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Energy from warm rocks

Ron Oxburgh examines the prospects for geothermal energy in Britain, where a new research programme is to begin

IN the first few years of this century, an electrical generator with an output of several kilowatts was installed at Lardarello in northern Italy, to be driven by the steam which emanated naturally from the ground. It was the first modern attempt to harness the natural heat of the Earth to man's purposes. Relatively little further progress was made until the 1930s, but since then the use of geothermal energy has increased considerably, until today about 1100 MW are generated by this means in seven countries. Most of these installations pre-dated the rapid rise in fossil fuel prices of the past few years, and even then were competitive with conventional means of power generation. Today their situation is still more favourable.

Fifty or more countries are now involved in geothermal exploration. The number was recently increased by one with the decision announced by the UK Department of Energy to spend £840,000 on the geothermal exploration of Britain over the next three years. That decision was made largely on the basis of Energy Paper No. 9 (*Geothermal energy: the case for research in the United Kingdom*), a special report prepared by the Energy Technology Support Unit at Harwell, in which Dr John Garnish, the author, argues cogently for a cautiously optimistic approach to the prospects of geothermal energy in the UK.

Heat by convection

Heat is continuously generated within the Earth by the radioactive decay of unstable isotopes (mainly of U,Th and K) and is lost from the surface at an average rate of about 1.5 μcal cm^{-2} s^{-1} (63 mW m^{-2}). At depths greater than about 80 km heat transfer within the Earth is mainly by convection, but above that mainly by conduction; rocks are relatively poor conductors of heat and within this outer zone the conductive thermal gradient ranges from less than 10 °C km^{-1} to about 60 °C km^{-1}. This is true over more than 95% of the Earth's surface, within the interiors of the great tectonic plates.

Along the margins of the plates, however, and very occasionally within them, heat may locally be transferred to the surface or to within a few kilometres of it by convection. The convective medium in these cases is magma, or molten rock, at temperatures between 800 °C and 1100 °C. The magma commonly interacts with ground water circulating in the pores of the near surface rocks to give rise to geysers, hot springs or fumaroles. Drilling to 1,000 m or so in such areas may provide flows of water or steam at between 200 °C and 300 °C which, in favourable circumstances, can be used to drive turbines and generate electricity. All the major producers of geothermal electricity—Italy, the Western USA, New Zealand, Japan and Mexico (1,030 MW together)—exploit situations of this kind, and are all situated in the tectonically unstable earthquake and eruption-prone margins of plates.

Rocks at comparable temperatures may be found beneath other parts of the Earth's surface, such as the UK, where subsurface temperatures are governed largely by conduction, but they are much deeper. At the depth limit of present drilling experience (~9 km for a cost of £2–3 million), temperatures in such areas rarely exceed 300 °C. Furthermore, it is not sufficient to reach hot rock; if the heat is to be used it must be extracted by means of circulating fluids, and for this process to be effective the fluid must be able to permeate the hot medium thoroughly through pores and fissures. With increasing depth, however, the weight of the overlying rock tends to close pores and fissures and reduce the permeability to a very low value.

For these reasons, in most places the hot rocks which everywhere underlie us are at present both too expensive to reach and too impermeable to exploit, and are rather unlikely to provide the large quantities of water suitable for the economic generation of electricity by conventional technology (temperatures in excess of 200 °C are required).

Alternative applications

If, however, we consider alternative applications of geothermal energy, the position is quite different. There is a wide range of uses for water above 65 °C when it is used directly in a heat exchanger rather than to generate electricity. Taking 100 °C as a convenient reference value, rocks at this temperature may be reached virtually anywhere in the world by drilling holes well within the depth range of present technology. Whether these "warm rocks" constitute an exploitable natural resource depends upon the drilling costs of reaching them, their permeability structure, and the availability of a local demand for the low grade heat they can supply.

The economic considerations are now more finely balanced. As a very rough indication: given both suitable reservoir conditions at depth, and a suitable local market for the hot water, warm rock geothermal energy is at present competitive with fossil fuels if temperatures of 100 °C can be reached at 3 km or less. If, however, the cost of fossil fuels rises faster than drilling costs, this depth will be increased and the position of geothermal resources relatively improved.

Viewed in this way, the evaluation of UK geothermal resources becomes a problem of identifying those areas with slightly higher than average geothermal gradient and of understanding the subsurface distribution of permeability sufficiently well to distinguish those which are capable of successful exploitation. This latter problem is not a simple one, but is tractable by combining the expertise of the oil industry in understanding and controlling the flow of fluids underground with experience of hydrogeologists of rock permeabilities and natural underground circulations of water in the UK.

The problem of identifying regions of sufficiently high temperature is less easy. In the UK these are unlikely to be so pronounced that they give rise to significant perturbations of the surface magnetic field or the electrical conductivity structure of the crust, and there is little alternative to some kind of direct measurement of temperature. Broadly, two approaches are possible. Deep holes may be drilled and temperatures measured at the proposed depth of exploitation. This is undoubtedly the safest method of exploration, but it is impossibly expensive unless the hole has been drilled for some other purpose which meets most of the costs.

The other approach is to make very precise measurements in shallow holes and use these as a basis for extrapolation to greater depth. The difficulty here is that near surface temperatures may be influenced by climatic changes (ice age effects may still be recognised hundreds of metres below the surface), the circulation of ground water, topographic irregularities of the surface and even erosional processes; for these reasons measurements are made in holes more than 200 m deep and preferably more than twice that depth, and are then corrected for the effects of the various perturbing factors. The heat flux, q, is given by $q=k\beta$ where k is the mean thermal conductivity of the rock, and β the mean thermal gradient over a particular depth interval. The heat flow value determined in this way may then be used to predict the temperature at some greater depth with an accuracy which depends largely upon how well the thermal conductivity of the rocks down to that depth

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nown. Heat flow measurements of his kind must form the main basis of ny exploration programme.

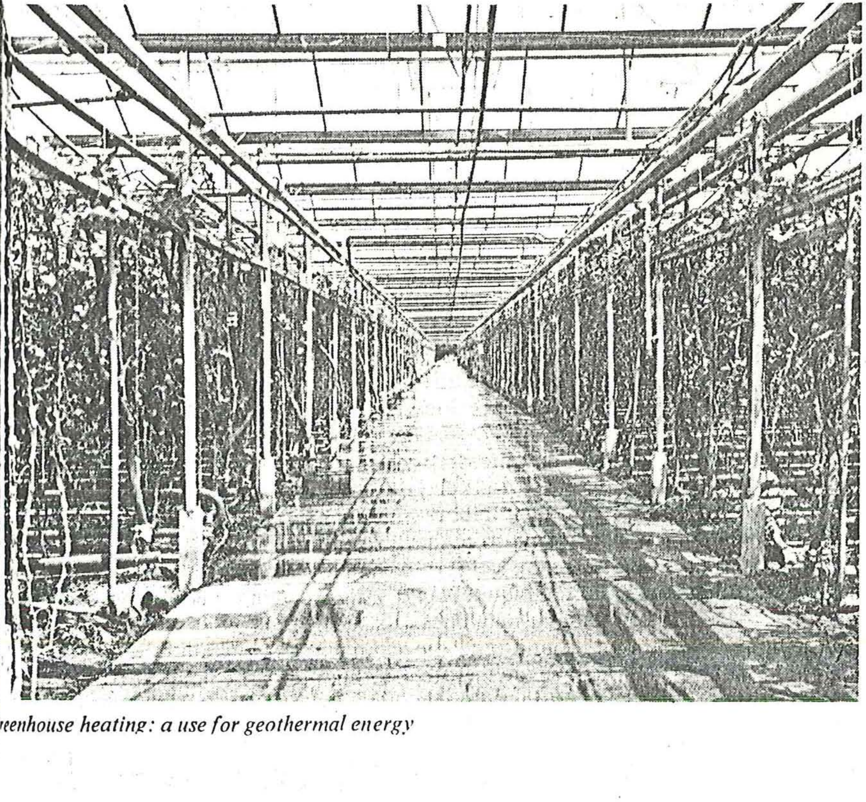
Although a relatively large number d underground temperatures have een measured in the UK, there have een relatively few reliable heat flow neasurements—about 25. Although nany of the temperature measurements ere sufficiently accurate for the purposes for which they were made (ventiation in mines, for example), they do o not form a reliable basis for extraolation to significantly greater depths. imilarly the temperature logs obtained y oil companies, by measurement in oles when drilling is complete, are ubject to very large errors because he temperatures around the hole ave been seriously perturbed by the rilling process itself; the circulation of old drilling fluid from the surface to he bottom of the hole may change the ock temperature by some tens of legrees and it is months or years efore the rock returns to its initial emperature.

nformation inadequate

Energy Paper No. 9 synthesises the bservational information at present vailable from a variety of sources and concludes that although there are some arts of the country where it is very ikely that geothermal energy would e competitive with fossil fuels, the emperature information at present vailable is inadequate to make any verall assessment of the country's eothermal resources. Detailed cost nalyses are presented to support the nain recommendation that the possible enefits to the national energy budget ustify the initiation of a national programme of geothermal exploration. Although the report itself makes an excellent case for such a programme, perhaps the most telling argument is that in France today there are several district heating schemes operating competitively on low grade geothermal energy, and that a number more are planned or are under constructon; these schemes have been established in situations which can be matched closely in the geology, and probably in thermal structure, by the Mesozoic sedimentary basins of this country.

It should perhaps be emphasised that although heat is continuously generated within the Earth, in most situations geothermal energy must be regarded as a depletable resource, and its exploitation as heat mining; the rate of convective removal of heat from the rocks of a hot source area is orders of magnitude faster than the heat can be replaced by conduction from below. In most cases geothermal fields are exploited at a rate designed to exhaust them in about twenty years. In a minority of situations (active volcanic regions, for example), the transport of heat to the surface by magma may match or exceed its extraction rate and the resource is not depletable, at any rate not significantly so. Questions now arise of just how and when possible geothermal resources should be exploited, and how large a contribution they might be expected to make to the national energy budget.

The answer to the first of these questions to some extent depends upon the answer to the second. If legitimate geological expectations were satisfied and suitable markets for the available energy were found, it would not be unreasonable to think of geothermal energy providing 1% or even 2% of the country's energy for 20 years. The greatest uncertainty must, however, be the availability of the market. The energy is available in the form of hot water in the temperature range 65–100 °C, temperatures which at present are generally considered too low for the efficient generation of electricity, and so the heat must be extracted from the water directly.



reenhouse heating: a use for geothermal energy

Photo: *The Grower*

Furthermore, if additional heat losses by conduction are to be avoided, the hot water should ideally be used within a few miles, but certainly a few tens of miles, of the well head. There are various uses for low grade heat of this kind—domestic and industrial space heating, greenhouse heating, soil warming, fish farming and animal husbandry, various industrial fermentations, the drying of a range of organic materials and so on. It has also been shown to be economically viable to use geothermal energy for pre-heating of water, which may then be heated further by electricity, for a wider range of applications.

Policy decisions required

The problem therefore of exploiting "warm rock" geothermal resources is not purely scientific or technological. It involves either a happy 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 the deliberate encouragement of suitable industrial development in the geothermal areas and the use of district heating schemes in any new housing developments in the area. These clearly require major decisions of public policy. Attractive features of such developments would be the fact that warm-rock geothermal energy is virtually pollution-free—rejected warm water which has been used is reinjected into the ground for re-circulation. The surface plant is small and inconspicuous by comparison with any conventional power station.

The time scale of possible exploitation of UK geothermal resources now becomes clearer. It is reasonable to expect that the programme planned for the next three years will give reconnaissance information for much of the country. If the prospects appear reasonable at that level it would be appropriate to undertake a more intensive study of areas of particular interest. This second stage would require extensive shallow drilling (about 500 m) and some deep drilling, and could take five years; the rate of progress would be constrained by both the availability of drilling capacity and the time taken for drilling—although there is great variation, a 4 km hole could take nearly 12 months to drill. It might then be possible to make an informed decision on whether to attempt commercial exploitation of the country's geothermal resources in the latter part of the 1980s.

If a positive decision were taken at that stage a third phase of development could begin with drilling of production holes, the planning of distribution systems and the stimulation of the potential market. The use of geothermal energy on any significant scale could not be expected before the turn of the century. This timetable is probably about the fastest which is practicable, and if desirable it could easily be lengthened: it would, however, mean that geothermal power became available about the time that production from the North Sea oil and gas fields began to drop significantly, and Britain changed from being a net exporter of oil to an importer once more.

Any consideration of the geothermal prospects of the UK, however, goes beyond the question of the heat which may be extracted from warm rocks of the upper crust. Experiments have been going on for some years at the Los Alamos Scientific Laboratory in the United States with a view to generating fractures artificially to permit water circulation both through rocks which are naturally impermeable, and through those which are so deeply buried in the crust that natural pores and fissures have normally closed. If these experiments were successful, it could become feasible to use such "hot rocks" to heat circulating water sufficiently for the generation of electricity.

The economic viability of such a scheme would be much enhanced by improvements in deep drilling methods; at present drilling costs roughly double for every 2 km increase in hole depth. Such a development would increase the available geothermal resource by more than a factor of 10 and free it from the geographical constraints which limit the use of warm water. The national long term geothermal strategy should, therefore, be seriously re-appraised if the Los Alamos experiments are promising. But no one should pretend that geothermal energy will solve the UK's energy problem; a small and possibly highly profitable resource, on the other hand, probably does exist—it is also a resource for the exploitation of which there are no large savings of scale, so that piecemeal development to satisfy local requirements is possible.

No complacency

It is probably fair to say that in the present world economic climate a country cannot afford not to investigate its geothermal resources further. It might be asked whether it is proposed to carry out the UK's geothermal exploration sufficiently rapidly: at present there is neither the drilling capacity nor sufficient trained manpower to mount an extensive cra programme, but even if there were would not necessarily be more effecti than a phased and progressively increasing effort over the next 10 year The essential point is that no one b lured into a false sense of energy complacency during the next two decad of oil abundance, to the detriment o the development of other resources o which everyone will later depend.

A few may wish to ponder the por that many of the UK's large pow stations reject hot water at tempe tures which are regarded as suitab for geothermal exploitation in oth parts of the world, and perhaps question the wisdom of today conti ing to charge a government author with the limited mandate of generati electricity at the lowest possible pri And for those to whose lot it f from time to time to defend the r of "pure science" in straitened e nomic circumstances, it is worth poi ing out that the study of terrestrial h flow which was until two years ago o of the most esoteric, albeit fascinati branches of geophysics, has overni become directly "relevant" a applied. Had not the Natural Enviro ment Research Council (NERC) su ported two university groups in th fields for a number of years, the U would have completely lacked t technical expertise with which to i plement fully its present geotherm programme.

Adjust, amend and heal

The face of big science is changing constantly. **Wil Lepkowski** reports from Berkeley, California, on the way a famous laboratory has tried to adapt

OSCAR WILDE was once heard to say of an old acquaintance, "There goes a man with a promising past." One might be tempted to direct the same comments at the Lawrence Berkeley Laboratory of Berkeley, California, where eight men have won Nobel Prizes for work in high energy physics, nuclear physics, nuclear chemistry, and photosynthesis. All winners, save the famed, forceful Ernest Orlando Lawrence, still live and form a solid command of senior directors who continue to chart the fortunes of the facility.

It is clear that the time of grand high drama in research is over at the old Lawrence Radiation Laboratory. For one thing, its support now comes from the Energy Research and Development Administration (ERDA), whose mission is much more broad and ambitious than that of its predecessor, the Atomic Energy Commission (AEC). For another, the research budget for the things the Rad Lab always did best no longer arises at the rate it once did. And for a third, ERDA's new mission is not only much broader that the AEC's but is focusing its formula on industrial commercialisation of energy research and development, chiefly big scale systems.

Physics remains the most potent resource of the Lawrence Berkeley Laboratory (LBL). But the Laboratory is no longer the mecca for the brightest young minds seeking achievement through that once unique Rad Lab combination of men and machines. The men might still be around (and the use of the word "men" is deliberate, for the Laboratory is distinctly male dominated), but the machines are n High energy physics is no longer d on site. The famed Bevatron is us now for cancer research and treatm and for nuclear physics. Officials sa new and exciting era could come i being through the Positron–Electr Project with Stanford University. that project Stanford's Linear Accele tor would inject electrons and posit into a new storage ring and the t particles would collide to prod energy patterns of unprecedentedly detail. But critics note that the n machine will not be at Berkeley but Stanford. Laboratory officials may it doesn't matter, but it really d The place to be will be Stanford.

Sinking sensation

One thus hears oddments of comm tary in the labs, and on the bus t shuttles researchers between the U versity of California campus and t Laboratory, that LBL is "sinki The precise reasons are hard to tr down because the Laboratory is longer laying people off and the search budget is rising—from current $47 million to around million by the end of the next f year. The sinking sensation is c

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