniform fashion; they are concentrated mainly within the pre-Apennine belt of Tuscany, Latium, and Campania, which can be said to contain more than 90% of Italy's entire geothermal resources. Within this belt the most favoured area as far as geothermal energy is concerned are: Larderello, Radicondolo-Travale, and Mt. Amiata in Tuscany; The Volsini and Sabatini Mounts and the Albani Hills in Latium and the Phlegraean and Ischian along with the Vesuvian areas in Campania. The main activity should therefore be concentrated in these areas (Fig. 9.).

Where the Larderello field is concerned, ranking foremost of all the others for the excellent characteristics of its fluids, production is expected to increase with drilling of new wells in the marginal areas and with the reinjection of part of the condensate from the power plants.

Current experiments and studies would appear to confirm that the waters reinjected into the field represent at least a partial recharge to the reservoir.

With regard to the other known, but water-dominated, fields, research and experiments are now being carried out to investigate all possible alternatives for generating electricity. Attempts are also being made to solve the many problems caused by the dissolved salts, such as incrustation, corrosion, depositing, waste disposal, etc.

A demonstration plant will begin operating shortly in the Cesano field, whose fluid consists of water with an extremely high salt content.

Operation of this plant will hopefully provide useful indications for utilizing this type of resource. The Helical Screw Expander, a total flow machine, will be tested in this plant.

Experimental flash steam and binary cycle plants are also planned, to test the technical and economic feasibility of generating electricity from mid- and low-enthalpy fluids.

H_2O	=	955.29 g
CO_2	=	41.85 g
CH_4 and H_2	=	1.10 g
H_2S	=	0.92 g
N_2	=	0.30 g
H_3BO_3	=	0.35 g
NH_3	=	0.19 g
Rare gases	=	1.00 g

When 1 Kg. of fluid is condensated, the volume of gas left uncon= densated is equal to around 25 litres; the composition of this gas is:

CO_2 = 92-95%

H_2S = 2-2.5%

The remainder is made up of H_2, CH_4, N_2 and rare gases (residue not absordable with KOH and NaOH)

Fig. 1 - Average composition of 1 Kg of endogenous fluid.

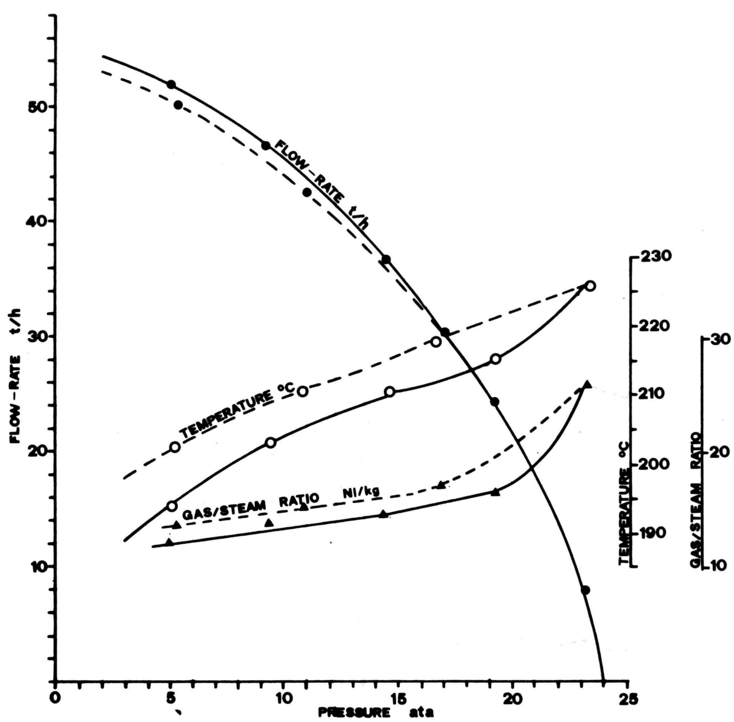

Fig. 2 - Back-pressure curves of a geothermal well

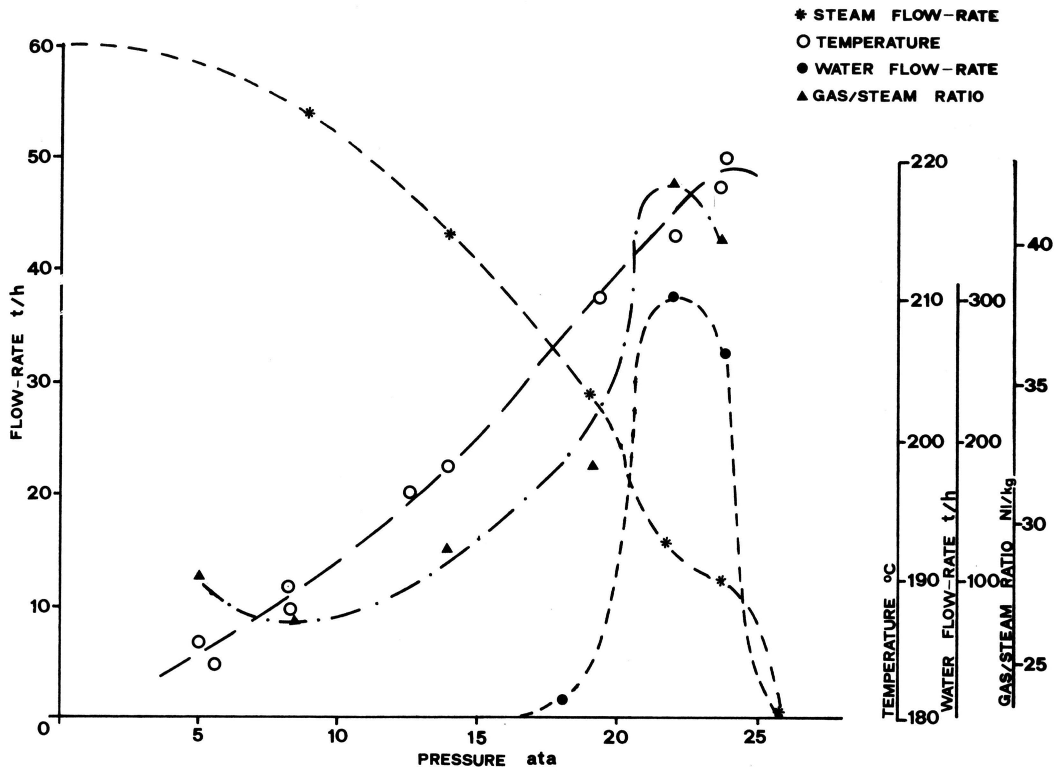

Fig. 3 - Back-pressure curves of a geothermal well

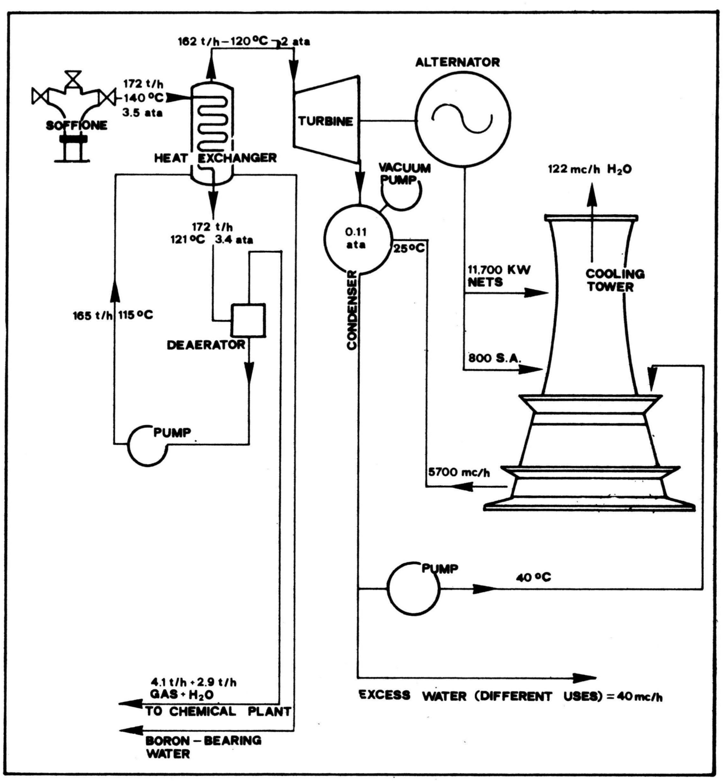

Fig. 4 - Pure condensation steam power (Cycle 2)

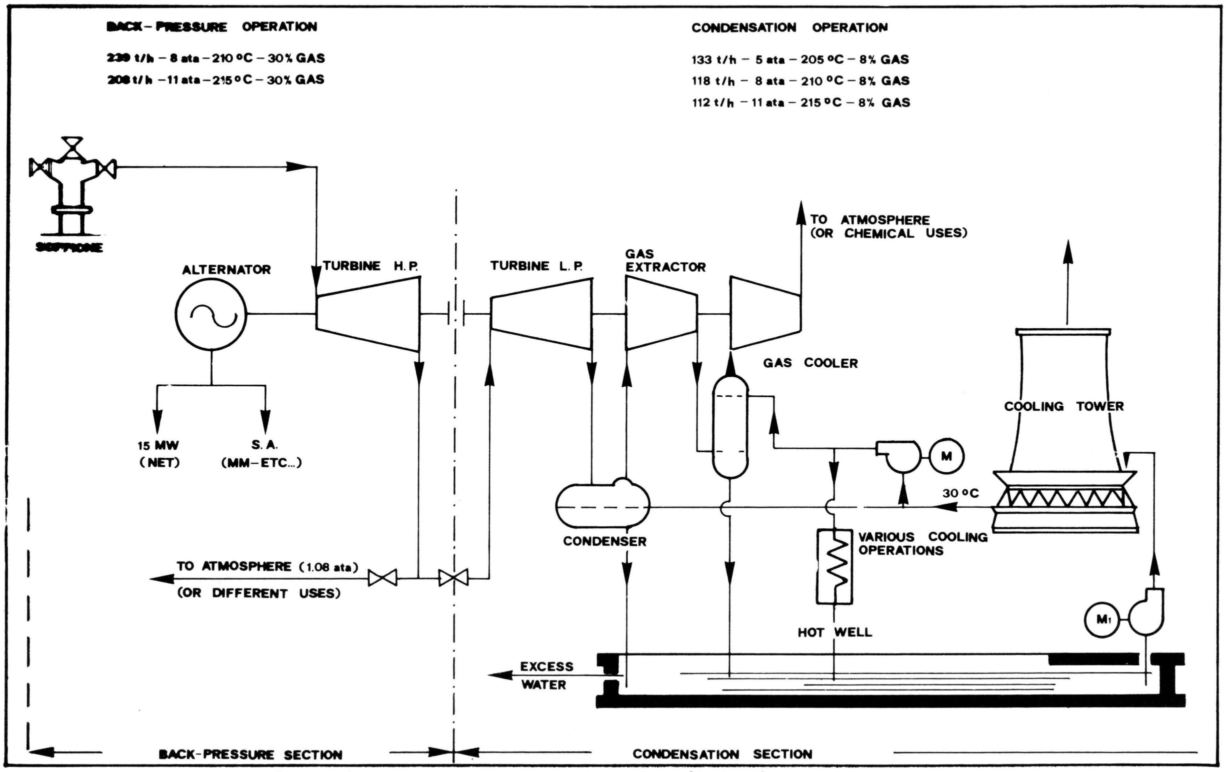

Fig. 5 - Back-pressure plant (Cycle 1). Convertible to condensation plant (Cycle 3)

Power plant	Cycle	Number of units	Capacity per unit	(kW) Total
Larderello 2	3	4	14,500	58,000
Larderello 3	3	3	26,000	
	3	1	24,000	111,000
S. Martino	3	1	9,000	9,000
Gabbro	3	1	15,000	15,000
Castelnuovo V.C.	3	1	26,000	
	3	2	11,000	
	3	1	2,000	50,000
Serrazzano	3	1	15,000	
	3	2	12,500	
	3	2	3,500	47,000
Lago	3	1	14,500	
	3	1	12,500	
	3	1	6,500	33,500
Monterotondo M.mo	3	1	12,500	12,500
Sasso Pisano 2	3	1	12,500	
	3	1	3,200	15,700
Radicondoli 2	3	2	15,000	30,000
Condensing plants in the boraciferous region	3	27	-	381,700
Travale-Radicondoli	1	1	3,000	
	1	1	15,000	18,000
Sasso Pisano 1	1	2	3,500	3,500
Molinetto	1	1	3,500	3,500
Lagoni Rossi 1	1	1	3,500	3,500
Lagoni Rossi 2	1	1	3,000	3,000
Vallonsordo	1	1	900	900
Back-pressure plants in the boraciferous region	1	8	-	35,900
Total plants in the boraciferous region		35		417,600
Bagnore 1 (M. Amiata)	1	1	3,500	3,500
Bagnore 2 (M. Amiata)	1	1	3,500	3,500
Piancastagnaio (M. Amiata)	1	1	15,000	15,000
Back-pressure plants (M. Amiata)	1	3	-	22,000
Grand total: Power plants	-	38	-	439,600

Fig. 6 - Installed capacity of italian geothermoelectric power plants

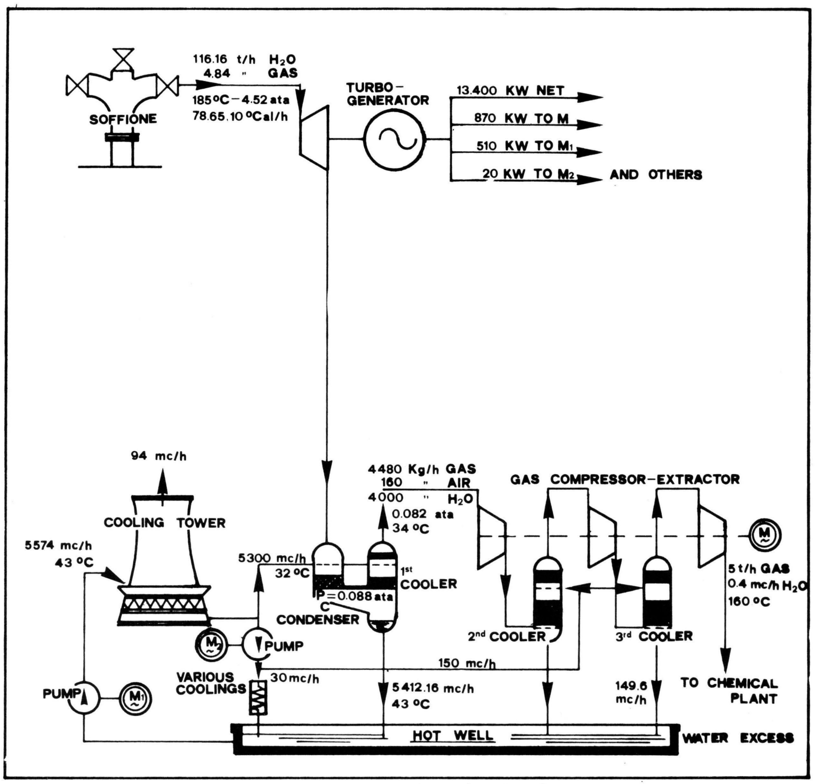

Fig. 7 - Natural condensation steam power plant (Cycle 3)

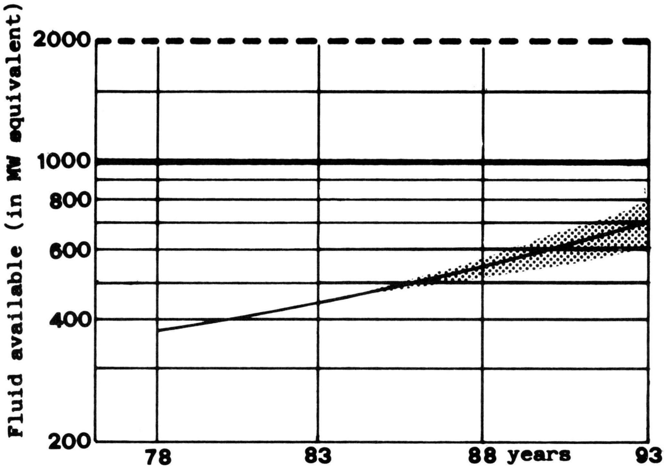

Fig. 8 - Predictions for the availability of geothermal resources for electricity generation.

ENEL

1 - Orciatico, Montecatini
2 - Larderello
3 - Travale-Radicondoli
4 - Roccastrada
5 - Monte Amiata
6 - Torre Alfina
7 - Cesano

ENEL - AGIP JOINT VENTURE

8 - S. Donato Milanese
9 - Ferrara
10 - Latera
11 - Aurelia
12 - Cimini Mounts
13 - Sabatini Hills
14 - Alban Hills
15 - Patria lake
16 - Ottaviano

OTHER ZONES

17 - Roccamonfina
18 - Ischia Island
19 - Vulture
20 - Eolian Islands
21 - East Sicily
22 - Central Sardinia
23 - North Sardinia

Fig. 9 - Areas of geothermal interest