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TITLE: THE POTENTIAL FOR THE PRODUCTION OF POWER FROM GEOTHERMAL RESOURCES

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Statement by Morton C. Smith, Project Manager, Geothermal Energy,
Los Alamos Scientific Laboratory, The University of California,
Representing the United States Atomic Energy Commission, before

The Subcommittee on Water and Power Resources,
Committee on Interior and Insular Affairs,
United States Senate, Hearing on

The Potential for the Production of Power from Geothermal Resources.

INTRODUCTION

Mr. Chairman, Members of the Subcommittee on Water and Power Resources: I am honored to have been asked by the Atomic Energy Commission to discuss with you that part of our Nation's geothermal resource which exists simply as heat in the earth's crust. It is the largest reservoir of directly usable energy that is accessible to man; it is inherently clean energy; and I am deeply involved in the challenging job of learning how to make it useful.

For brevity, many of us identify this as the "hot dry rock" type of geothermal energy. Actually, most of the hot rock that is within our reach is not completely dry. For any of several geologic reasons, however, it does not usually have within it the combination of a large water content, connected circulation channels, and impermeable barriers, that together produce a useful natural reservoir of steam or hot water. As a result, we cannot in general simply drill a hole into hot rock and expect nature to bring the heat up to us in the convenient form of steam or hot water. If we are ever to use a significant fraction of this very large energy resource we must develop it more aggressively, and actually create the circulation systems within it that in most places nature has failed to provide.

We are now quite optimistic that man-made geothermal systems are possible; that we have both the ideas and the tools to develop them; and that they are very much worth making. However, to prove all this will of course require a significant investment of time, effort, and money.

THE MAGNITUDE OF THE DRY ROCK RESOURCE

In its broadest sense, geothermal energy is all of the vast amount of heat in the earth's interior. Most of this heat is so far beneath the earth's surface that it is beyond our present reach, and much of the rest is at too low a temperature to be immediately interesting as a possible energy source. However, even that relatively small fraction of the earth's crust which we can penetrate now, with existing drilling equipment, certainly contains enough useful heat to satisfy all of mankind's energy needs for many thousands of years.

Suppose for example that we could isolate the 40 cubic miles of hot rock shown in this sketch (Sketch "A")* and somehow cool it by 200°C (360°F). The amount of energy that we would have extracted in cooling it is shown on the sketch. Neglecting the numbers themselves, the significant fact is that they represent just the amount of energy that was used in the United States in 1970 for all purposes -- not just for generating electricity, but also for heating houses and driving automobiles and smelting iron ores, and everything else. This is also approximately the energy content of all of the oil on the north slope of Alaska. It is a surprisingly large and very useful amount of energy.

As a boulder in someone's driveway, 40 cubic miles would be an impressive amount of rock. As a fraction of the earth's crust, it is much less than a drop in a bucket. At depths

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*Attached illustrations to be screened as indicated in test.

that we can now reach routinely with rotary drilling equipment, there are within the United States many thousands of cubic miles of rock at temperatures at least as high as that implicit in the sketch -- 570°F. Where lower temperatures are useful, say 200°F to heat a house, we can reach usefully hot rock almost anywhere by drilling downward not more than a few thousand feet.

The heat in "dry" rock of the earth's crust is, then, by far our largest accessible reservoir of immediately usable energy. It is also by far our most broadly distributed energy source; at sufficient depth it exists everywhere, and that, unfortunately, is not equally true even of sunlight. Hot rock is a completely reliable energy supply, which will not be disturbed by a storm or a pipeline failure or a shipping problem. And it is a relatively clean source, since the energy already exists in it as heat so that we do not have to burn a fuel or operate a reactor to produce it. It is, in fact, a most attractive energy source, although with two obvious disadvantages: (1) In most places it is a relatively low-temperature source of heat, and it is therefore not the ideal energy supply for all purposes. It is evident, for example, that we cannot use geothermal energy directly to melt iron or propel jet aircraft. (2) The engineering methods required to extract energy from hot dry rock, economically and at a usefully high rate, appear to exist, but they have not yet actually been demonstrated together in this specific application.

AN ENERGY EXTRACTION SYSTEM

Under sponsorship of the Atomic Energy Commission, Los Alamos Scientific Laboratory has undertaken to investigate the possibilities, problems, and probable usefulness of man-made geothermal-energy systems in hot dry rock. Our general concept is a simple and straightforward one. As is indicated in this sketch (Sketch "B"), we propose to drill a hole downward into the hot rock -- and there are many places where the hole needed to reach usefully hot rock will not be as deep as the 15,000 feet shown here. Through this hole we will inject the water that in most places does not occur naturally. The water, in its passage through voids and cracks in the rock, will be heated to very nearly the temperature of the rock itself, and will then be returned to the surface either as steam or as very hot water. At the surface we will extract and use this heat, and we will then reinject the water into the underground system. Undoubtedly we will bring some dissolved material to the surface in the hot fluid, but in a closed circulation loop such as that shown we should be able to contain and control it. It will be necessary to add some water to the system to make up for leakage and for shrinkage of the rock as it cools, but in a well-engineered system the amount of makeup water required should be relatively small. We foresee no reason for releasing water from the system into the surface drainage, and operation of such a circulation loop should involve no danger of chemical or thermal pollution of streams or lakes.

We have of course considered a number of variations of this general system, according to the characteristics of the subsurface geology, and eventually we would like to try several of them. For example, in a permeable formation, we might use a water-flooding technique similar to that being used so successfully in secondary recovery of petroleum. This would involve drilling an array of holes, injecting cool water through some of them, letting the water sweep through the formation to extract most of its heat, and then recovering it as hot water or steam from the rest of the holes. Such a system could be developed on a very large scale, and it should be a very economical one.

However, in our first investigations, we would prefer to try a simpler and more modest system, at the smallest size that will be representative of the concept and convincing to industry. This minimum system appears to be of the type shown in the sketch, which should be practical wherever the hot rock is reasonably impermeable to water. We would create it by drilling two holes of unequal depth into the hot rock, connecting them underground through a very large crack system produced by hydraulic fracturing, and then connecting them at the surface through a heat exchanger -- which eventually might provide energy to a small power plant.

Hydraulic fracturing is a common method of completing oil and natural gas wells. It is done hundreds of times a week simply by pumping water down a pipe to create a fluid pressure within the hole sufficient to crack the rock around it, and then continuing to pump water into this crack until it has extended to the desired size. In a deep hole the usual result is a vertically oriented, pancake-shaped fracture, which is generally less than half an inch across at its widest opening, but may have a radius of hundreds or even thousands of feet. A crack of these dimensions would provide not only an underground connection between the two drill holes but also a heat-transfer area great enough so that a large flow of water passing through it could be heated continuously, and a high rate of energy extraction thereby maintained. In experiments just completed at a depth of about 2500 feet under the Jemez Plateau of north-central New Mexico, we have produced a series of hydraulic fractures in hot granite. The surface pressures required were in the range of about 1100 to 1700 pounds per square inch, and we had no particular difficulty except with the cold weather and some of our rented equipment. The fractures produced were thin and vertically oriented, and had a consistent northwest-southeast trend -- their direction being controlled by the earth's natural stress field in the region.

There are, of course, possible methods other than hydraulic fracturing that might be used to create the underground connection and the heat-transfer surface required -- in particular, the use of chemical or possibly nuclear explosives. Eventually, some of these should probably be tried experimentally. Hydraulic fracturing, however, appears to be cheaper, simpler, and safer than the use of explosives, and so we propose to try it first.

In the system shown in the sketch, cold water descending in the deeper hole will weigh more per unit of volume than will hot water rising in the other hole. This density difference should be enough to maintain circulation of water through the system without pumping. Further, thermal contraction of rock near the point where the cool water enters it will continuously create new void volume, probably in the form of thin cracks extending outward and downward from the original fracture. If the new cracks open widely enough so that the water can circulate through them, then new, hot rock may be exposed rapidly enough to make up for cooling of the rock adjacent to the original crack surfaces. Anything useful that both operates and perpetuates itself sounds much too good to be true, but our computer says that all of this is possible -- and I believe that it will occur.

In operating such a system, it would certainly be possible to bring the heat to the surface as steam. However, per unit volume, water is a great deal heavier than steam, and at the same temperature its energy content is correspondingly higher. To increase the rate of energy extraction from the system, we would therefore prefer to operate it with superheated water rather than steam. This should also assist in extracting heat from the thin ends of newly formed cracks. It will, however, require that we maintain a pressure of a few hundred pounds per square inch at the surface to keep the water from boiling. We have worried about the leak-off of water that might result from pressurizing the system, but we have been reassured by our recent experiments on the Jemez Plateau. After extensive hydraulic fracturing, our test hole there loses water at a rate of only a few gallons per day, even when we maintain surface pressures of as much as 1000 pounds per square inch. We do not know that this degree of impermeability is typical of granitic rock every where, but of course we hope that it is -- and, at the depths usually required to reach usefully hot rock, we think that it may be typical. If it is, then this very simple man-made system may be immediately useful in many parts of the world.

POWER POTENTIAL AND COSTS

Suppose that we can in fact create and operate a pressurized-water circulation loop such as that which I have just described, with standard oil-well size holes -- say 9 inches in diameter -- and a hydraulic fracture with a radius of 4000 feet. Using pressurized water circulating through rock at 300°C (572°F), the system should be capable of delivering 250 megawatts of heat to the surface continuously for at least 10 years. If thermal-stress cracking occurs, as we think it will, then the life of the system may in fact be many times 10 years.

If we choose to generate electricity with this energy, we will have the same problems to face as does any other low-temperature power plant: in particular, there will be a great deal of waste heat to dissipate. However, such a power plant would produce at least 30 megawatts electrical, which would satisfy the needs of a community of about 30,000 people. Much larger plants could of course be developed simply by drilling more holes and piping the hot water to a central location. However, there is much to be said for a small power plant at the edge of every town or military base. Among other things, this decentralization would greatly reduce the need for new cross-country transmission lines.

Even at a small plant size, the economics of systems of this kind appear promising. We can estimate the cost of the holes fairly accurately and it is of the order of a million dollars per hole, depending of course on their depth. However, the "fuel cost" of the final plant is simply the capital charge against the cost of producing these holes, the cost of the hydraulic fracture, and the cost of the associated surface plumbing, and this charge is quite low. The surface plant itself is simple because it requires no fuel handling facilities, combustion equipment, or smokestack, and its cost therefore is also relatively low. At this point we do not know how much to allow for such potential construction and operating problems as lost holes, corrosion, and plugging of our heat exchangers by precipitated minerals, and so our cost estimates are still very preliminary and uncertain. They suggest, however, that an energy system of this type would be at least competitive with existing fuel-fired or nuclear plants in the western United States, and would be marginal in the East -- where our costs would be higher because we would need more and deeper holes, and where we may also have to use lower-temperature turbines. Potentially at least, this is a low-cost energy system, as of course it should be; the heat that we start with is certainly inexpensive.

THE LOS ALAMOS PROGRAM

We have been sufficiently encouraged by these analyses and by our own experimental results so that we have proposed to the Division of Applied Technology of AEC a first field demonstration of a dry-rock energy-extraction system. As is indicated by this diagram (Sketch "C"), the proposed system would be essentially the same as a commercial one except that the hydraulic fracture would be somewhat smaller and, at least initially, we would not build a power plant. Instead we would use a forced-draft, air-cooled, heat exchanger, and dissipate heat as a rising plume of warm air. On this scale, such a plume should have no detectable environmental effect.

Once site occupancy has been arranged and drilling contracts let, it will take about one year to construct such a system. Simply creating it and establishing water circulation through the underground loop will represent a major milestone, and a very important demonstration to industry of the power possibilities of dry-rock systems. We would then propose to operate the system for something like three years. After about 10 months of circulation, our temperature records should tell us whether we are simply cooling off the initial crack surfaces -- which still would represent a very useful energy system -- or whether instead new cracks are forming and spontaneously extending the system -- which would further improve both its convenience and its economics. This will be a second major milestone. Finally, we propose to continue to operate the system for about two more years, to investigate in detail its thermal and mechanical behavior and, particularly, its chemistry. We know that pressurized hot water will dissolve a great deal of mineral -- chiefly silica -- from the rock, and that this may tend to precipitate in and plug our piping, valves, and heat exchanger. In granitic rocks at the expected temperatures and pressures, we think that this problem will be minor. However, it will not be trival, and we must learn to control it. The same is true of corrosion of the metal components of the system. There is also the possibility of recovering at least one useful by-product from this particular demonstration: copper, which is present in significant concentrations in the granite of the Jemez Plateau. There are evident and very practical reasons to explore the possible use of a circulation system of this general type simply for the selective extraction of a wide variety of minerals. It may be a very good mining system.

To this point, supported by research and development funds of our Laboratory, we have examined the existing scientific and technical knowledge related to creation and operation of an underground circulation system of the proposed type, and we have found no reason to suppose that the engineering problems presented by such a system do not have straightforward engineering solutions. We think that we can create and operate it now, with existing equipment and technology. However, with support from the Division of Physical Research of AEC, we have also initiated research in several disciplines in which it appears that the scientific background should be strengthened -- in particular in the areas of rock mechanics, terrestrial heat flow, seismology, and geochemistry. In addition, we have investigated the geology, geophysics, and heat flow of a region of relatively recent vulcanism just west of Los Alamos, and have identified in it an area which appears suitable both technically and environmentally for development of our proposed geothermal energy demonstration. This area is within the Santa Fe National Forest, and an understanding for temporary occupancy of a 7-acre site within it is now being discussed by the AEC and the U. S. Forest Service, Department of Agriculture. In the meantime, we have drilled a deep exploratory hole in a canyon within the Forest Service area and, under a special use permit issued by the Forest Service, are continuing experiments in this hole. It is 2575 feet deep, and extends about 500 feet into the hot, granitic basement rock. At the bottom of the hole, the rock temperature is 213°F, which -- at our altitude -- is significantly above the boiling point of water. Our experiments to date have demonstrated convincingly that we can drill and hydraulically fracture rock of this type with no unusual difficulty, and that -- even after fracturing -- the rock is competent to contain pressurized water. We have, then, identified an area which appears suitable for development of a dry-rock geothermal-energy system, and are continuing to investigate it.

When we are funded to do so and have made the necessary arrangements with the Forest Service, we propose to move to the site that I have described, drill another exploratory hole there, verify our horizontal and vertical extrapolations of temperature, geology, and rock properties, and improve our developmental and experimental techniques. This will take about six months. Then, if the results from this second deep hole are as encouraging as those from our first one, we will be ready to undertake development of the two-hole demonstration system that I have described to you. Unless we encounter some unexpected major difficulties, we should then, in less than five years, produce the evidence on which industrial development of a completely new and presumably environmentally acceptable energy system can be based. The first commercial power could come from such a system in 10 years or less, and within our lifetimes these systems could improve life for people all over the world.

The program that I have outlined to you is a single demonstration in a specific temperature regime and geologic environment. We think that it represents conditions typical of perhaps the western third of North America and that it is the right thing to try first. There are, however, many other situations that should also be investigated as soon as possible, to determine what variations in this general type of energy system are required to make it even more broadly useful. These other situations include rock at both higher and lower temperatures; deeper and shallower holes; more permeable formations; lava flows and sedimentary beds as well as crystalline rocks; and more complex geology. The particular demonstration that I have outlined to you is, of course, my own immediate and overwhelming interest. I suggest, however, in view of the urgency of both our Country's energy needs and its pollution problems, that we should not wait upon the results of one demonstration to begin investigating these other areas. The initial Los Alamos demonstration should be just the first component of a much broader investigation, and so far as possible its other components should be attacked promptly, vigorously, and in parallel rather than in sequence.

PROBLEMS

To return specifically to the Los Alamos program, I can foresee several questions that you might ask concerning our situation and the field demonstration that we propose to undertake. Perhaps I can save time by answering some of the more obvious questions before we go on to other things.

1. We are not now funded either to drill the next exploratory hole or to begin development of a demonstration system. The funding requirement for this project will be of the order of $4 million per year, and we are ready to start as soon as money to do so becomes available.

2. The proposed site for our next deep exploratory hole and for the demonstration system occupies about 7 acres on the Jemez Plateau, about 20 air miles west of Los Alamos. It is in a burned-over section of the Santa Fe National Forest, immediately adjacent to an all-weather road and to power and telephone lines. We believe that the principal environmental effect of occupying it will be simply to delay its reforestation by about 5 years.

3. We foresee no major difficulty in completing the underground system. We have investigated the local geology and hydrology carefully, and have drilled into the local granite at a location about a mile away. Of course we learned a great deal from drilling that hole. Drilling still deeper holes will be slow and expensive, but we are sure that it can be done, and so are the drilling consultants and operators with whom we have discussed it.

   We expect to drill the first hole, hydraulically fracture from it, and then intersect the fracture with a second hole drilled perhaps 200 feet away. When we begin the second hole, we will already know the depth at which the fracture was initiated and, from the volume of fluid injected, we can estimate its probable dimensions. We will have investigated the local stress field in the hot rock during experiments in a nearby exploratory hole, and from this we will have a basis for predicting the probable orientation of the fracture. We will also try to map the fracture as it forms, using microseismic methods, and we will examine the hole wall after fracturing for indications of the initial crack direction. Without any of this background, I think that -- using directional drilling methods -- we would probably find the crack with our second hole rather easily, and at worst with no more than a few hundred feet of wasted hole. However, with the other evidence that we will have collected, our own confidence in our ability to produce this intersection will be considerably increased.

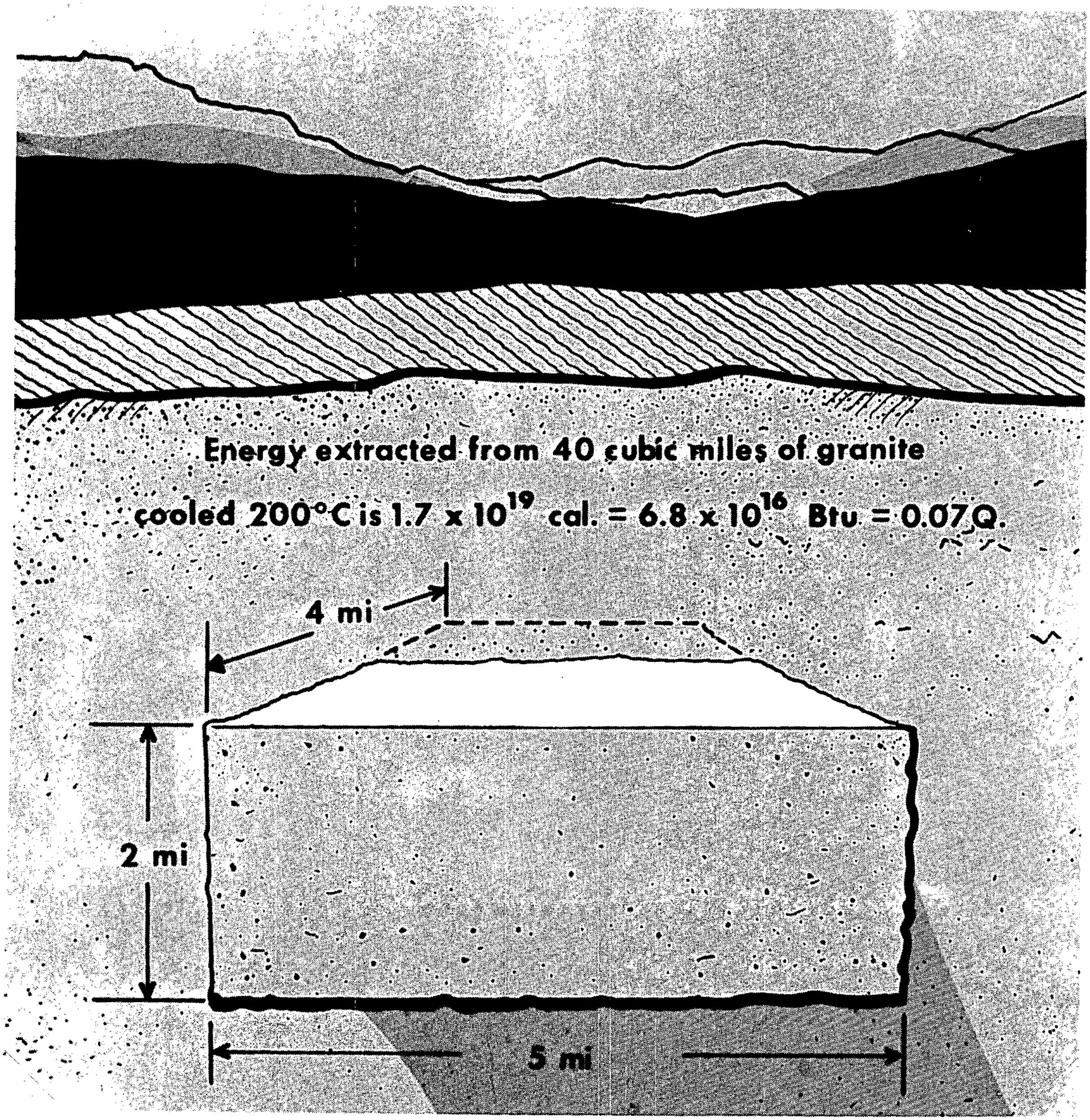
4. There appears to be no real danger that these experiments will cause local earthquakes. The Denver earthquakes, about which we are often asked, appear to have resulted from the injection of large volumes of fluid under high pressure into an active fault system. A series of experiments at Rangely, Colorado, conducted by the U. S. Geological Survey and still in progress, has produced small earthquakes under controlled conditions. Significantly, there appear to have been no earthquakes at Rangely even when fluid pressures were high and fluid volumes large, so long as the injection holes were some distance from the active fault system. In our experiments, we of course intend to avoid active fault systems.

   Two criteria for the selection of our proposed demonstration site were the absence of faults locally and a low background of natural seismic activity. We will be injecting relatively small volumes of fluid under carefully controlled pressures into rock that appears to be entirely free of faults, and we believe that the seismic risk of our experiments is very nearly zero. We will, however, monitor the area carefully with an array of sensitive seismometers before, during, and after our experiments and, if there is ever an indication of unusual activity in the vicinity of our system, we will be prepared to depressurize it very promptly.

5. There is also no reason to believe that our demonstration will produce subsidence of the earth's surface. Our system will be very limited in its lateral extent; deeply buried in strong, competent rock; and always full of water. Its structural and stress situation will be such that the overlying rocks will be completely supported, and there is nothing to suggest that this support will diminish significantly within even many thousands of years.

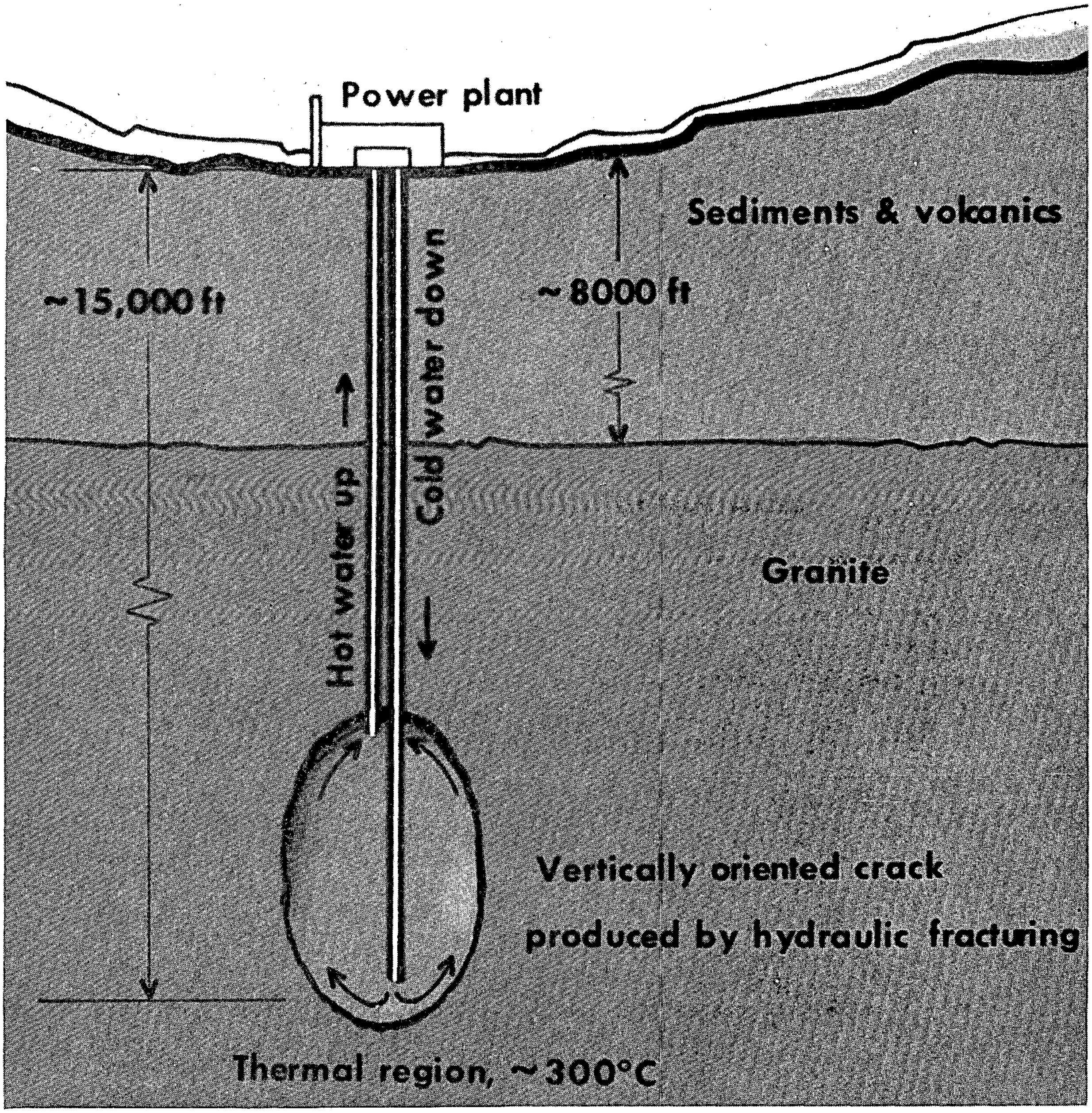
CONCLUSION

The nature and magnitude of the hot, dry rock geothermal energy resource are such that within the next 10 to 15 years it could begin to contribute significantly to the solution of some of our Nation's most urgent energy, pollution, and balance-of-payments problems. A program to investigate and develop this resource has therefore been undertaken by the Atomic Energy Commission at Los Alamos Scientific Laboratory, and initial results from that program are very encouraging. It appears that the equipment and techniques required to make this vast energy reservoir useful already exist, and that a convincing demonstration of its usefulness is possible within less than five years.

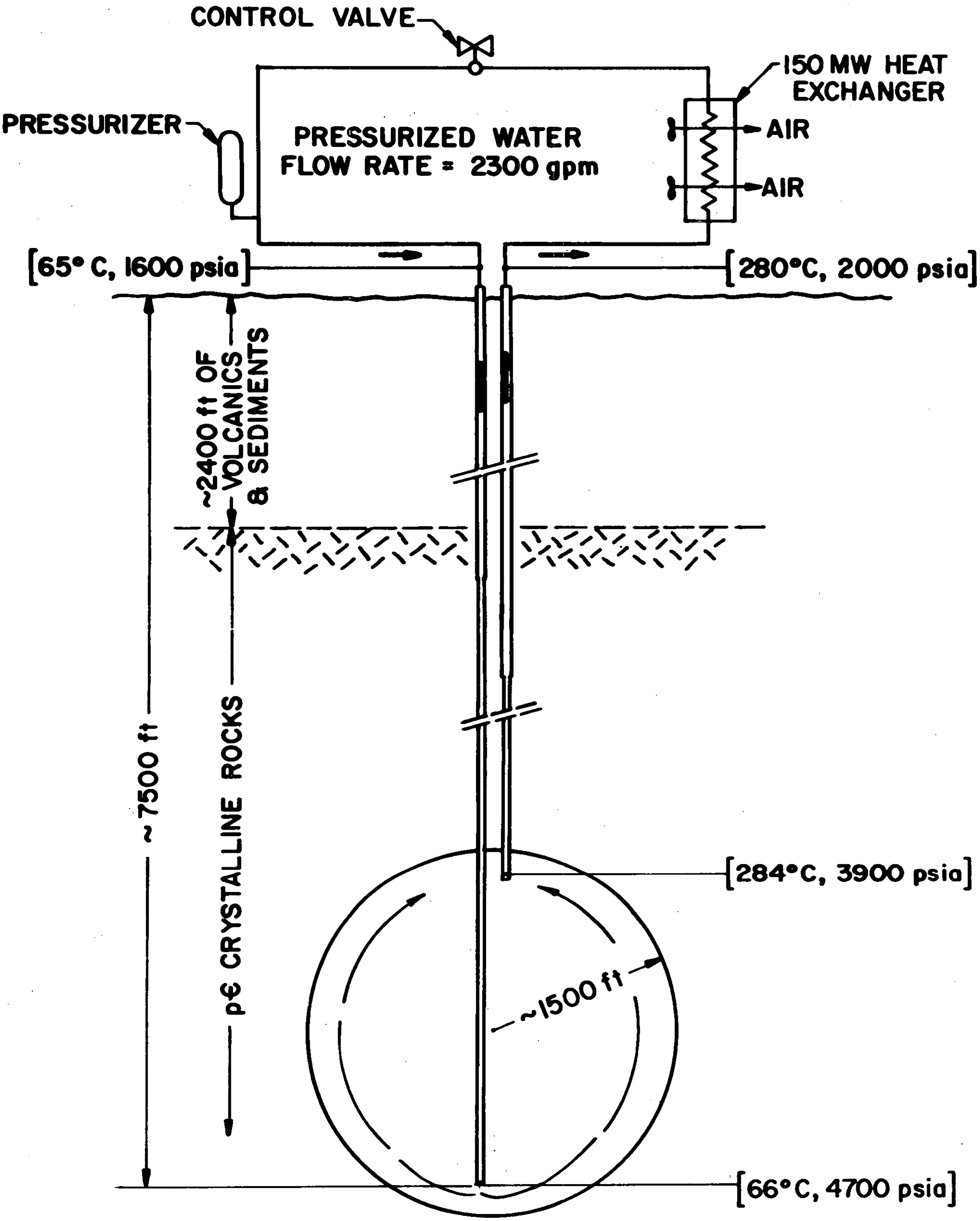


The energy content of hot, dry rock in the earth's crust.

-B-



A pressurized-water circulation system for extracting energy from a dry geothermal reservoir.



The proposed Los Alamos demonstration system.