# BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

## RECORD

1980/80

GEOTHERMAL ENERGY IN FRANCE

by

J.P. Cull

1980/80

# GEOTHERMAL ENERGY IN FRANCE

by

J.P. Cull

# CONTENTS



## TABLES



## FIGURES

## SUMMARY

In view of the economic and physical constraints associated with the supply of fossil fuels it is now essential to consider the extent of indigenous alternatives including all types of geothermal energy. Consequently BMR supported an independent application to the French Government seeking the award of a scholarship for research in Science and Technology. Facilities were made available at BRGM in Orleans for a 3-month period (June-August 1980) and provision was made for a living allowance and a one-way air fare from Paris to Sydney.

The BRGM (a semi-private French Government agency) maintains an active role in both high-enthalpy and low-enthalpy geothermal research. It is responsible for many innovations in exploration and exploitation, and the emerging scientific and economic principles can be used as a model for BMR studies in Australia. The BRGM experience in low-enthalpy systems has a special relevance since sedimentary basins occupy more than 60% of the total land surface in both France and Australia. Because the geological conditions are similar, the conclusions now emerging concerning exploitation of geothermal energy in France should also be valid for Australia.

Most sedimentary basins contain high-yield aquifers with large volumes of hot water. Bores can be used to extract this geothermal energy source for direct use in refrigeration, desalination, greenhouse horticulture, fish farming, space heating, and process heating. Additionally, electricity can be generated using binary turbines (or heat exchangers) with water temperatures as low as 80°C. Consequently geothermal energy may become a valuable resource, particularly in isolated communities which depend on oil supplies for primary energy.

## 1. INTRODUCTION

The Bureau de Récherches Géologiques et Minières (BRGM) is a semi-autonomous agency partly funded by the French Government. It maintains an active role in both high-enthalpy and low-enthalpy geothermal research and is responsible for many innovations in geothermal exploration and exploitation. The scientific and economic principles now emerging can be used as a model for BMR studies in Australia. The BRGM experience in low-enthalpy systems is of particular value in this regard. Sedimentary basins occupy more than 60% of the total land surface in both France and Australia. The geological conditions are similar, and any conclusions concerning exploitation of geothermal energy in France should also be valid for Australia.

Geothermal energy can be readily identified only in regions of recent volcanism. Heat is concentrated near the surface by obvious mechanisms of melt intrusion/extrusion, and high temperatures are indicated by the presence of lava flows, geysers, and fumaroles. Exploration has been necessary in these circumstances only to quantify known resources before exploitation. Large volumes of steam can be readily obtained at shallow depth and electricity can be generated using conventional turbines. In other areas geothermal activity may not be obvious and exploration programs must be formulated to evaluate potential resources.

Heat is generated within the Earth mainly by the decay of radioactive elements in crustal rocks. As a result, temperatures normally increase with depth at rates of approximately 30°C/km even in the absence of volcanic activity. Water circulating in any deep aquifer may therefore be extracted at temperatures exceeding 100°C. Some steam may be made available for use in conventional power turbines but usually there is significant water content which must be removed at the well head. Consequently a large quantity of heat is wasted in any immediate attempt to generate electricity. More direct and efficient uses have therefore been suggested in France for all types of geothermal energy. In view of the economic and physical constraints associated with the supply of liquid fossil fuels it is now desirable to consider similar applications appropriate to Australia.

The observations contained in this report were made possible by a French Government Scholarship for Science and Technology. The award was tenable at BRGM in Orleans for a 3-month period June-August 1980. Under the terms of the award provision was made to the author for living allowances and a one-way airfare from Paris to Sydney.

## 2. BUREAU DE RECHERCHES GEOLOGIQUES ET MINIERES (BRGM)

BRGM is a French government-supported institute with industrial and commerical features normally found in a private company. Its principal task is to study and develop geological resources both at home and abroad. It has offices in all regions of France and in about 30 foreign countries, mostly in Africa. Activity outside France now accounts for half the total budget.

In France the BRGM is effectively the National Geological Survey. It is responsible for all basic surveys but maintains a vigorous research component. Its activities extend to the non-mining applications of earth science including engineering, hydrology, geothermics, environment, hazard, etc. All phases of the mining process are included in a second branch of BRGM called the Directorate of Mineral Exploration and Development. The responsibilities of this second branch extend from basic exploration to actual working of known deposits.

To accommodate the commercial role of BRGM both at home and abroad there are a number of subsidiaries and shareholdings operating with independent structure. An exploration subsidiary SEREM conducts basic surveys on behalf of BRGM in several countries through its own local subsidiaries. SEREM also holds BRGM shares in the mining consultancy firms SOCOMINE (giving advice on development and production), CFFM (drilling), and SOFREMINES (mine management). A mining subsidiary, COFRAMINES, manages the BRGM holdings in working mines and is responsible on its own or with outside partners for developing new deposits - in particular those discovered by BRGM or SEREM.

At the end of 1979 BRGM employed 2600 staff of which 1850 were permanent. Allowing for inflation, activity has increased by 50% since 1973. The total financial turnover now exceeds 500 million francs about $A100 million) with expenditure almost equally divided between domestic and foreign projects. Commerical operations account for half of the total and the remainder is allocated to research; including scientific regional and non-mining surveys. The French Government contributes about 30% to annual funding to ensure continuity of the public service component which is identified as the Geological Survey. The bulk of the remaining funds is generated from contract work, interest, and dividends. However, BRGM may also apply for special purpose grants (similar to NERDDC projects in Australia), possibly totalling 5% of available funds.

Approximately 2.3 million francs ($A500 000) is currently allocated to geothermal studies in France. In addition private contracts have been negotiated totalling 10 million francs ($A2 million) for work outside the country. The internal structure of the geothermal studies group (Table 1) reflects both the level and type of professional activity. Most basins are well characterised in terms of aquifer flow rates and temperatures available for exploitation. Consequently there is no great need for regional studies of the type conducted in Australia. Much of the activity is of an engineering type with input from specialists in geology, geophysics, and economics. Where low-enthalpy resources have been demonstrated there is a need to publicise the exploitation potential. Industry groups or municipal authorities may be contacted directly as "target" consumers. If feasibility studies are accepted a contract is let to BRGM, often with the target group obtaining funds from the central government or from the EEC energy program.

## The BRGM in Australia

Since 1977 SEREM-Australia Pty Ltd, a BRGM subsidiary, has devoted most of its efforts to the search for tungsten and alluvial tin, mainly in the eastern part of Australia. Shareholdings or options have been negotiated on a number of known tin deposits in north Queensland; the Lee Creek deposit was scheduled to start working in 1980. In addition the wolfram-bearing quartz vein of Mount Pelion (Tasmania) will be developed in 1980 after underground proving tests; BRGM holds a one-third equity in this venture.

Training in BRGM

In addition to the specifically technical activity of its engineers and geologists, the BRGM contributes to the training and research of foreign personnel. The French government has ratified several types of training schemes involving direct tuition, research, and exchange. In accordance with this policy BRGM has developed a training section to co-ordinate the activities of all personnel engaged in the transfer of technology. Liaison may involve several groups in university, industry, and various French ministries. The principal organisations of this type are the Centre International des Etudiants et Stagiaires (CIES), the Agence pour la Coopération Technique, Industrielle et Economique (ACTIM), and the Centre d'Etude Superieures des Matieres Premières (CESMAT).

In Australia the possibility of such a transfer was announced by the Education Department in a press release authorised by the French consulate. Applications were invited for expression of interest in technical scholarships administered by CIES for study in any French institute. Applicants were evaluated by the Department of Education and their recommendations were submitted to the French consulate. Subsequently the selected personnel were invited to apply directly to the French Government for the award of a CIES scholarship. At the same time the candidate was required to arrange a place in the host institute in France. Agreement was then arranged between CIES and the host (BRGM) concerning financial liability. The candidate receives a total accommodation award in the region of $300 per month (1980) plus a single one-way ticket from Paris to Sydney. However, CIES may be required to pay considerably larger sums direct to BRGM in the form of training fees.

Administration records are maintained on BMR file 79/595.

3. GEOTHERMAL ENERGY APPLICATIONS

A preliminary evaluation of the geothermal resources in the major sedimentary basins of France was completed in 1979 on the basis of data from oil exploration wells. Data were obtained in the regions of Paris, Aquitaine, and Alsace (Fig. 1). In subsequent

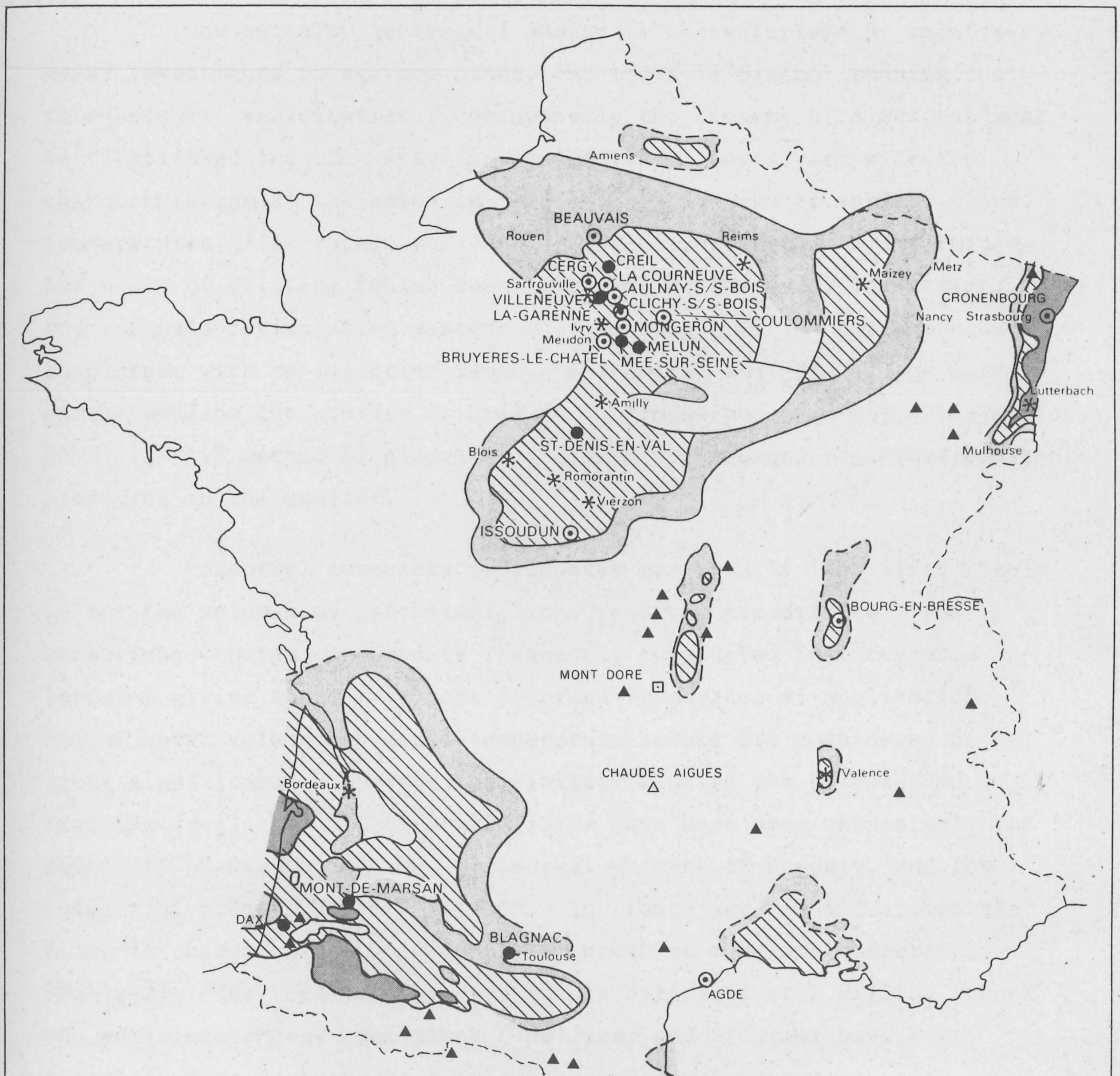



Fig. I GEOTHERMAL ENERGY RESOURCES OF FRANCE. (State of knowledge and projects at 1st January, 1980) programs, tests were conducted in several regional centres to examine the feasibility of exploiting all grades of geothermal energy for domestic and commerical applications. The approach presently adopted assumes that an immediate economic advantage can be demonstrated to the consumer. However, new sources of R & D capital are an integral concept (see section 8).

Low-enthalpy geothermal energy is characterised by relatively heavy investments in surface plant, but there is minimal running cost in subsequent exploitation. Consequently the economy of a project must be established for each specific application. Costs vary with the characteristics of the resource, and with the design of surface plant. Temperatures, flow rates, and depths must be considered to determine the costs of drilling (which constitute 80% of the total investment) and adequate reticulation systems must be specified for optimum power consistent with re-injection rates. A chemical analysis of the water extracted from the aquifer is used to determine the need for re-injection. However, this method of disposal is always recommended to ensure constant pressures in the aquifer.

Potential consumers in industry are readily identified (Table 2) but the volumes of geothermal fluid required are difficult to establish; energy consumed is frequently considered in integrated formulae giving total fuel cost divorced from rates of application. Actual water volume and final temperature levels are considered of equal significance. However, feasibility studies can be based on existing facilities. Geothermal fluids have been used extensively for diatomite plants in Iceland, for market gardens in Hungary, and for industrial process heating in USSR. In France several industries are known to consume large volumes of hot water at moderate temperatures (Table 3). The total energy required is estimated at 2 million tonnes of petroleum energy equivalent (Tep)/year and programs have been established to demonstrate a role for geothermal resources as a substitute for fossil fuels.

Geothermal energy of low-enthalpy is used most extensively by public utilities for central heating. There are several such facilities in France but typical features can be considered with the two examples, Creil and Melun l'Almont. Other applications indicating the range of BRGM studies include market gardening at Melleray and binary cycle power plants in the Central Massif.

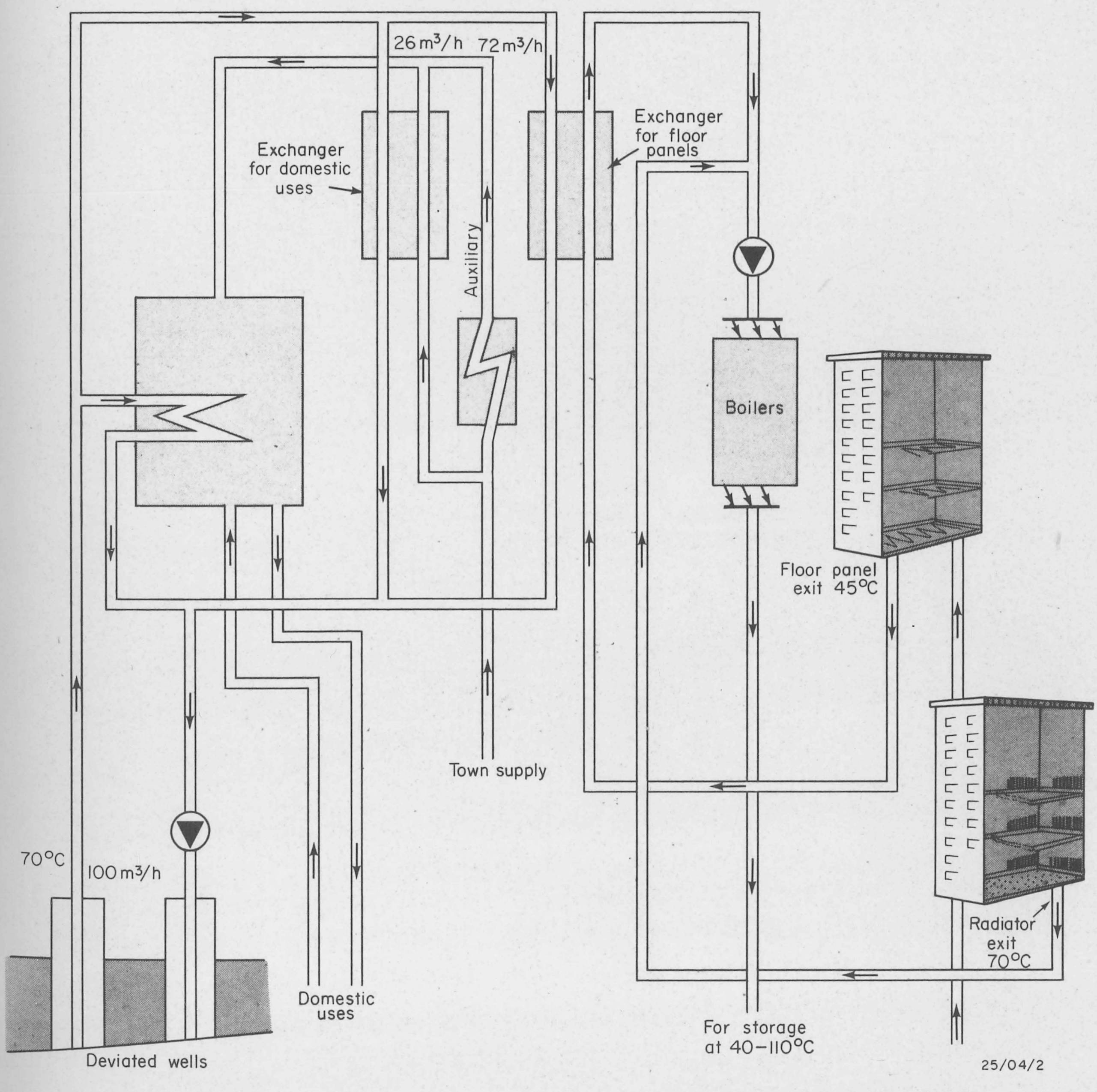
## 4. CENTRAL HEATING, MELUN L'ALMONT

Geothermal energy was first exploited in France for district heating at Melun, southeast of Paris. Plant was installed during 1969 with the object of supplying heat in various forms to a complex of nearly 3000 apartments. This installation is now considered a prototype for the Paris Basin with excellent records of technical and economic success.

Water is extracted from an aquifer at a depth of 1800 m (the Dogger) where temperatures are near 70°C. At the surface the water is circulated through a heat exchanger and is returned to the same formation using a second well for re-injection. Both wells are inclined 20° to the vertical giving separations of 900 m within the aquifer from an initial 10 m surface spacing. Normal petroleum techniques are used for drilling such a doublet, with bore diameters stepped from 34 cm at the surface to 15 cm diameter in the zone of production.

Artesian flow rates exceed 90 $m^3$/hr and no pumping is required in the production well. However a pressure of 1.7 MPa must be maintained for re-injection. Two pumps rated at 55 kW are provided for this purpose but they are not used at constant output. In summer there is no demand for space heating and flow rates in the doublet are reduced. The increase in the water density caused by cooling is then sufficient for re-injection, and no pumps are required in either side of the doublet.

Geothermal energy is extracted first to maintain the total supply of domestic hot water. For this purpose there are two reservoirs each with a capacity of 225 $m^3$. Excess heat is subsequently exploited for space heating. Floor panels used in some apartments consume 20% of total output by volume at a temperature of 45°C which is readily maintained by a geothermal heat exchanger. The remaining apartments contain conventional high-temperature hot-water radiators and the geothermal output must be boosted using oil-fired burners. Even with such a constraint it is estimated that geothermal energy supplies 40% of total heating needs for an installed capacity representing 10% of total plant investment.




Record No 1980/80

Fig 2  Schematic of geothermal energy plant at Creil

The cost of maintaining the facility is small. There is no deterioration in well fittings, and flow characteristics are constant. However, routine service is required for each of the three titanium heat exchangers. No corrosion is evident but minor deposits of scale must be removed in a chemical bath lasting 4-5 hrs each week. Consumers pay a constant annual levy with no constraint on volume - as a result, local use of domestic hot water exceeds the national average. However, the use of geothermal energy represents an annual economy of 1600 tonnes of petroleum energy equivalent.

The principal features of the Melun installation are presented in Figure 2.

5. CENTRAL HEATING, CREIL

The geothermal installation at Creil differs from Melun both in scale and in complexity. Situated north of Paris, the system heats 4000 apartments in several buildings. Construction was completed in 1975-76 and was integrated with existing fittings designed for conventional boilers.

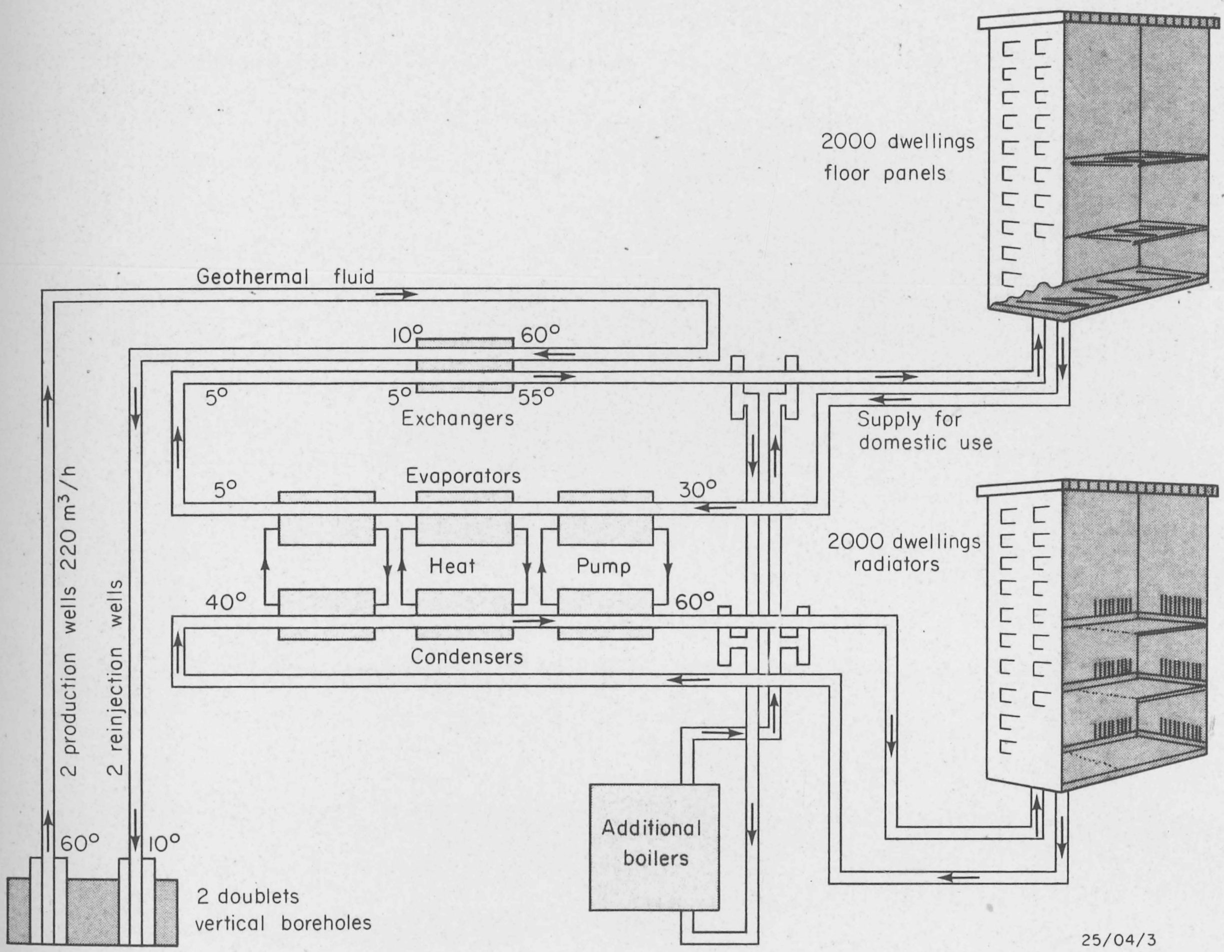
Water is extracted from the extensive Dogger formation, which is readily exploited elsewhere in the Paris Basin, but temperatures are only moderate at Creil ($57^{o}$). Such low values reflect a thinning of the sediment sequence in this region. Four wells, penetrating to depths of 1650 m, are required to ensure adequate supplies of energy. Two are used for production and two for re-injection. Unlike the Melun doublet, all wells at Creil are vertical. Consequently, individual sites are required for well-head installations at separations of at least 1 km. With such a spacing there should be no feedback of re-injected water for at least 30 years. In addition some reheating is possible from within the formation and it is anticipated that there will be no significant change in existing temperatures for at least 50 years.

Artesian flow rates of 120 $m^3$/hr can be maintained in one of the two production wells. However, only 85 $m^3$/hr is obtained by artesian flow in the second production well, and a pump rated at 60 kW is required to augment the flow to 150 $m^3$/hr. Geochemical analysis of the geothermal fluids indicate a total salinity of 30 g/L (dissolved solids); consequently the reticulation system is designed to resist corrosion. Surface pipes extending a total distance of 7 km are constructed from a resin base with an external layer of foam provided for insulation. Heat exchangers are subject to scaling but any deposits in the titanium elements can be readily removed by chemical solution during routine maintenance.

The energy consumed at Creil varies with the ambient temperature according to application. A base load must be maintained to ensure a constant supply of domestic hot water; geothermal energy is sufficient for this purpose at all times. However, a complex procedure is adopted to extract the maximum quantity of heat before re-injection. There are three heat exchangers constructed from titanium on sufficient scale to extract $10^{12}$ J/hr ($10^5$ kW). After providing for domestic hot water there is sufficient energy for all space heating when air temperatures are at least $11^{o}$C. In more extreme conditions additional energy is extracted using staged heat pumps.

The costs associated with the use of heat pumps remain contentious. Three units are installed at Creil each equipped with freon compressors variously rated at 892 kW, 745 kW, and 475 kW. Output varies according to the condition of the external coolant, but generally a further $5 \times 10^{11}$ J/hr ($5 \times 10^4$ kW) can be made available. Geothermal energy can therefore supply 100% of domestic hot water and central heating for average air temperatures greater than $8^{o}$C.

At very low air temperatures, geothermal heat becomes inadequate and conventional boilers must be used to satisfy the additional demand. The original fuel-fired boilers (carbon/oil) have been retained for this purpose. They have an installed capacity of $2.7 \times 10^{12}$ J/hr ($7.5 \times 10^5$ kW) - exceeding total demand from all sources. For the year 1977/78 it is estimated that this auxiliary heating source was required to satisfy only 35.6% of total demand. The consumption of fossil fuels was limited in that year to approximately 2500 tonnes compared to projections of 6300 tonnes in the absence of geothermal energy. With the cost of electricity included (for heat pumps and circulation) there is a net annual saving of about 3000 tonnes of petroleum equivalent.




Record No 1980/80

Fig 3 Geothermal installation with heat pumps at Melun

Although the consumption of fossil fuel is much reduced at Creil the economic advantages are difficult to assess. The total capital investment exceeds $5 million (1975) of which more than $1 million relates to the provision of heat-pump facilities. Such investment is marginal for amortisation over 30 years at an interest rate of 7%. However, in view of the escalating cost of fuel further options may be considered. In particular there is considerable technical and economic complexity related to the use of heat pumps; finance may be more readily obtained if these are eliminated from future plant designs. Costings at Creil are also complicated by excess capacities which are available from the previous installation. The capital costs of such existing systems must be amortised along with the geothermal plant and should therefore be included as the cost of conversion ("retrofit" in U.S.). Duplicate capital plant of this type can be avoided only if the geothermal facility is developed to its full extent as an integral part of new housing developments.

A schematic of the Creil plant is presented with a summary of the principal features in Figure 3.

## 6. GREENHOUSE HEATING, MELLERAY, ST DENIS-EN-VAL

In the Loiret region near Orleans more than 95% of the greenhouses are controlled by members of one organisation. The administration of this co-operative group consists of 15 committee members directed by a President. Consequently communication and liaison is relatively simple. A permanent staff is maintained in the form of a counsellor, two assistants, and a secretary. Their function is to assist members with technical matters, advise on new developments, and assess experimental data. Related matters concern the purchase of materials and equipment, selection of plant varieties, cultural techniques, management, marketing, and economics.

Many new techniques now in use by co-operative members were developed after experiments conducted at Melleray. This complex consists of 14.2 ha devoted to market gardening and 1.6 ha devoted to horticulture. In both areas it has been demonstrated that the price of fuel constitutes a very large part of costs in greenhouse cultivation. Members are therefore receptive to substitute technology based on geothermal resources. The interests of the group can be assured by committee representations, and negotiations can be conducted at group level concerning matters of finance and planning.

The advantages of conventionally heated greenhouse cultivation have diminished considerably with the rapidly increasing costs of fuel oil used for winter heating. Economic factors have forced a decline in fuel consumption accompanied by a loss of production. There has been some corresponding increase in fuel efficiency, and more appropriate crops have been selected for planting. However, previous profit levels can only be regained by substituting alternative sources of heat for oil furnaces. This rationale is easily demonstrated at Melleray where the average yearly oil consumption since 1975 remains at a level of about 3300 tonnes - representing a ratio of 210 t/ha (previous consumption had exceeded 500 t/ha). The cost for such a quantity exceeds $A300 000/ha/yr. As an indication of price penalty it can be demonstrated that provision for oil heating represents 35% of the cost in cultivating cucumbers in greenhouses.

Although these calculations identify a potential customer for geothermal energy it is essential to establish profiles of consumption before central sources of heat can be specified. For greenhouse cultivation, rates of energy consumption are highly variable, and simple averages may be inadequate as an indication of demand. In general, most florists maintain a constant temperature requiring a variation in energy consumption to accommodate loss of heat to the atmosphere. In contrast the market gardeners employ a temperature cycle with periods of dormancy, germination, and growth. Temperatures required in each period are about $5^{o}$C, $18^{o}$C, and $16^{o}$C respectively. Fuel consumption again varies with the ambient conditions but maximum consumption occurs in Spring with March and April accounting for about half the annual total.

Daily consumption levels are more difficult to predict. Fuel requirements cannot be anticipated because of variations in sunshine according to random cloud cover in each season. Similarly predictions are complicated by variations in wind strength and direction with corresponding changes in the cooling rates of the outer surface. It is certain, however, that there will be increased demand during the course of each night, and no matter how diffuse, some sunshine is always available during the day to augment artificial heating. Variable demands of this type are not easily satisfied by geothermal energy from a single well. At some times the geothermal capacity may exceed demand and therefore

## TECHNICAL AND ECONOMIC STUDIES

### ESTIMATES OF GEOTHERMAL ENERGY

Reservoir : TRIAS

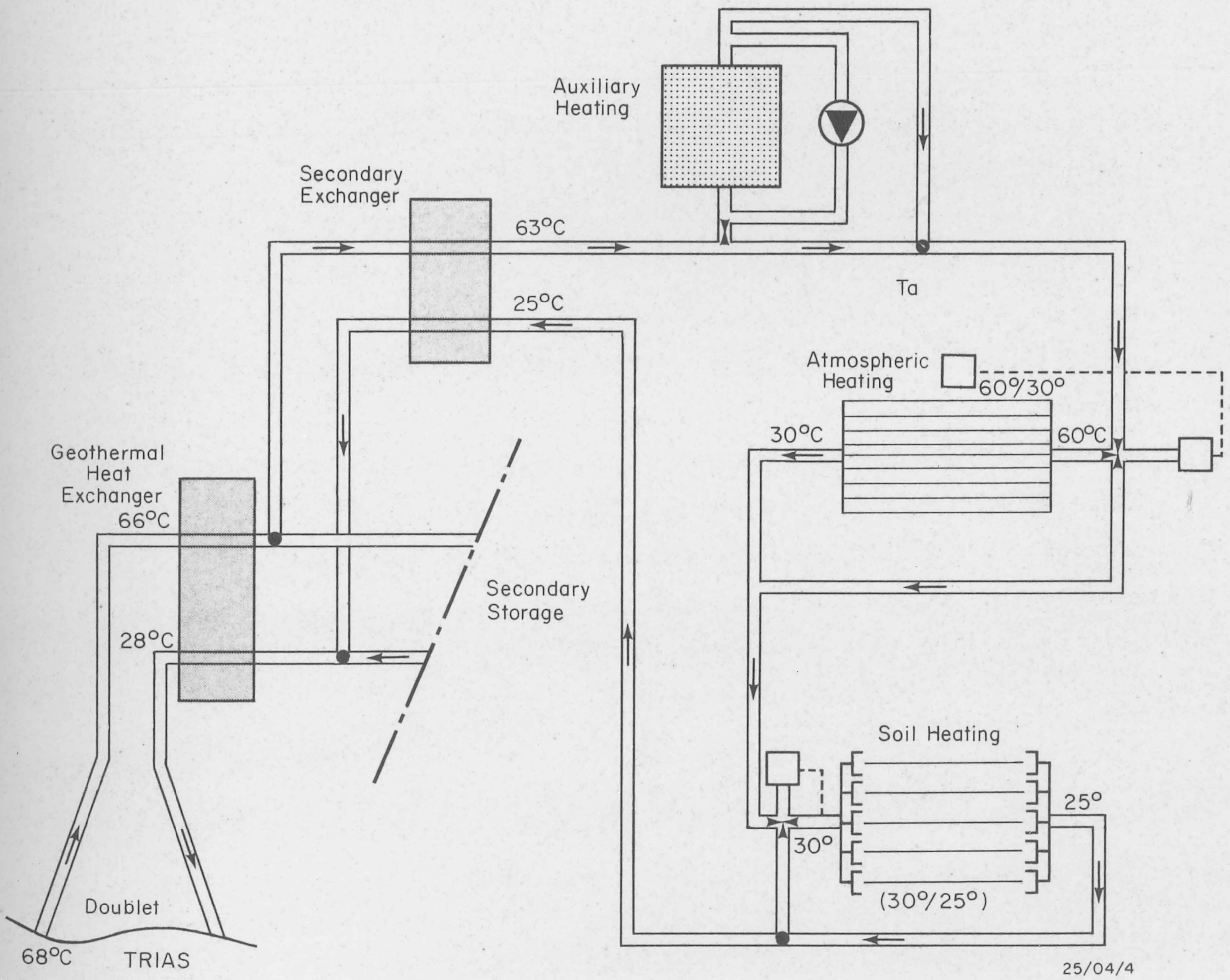
Depth of well 1800 metres

Minimum temperature in the reservoir 68°C (being 66°C at well head)

Flow rates projected : 200 $m^3$/h with 7 inch casing

300 $m^3$/h with 9 5/8 inch casing

Schematic of possible installation




Record No 1980/80

Fig 4 Technical and economic studies of geothermal heating at Melleray maximum efficiency can only be achieved if a thermal reservoir is incorporated in the design.

It is evident that the quantity of heat delivered from a geothermal resource depends on the temperature of the water that is returned for re-injection. If ground tubing is used, the return temperature may be less than 20°C. In contrast, if the preference is for atmospheric heating with minimum ground coupling, the water temperature remains high (above 40°C) but response time is reduced. Additionally culture beds may be heated directly with water at relatively low temperatures (below 40°C) but uniformity of temperature demands high circulation velocities with discharge temperatures rarely less than 30°C. Such conflicting requirements can be satisfied only with separate systems of reticulation. A system of heat exchangers is therefore necessary if all users are to be serviced from one production well. A suitable scheme is shown in Figure 4.

## 7. BINARY CYCLE GENERATORS

Geothermal resources of low-enthalpy such as those discussed in chapters 4 to 6 have been exploited directly for a variety of commercial, industrial, and domestic purposes. These installations have been constructed with specific objectives but in all cases heat is extracted for immediate consumption close to the well head. Such plants may be designed with high levels of efficiency to ensure maximum economy in long-period applications. However, if there are modifications in the existing process technology, or if new consumers are located at great distance from the available resource, existing plant may become obsolete. Consequently the installation of a central electric generator may be considered appropriate.

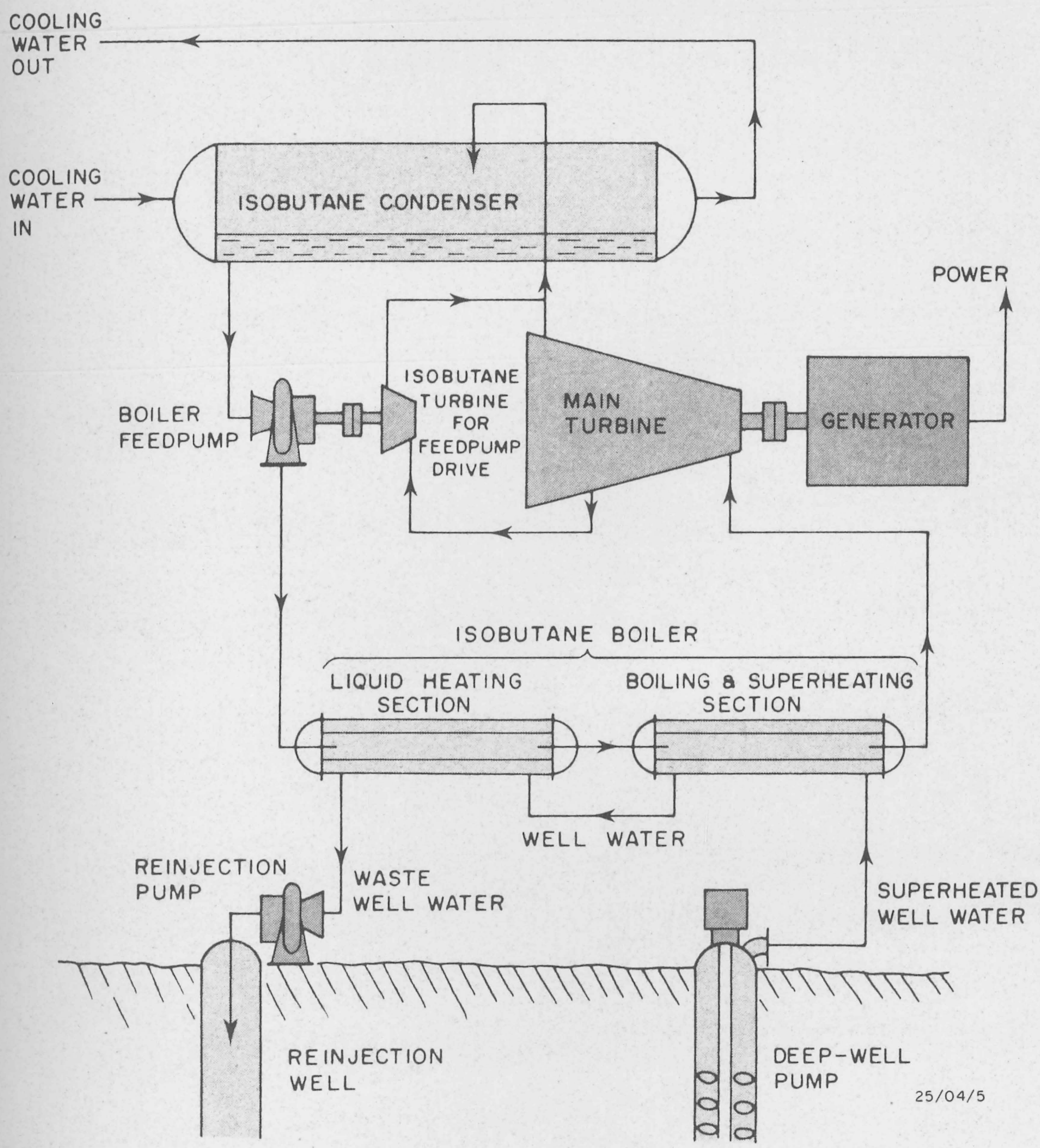
BRGM is associated with a subsidiary (SOFRETES) in a joint venture (GEOWATT) to promote and install small-scale geothermal electric power plants based on binary cycle turbines. The SOFRETES subsidiary is a French company engaged in thermal studies and solar power applications. It has industrial experience in converting solar energy into electric power by means of collectors at temperatures from 60 to 150°C. Prototype binary cycle turbines have been developed to exploit solar power, and similar units are being adapted to use low-temperature geothermal resources. Hybrid systems have also been considered, with solar power giving peak day-time output while base-load continuity is maintained by geothermal power. BRGM has been engaged to conduct site inspections and to provide engineering studies concerned with aquifer configurations, bore spacing, output volume, and resource management.

Any source of heat can be used for Rankine cycle thermodynamic conversion in turbines or compressors powered by freon vapour. The principles of the binary cycle system are illustrated in Figure 5. In Mali (West Africa) solar energy has been used as the primary source in existing SOFRETES plant. Temperatures of 75°C maintained within the evaporator allow outputs of 80 kW. However, elaborate solar collectors are required together with large-volume thermal reservoirs. These items can be eliminated where geothermal resources are available. Furthermore, a constant temperature can be ensured at all times, so allowing continuous operation with a predictable specified power. Estimates of power available with geothermal configurations depend on actual flow rates, source temperatures, line losses, pump efficiencies, and cooling spans. For low-enthalpy sources it can be demonstrated that outputs exceed 100 kW where water is extracted at a rate of 20 L/s and is cooled from 100°C to 20°C. Cost estimates for 1980 are listed in Table 4; however, the cost of supplying the hot water is not included and drilling costs may be substantial. In Australia, many isolated communities are already supplied with hot bore-water and in this case the economic feasibility may be assessed directly from Table 4.

## 8. ECONOMIC FEASIBILITY STUDIES

User consumption profiles for planned geothermal applications are first determined in an attempt to indicate the types of plant required to satisfy demand. Specifications must then be drafted to accommodate the base-load with predictable annual drift. In addition, some provision is required to satisfy intermittent surges during periods of peak demand. A range of engineering solutions based on the one general scheme can be considered; a final choice depends on economic factors inherent in each.

*Vapor-Turbine Cycle for Geothermal Power Generation*




Record No 1980/80

Fig 5 Vapor–turbine cycle diagram

As an example, feasibility studies at Melleray are based on the assumption that there is a known aquifer at a depth of 1500 m containing large volumes of water at 66°C and water is to be extracted at a rate of 200 $m^3/h$ by means of a vertical production well with 7-inch casing. A second well used for re-injection is to be drilled at a distance of 150 m with some divergence from the vertical (about 35°). The cost of such a doublet is of the order of 15 million francs ($A3 million). However, finance is available from the Geothermal Committee of the French Government to cover approximately 80% of costs associated with the first well. This money is repayable to the Government only if adequate geothermal resources are demonstrated and the doublet is completed. The consumer is therefore provided with some insurance against the risk of a dry well.

Detailed costings of the final installation are complex and depend on the configuration adopted for distribution. However, the primary requirements are indicated in Figure 4 and the costs (for 1978) are summarised in Table 5.

The Melleray project constitutes a novel use for geothermal energy in Western Europe. Consequently the EEC was requested to provide aid consistent with stated aims of the energy research and development fund (equivalent to NERDDC). The relevant committee recommended a contribution approaching 30% of the total cost, half as a subsidy and half to be repaid within 8 years (the period of amortisation can be calculated assuming the cost of fuel consumed at present rates giving a cumulative total equal to capital costs of the geothermal installation). The total cost of the first well was therefore covered by the separate contribution from the French Geothermal Committee and the EEC. In the event of success, the French contribution would assume the nature of a loan.

The Melleray consumers were required to seek other sources of finance for the remaining 20-30% of capital. Submissions were made to the Ministry of Agriculture and other public bodies for direct loans extending for 20 years at rates near 10%. Additionally the commercial banks were approached for private loans ensuring bridging finance while allowing for a final balance adjustment. Possible sources of finance and patterns of expenditure are summarised in Table 5. With finance of this type it is estimated that the cost of geothermal energy at Melleray in 1991 will be 60% less than the cost of oil or gas for equivalent heat.

The Melleray project is designed for a high density of consumers in climatic conditions colder than Australia's. For other countries, consumption profiles for greenhouse cultivation in each country would have to be compared before generalising from the economics of Melleray. Such projects appear to be viable only if grants are available in the form of interest-free loans. The true cost of such loans is not reflected in present calculations and if similar plant is installed elsewhere all interest components may need to be revised.

## 9. COMMENTS

The use of low-temperature ($55^{\circ}$ to $80^{\circ}$C) geothermal energy requires very large, nondivisible investment with a minimum of about 5 to 6 million French francs ($A1 million) for each operation in 1974. This initial expenditure is partly independent of the quantity of heating to be supplied. It is possible, however, to vary the calorific power of the installation by hot-water pumping which then entails an operating cost. It should be noted in this context that for a given yield, the distance separating the production and re-injection wells determines the duration of the exploitation at constant temperature of the system, that is, the time between the beginning of the exploitation and the first appreciable temperature drop ($1^{\circ}$C, for instance) in the production wells. However, the yield itself constitutes one of the factors limiting the type and duration of the exploitation.

Furthermore, if additional heat losses by conduction are to be avoided, the hot water should ideally be used within a few kilometres, but certainly a few tens of kilometres, of the well head. Several types of exploitation have been suggested; they include domestic and industrial space heating, greenhouse heating, soil warming, fish farming, animal husbandry, various industrial fermentations, the drying of a range of organic materials, and so on. It has also been shown to be economic to use geothermal energy to pre-heat water, which may then be heated further by electricity, in a wider range of applications.

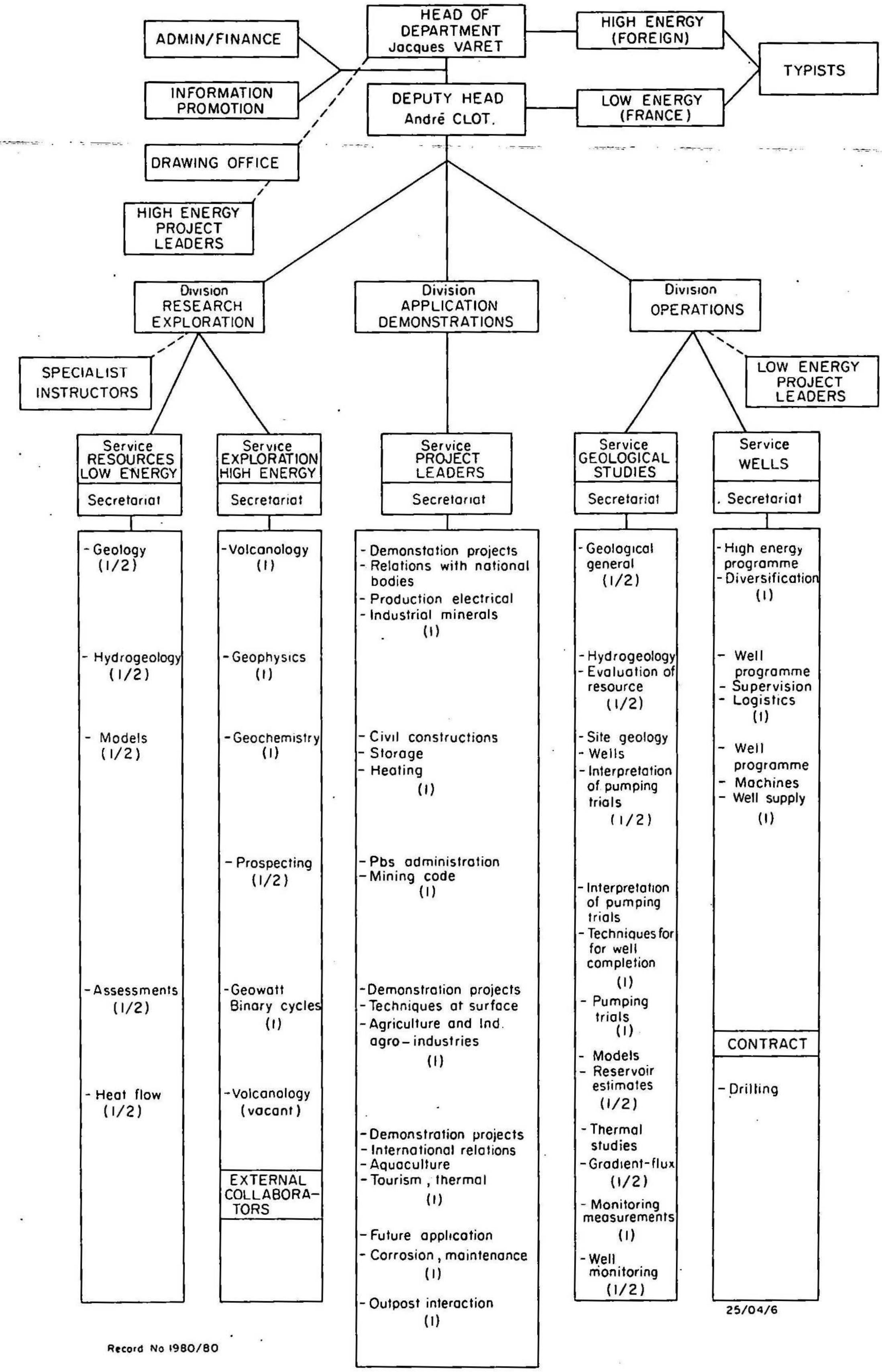
The problem therefore of exploiting "warm rock" geothermal resources is not purely scientific or technological. It involves either (1) a fortunate geographical coincidence, by which suitable consumers who are willing to change to a geothermal supply are situated in or near a geothermal source area, or (2) the deliberate encouragement of suitable industrial development in newly located geothermal areas combined with the use of district heating schemes in any new housing developments in the same area. These options clearly require major decisions of Government policy.

In most circumstances the size and siting of a residential district is determined by other factors more important than geothermal considerations. These include water problems, waste disposal, transport, financial problems, and, more simply, the choice of development zones for purely urban reasons.

Finally, it is possible in France to compare directly a central geothermal plant with a traditional boiler-house facility supplying communal energy needs. However, in Australia there are usually a number of individual or semi-collective solutions based on consumer preference for electricity, gas, oil, or solid fuel. Conversion to central units involving extensive reticulation grids can be considered only if financial benefits can be demonstrated over each alternative.

## 10. ACKNOWLEDGEMENTS

This report was made possible by a French Government Scholarship for Science and Technology. The facilities of BRGM in Orleans were made available by Dr J. Varet, and the administration procedures of that organisation were simplified by M. Napias. M. LePorz of the French Embassy in Canberra provided invaluable assistance in preparations for travel and every encouragment was offered by members of his staff. Numerous individuals extended their hospitality in France, making the duration of study entirely pleasant (except for the most inclement Summer on record!).




Record No 1980/80

**Table I.** Structure of the BRGM Geothermal Department
Figures noted in ( ) indicate number of persons employed in service groups

TABLE 2

APPLICATION OF GEOTHERMAL FLUIDS ACCORDING TO TEMPERATURE

| Fluid | °C | Application | |
|---|---|---|---|
| | 200- | | |
| | 190- | | |
| Saturated steam | 180- | Evaporation of highly concentrated solutions<br>Refrigeration by ammonia absorption<br>Digestion in paper pulp, kraft | Conventional power production |
| Saturated steam | 170- | Heavy water via hydrogen sulphide process<br>Drying of diatomaceous earth | Conventional power production |
| Saturated steam | 160- | Drying of fish meal<br>Drying of timber | Conventional power production |
| Saturated steam | 150- | Alumina via Bayer's process | Conventional power production |
| Saturated steam | 140- | Rapid drying of farm products<br>Canning of food | Conventional power production |
| | 130- | Evaporation in sugar refining<br>Extraction of salts by evaporation and crystallisation | |
| | 120- | Fresh water by distillation<br>Most multiple effect evaporations, concentrations of saline solution | |
| | 110- | Drying and curing of light aggregate cement slabs | |
| | 100- | Drying of organic materials, seaweed, grass, vegetables, etc.<br>Washing and drying of wool | |
| | 90- | Drying of stock fish<br>Intense de-icing operations | |
| | 80- | Space heating<br>Greenhouses by space heating | |
| Water | 70- | Refrigeration (lower temperature limit) | |
| Water | 60- | Animal husbandry<br>Greenhouses by combined space and hotbed heating | |
| | 50- | Mushroom growing<br>Baineological baths | |
| | 40- | Soil warming | |
| | 30- | Swimming pool biodegradation fermentations<br>Warm water for year-round mining in cold climates<br>De-icing | |
| | 20- | Hatching of fish, fish farming | |

TABLE 3

POTENTIAL CONSUMERS OF GEOTHERMAL ENERGY IN FRANCE

- Dairy farms and milk industry requires 1 to 1.5 litres of hot water (30°-50°C) per litre of milk;
- salt production requires 50 to 55 litres of hot water (20°-60°C) per kg of salt;
- brewing requests 0.4 litres of water (35° to 55°C) per litre of beer produced;
- canning of food requires 4 to 5 litres of water at 30° to 60°C per kg of canned food;
- paper industry requires an average of 0.5 TEP energy per ton of paper produced.

In France, this alone represents more than 2 million Tep/year, consumed mainly as hot water and steam.

(Tep - tonnes of petroleum energy equivalent)

TABLE 4

COST OF BINARY CYCLE GEOTHERMAL POWER PLANTS

NOTES

1. Costs herafter given are estimative costs. Following assumptions are taken into account:

   a) cold source temperature ..... 25°C ± 5°C
   b) hot spring temperature ..... 85°C ± 5°C
   c) no very serious corrosion problem concerning hot spring salts content
   d) geothermal power plant located close to the hot spring
   e) energy distribution network not included

2. Final costs will be fully known after site data gathering and preliminary project study.

3. Costs of transportation, civil engineering work (road, room, specific hot spring catching work if necessary, etc....) are not included.

4. Personnel training - An on-site training period for 1 or 2 local technicians ("assembling" item) is included in the costs below.

   A complementary training program in SOFRETES/MENGIN and BRGM facilities is proposed. This program takes place during assembling and test equipment activities in plant and laboratory : 15 free of charge training days, daily expenses : 3000 FF. + air flight tickets to be supplied by customer organisation.

5. Costs below are valid for 1 unit order. For 5 to 10 units, costs per unit will drop by 20 to 30%.

| Average power<br>Estimative cost | 3-5 kW to 5 kW | 10 kW | 15 kW | 30 kW | 45 kW |
|---|---|---|---|---|---|
| Capital investment (*) | 1) 750,000 FF<br>2) 170,000 $ | 950,000 FF<br>212,000 $ | 1,100,000 FF<br>245,000 $ | 1,500,000 FF<br>335,000 $ | 2,000,000 FF<br>445,000 $ |
| Installed kW estimative cost | 1) 150,000 FF<br>2) 33,000 $ | 95,000 FF<br>21,200 $ | 73,000 FF<br>16,200 $ | 50,000 FF<br>11,100 $ | 44,000 FF<br>9,800 $ |
| kWh estimative cost | 1) 1.90-0.95 FF<br>2) 42c-21c | 1.20-0.60 FF<br>26c-13c | 0.90-0.45 FF<br>20c-10c | 0.65-0.33 FF<br>14c-7c | 0.55-0.28 FF<br>12c-6c |
| 5 years maintenance contract spare-parts | 1) 50,000 FF<br>2) 11,000 $ | 50,000 FF<br>11,000 $ | 100,000 FF<br>22,000 $ | 100,000 FF<br>22,000 $ | 100,000 FF<br>22,000 $ |

FOB prices

(*) Capital investment includes thermodynmaic conversion loop, cold source, performance and factory tests, assembling on site, starting up and special project study.

1) Costs in French Francs
2) Costs US currency

1980 economic conditions

For higher powers in 50 kW to 500 kW power range, one single unit or a group of 30 kW - 45 kW module units.

Table 5

## Table of financial charges (in thousands of Francs)

HYPOTHESES :
- Geothermal Committee Loan 4460 (1st well)
- 1550 (2nd well)
- EEC loan 1949
- EEC grant 1950
- Autofinance : 3363 (20% of total project monies)
- complementary funding : (9% over 15 years) 5752

| YEAR | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - Investments | 5 800 | 12 965 | | | | | | | | | | | |
| - Exploitation costs | | | 451 | 681 | 749 | 824 | 906 | 996 | 1 096 | 1 206 | 1 326 | 1 459 | 1 605 |
| - Annual payments EEC | | | - | 366 | 366 | 366 | 366 | 366 | 366 | 366 | 366 | - | |
| INTEREST | | | | | | | - | 45 | 60 | 45 | - | | |
| Geothermal Committee | | | | | | | | | | | | | |
| CAPITAL | | | | | | | 1 502 | 1 503 | 1 502 | 1 503 | - | | |
| - Complementary funding (autofinancing) | | 259 | 714 | 714 | 714 | 714 | 714 | 714 | 714 | 714 | 714 | 714 | 714 |
| TOTAL CHARGES | 5 800 | 13 224 | 1 165 | 1 761 | 1 829 | 1 904 | 3 488 | 3 624 | 3 738 | 3 834 | 2 406 | 2 173 | 2 319 |
| . EEC grant | 840 | 1 110 | | | | | | | | | | | |
| . EEC fund | 500 | 1 449 | | | | | | | | | | | |
| . Geothermal Committee Fund | 4 460 | 1 550 | | | | | | | | | | | |
| . Autofinance | | 3 363 | | | | | | | | | | | |
| . Complementary funding | | 5 752 | | | | | | | | | | | |
| | 5 800 | 13 224 | | | | | | | | | | | |
| Output MWh | | | 22 000 | 25 000 | 30 000 | 30 000 | 40 000 | 40 000 | 40 000 | 40 000 | 40 000 | 40 000 | 40 000 |
| Selling Price MWh Geothermal | | | 59 | 65 | 70 | 75 | 80 | 84 | 93 | 96 | 61 | 57 | 57 |
| Receipts | | | 1298 | 1625 | 2100 | 2250 | 3200 | 3360 | 3720 | 3840 | 2440 | 2880 | 2280 |
| Cost MWh in Francs (1978) | | | 47 | 47 | 46 | 45 | 43 | 41 | 41 | 39 | 23 | 19 | 17 |