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THE STATUS OF PLOWSHARE GEOTHERMAL POWER

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THE STATUS OF PLOWSHARE GEOTHERMAL POWER

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In 1964 Professor George Kennedy, now at UCLA, suggested that nuclear devices could be detonated in high temperature rock deep within the earth, water could be introduced and power generated from the high temperature steam which would result.⁽¹⁾ The author and J. B. Burnham from Battelle Northwest ran some preliminary calculations on the concept (shown in Fig. 1) and believed the process might prove technically and economically feasible. Our work was reported in two papers, given at AIF and ANS meetings Dec. 1969 and Jan. 1970.^(2,3)

As a result of this work, the American Oil Shale Company (AOS) of Salt Lake City decided to sponsor Battelle for further work on the concept and AOS entered with a contract with AEC to jointly study the feasibility of such a process. The AEC provided expert assistance from the Lawrence Radiation Laboratory and the Nevada Operations Office and the industrial side of the study was greatly aided by assistance from the Westinghouse Electric Corporation which did the power plant design and costs. The study⁽⁴⁾ was published in April 1971.

The study concluded that Plowshare Geothermal power was technically feasible and that under certain conditions power could be produced for from 5 to 7 mills/Kwhr. For several reasons these numbers may prove conservative. Depletion allowance and terrain which would permit the mobile plant concept to be used could reduce these costs by 0.4 mill/Kwhr and 0.8 mill/Kwhr, respectively. It was announced after the study was completed

 George C. Kennedy, "A Proposal for a Nuclear Power Program," USAEC Third Plowshare Symposium, University of California, Davis, April, 1964.
D. H. Stewart and J. B. Burnham, "The Application of Plowshare to Geothermal Power," Atomic Industrial Forum, BNWL-SA-2803, December, 1969.
J. B. Burnham and D. H. Stewart, "The Economics of Plowshare Geothermal Power, ANS Symposium on Engineering with Nuclear Explosives, January, 1970.
"A Feasibility Study of a Plowshare Geothermal Power Plant," April 1971, Am. Oil Shale - Battelle Northwest - Westinghouse Electric Corp. -USAEC - Lawrence Radiation Laboratory - Nevada Operations Office. that the large diameter holes (24") required for the large device emplacement can now be much smaller - around 8 to 9". This would also effect a major reduction in field development costs and power costs of approx. 1.25 mills/Kwhr.

Key problems are the location of a geothermal site in an area which large nuclear devices could be detonated (>200 KT), a site with sufficient ground or surface water available to operate the power plant condenser, and a site reasonably near a large electrical market. Public opposition could develop and should be anticipated, but it is hoped that the relatively nonpolluting aspects of geothermal energy could offset any public opposition.

The several reasons for our original interest in the process are still valid. As the primary cycle is closed and, of course, no combustion is involved, it is believed that Plowshare Geothermal power would prove to be nearly pollution free. While it has been estimated by the Department of Interior that geothermal power could never supply more than 1 - 2% of the nation's electrical energy, the total energy which could be produced from Plowshare-Geothermal is impressive. One cubic mile of rock at 350°C cooled to 250°C would yield enough energy to support 3700 MW_{e} for 30 yrs., and it would require on the order of 40 to 60 nuclear explosives to produce this energy. As many geothermal areas in the U.S. are believed to range from hundreds to thousands of square miles, the occurrence of such rock is unlikely to prove rare and it appears that the potential exists to produce hundreds of thousands of megawatts. To be economic today, the selected temperature (350°C) should lie within 5000 to 10,000 feet of the surface and devices, sizes of greater than 200 KT, will be required. The Mexicans who are developing the Cerro Prieto field, located just below the California border, have reported these temperatures in dry rock at 5,000 ft.

It should be noted that the economics are very sensitive to hard rock drilling costs, which rise steeply with depth, and that a new drilling method such as that recently developed by $Gulf^{(1)}$ Oil could improve the economics greatly. Gulf has field tested a process which accelerates steel

 "Gulf's new abrasion drill: Is it the Breakthrough?", Oil & Gas Journal, July 26, 1971.

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balls through jets (2 tons/min. at 600 mph) and delivers 5,000 H.P. at the bottom of the hole. Drilling rates of 4 to 20 times conventional methods are reported. Bit changing times are also greatly reduced as the bit is retrieved by cable and returned down the hole by pumping. This sort of technology could permit drilling to much greater depths and lead to much higher temperatures. If temperatures over 1500°F can be attained, gas turbine cycles could prove attractive for power generation.

It is also noted that the cost of energy used to break the rock can be very low ranging from 25ϕ to $7\phi/10^6$ BTU depending on the size of the device and >90% of this energy is also recovered along with the sensible heat from the rock.

During the course of the study, Sept. 1970, we invited some utilities and resource companies to a briefing on the concept. All expressed interest in Plowshare Geothermal power but also the concern that before geothermal power could hope to become significant, public land - which had been withdrawn from geothermal leasing - would have to be made available. This concern was remedied on Dec. 24, when President Nixon signed into law Senator Bible's Geothermal Steam Act of 1970. The passage of this legislation caught industry by surprise as similar bills had been passed by Congress before, but had been vetoed by the President. This legislation has spurred the interest of numerous resource companies, and geothermal exploration programs are proceeding at an unprecedented rate.

Senator Bible on March 24, 1971, introduced another bill, S.1349, "To authorize the AEC to undertake a cooperative program to ascertain the feasibility of using atomic energy to develop the Nation's geothermal energy resources." The bill, similar to the power reactor demonstration program legislation, calls for the government to invest up to \$25,000,000 over a five to six year period to test the feasibility of the Plowshare Geothermal concept matching a like amount to be supplied by industry in exploration and construction of a demonstration plant. In commenting on this bill, the AEC suggested that separate legislation was not required as the authority already existed, and all that was needed was an amended AEC authorization bill and appropriations.

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These were added by the JCAE to the AEC's FY 1972 authorization bill, and funds have been appropriated by the House and Senate. The AEC authorization bill provides \$500,000 in FY 1972 and anticipates expenditures up to \$25,000,000 over the next several years.

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To realize the funds authorized for the program, it will be necessary to locate a suitable site - provided by a resource company, and power company or group of power companies willing to commit the investment for a demonstration plant, assuming economic steam production can be satisfactorily demonstrated. Also required is the R&D program to meet the environmental requirements, develop suitable devices, determine the quality of the steam, the degree of fracturing, the fluid flow and heat removal. The AEC plans to start some preliminary R&D once their appropriations become available. This work will largely be done by Lawrence Radiation 'Laboratory and Battelle Northwest.

During the course of the feasibility study, it became apparent that small nuclear devices might assist in making the known geothermal areas more productive and economic. As part of an investigation of the feasibility of the use of small nuclear devices to augment natural geothermal systems, termed Plowshare Stimulation, the AEC sponsored a trip to the major geothermal areas of the world to discuss the feasibility of Plowshare Stimulation. Iceland, Italy,New Zealand, Japan and the Geysers in California were visited. Considerable interest in a stimulation program was evidenced by many people in these countries and all were interested in the data as soon as it develops.

It is expected that nuclear stimulation could provide some or all of the following advantages to natural geothermal systems:

 Provide an increased well bore diameter effect. This effect is analogous to the natural gas stimulation experiments where a nuclear device can make a noneconomic well economically productive by increasing the flow rate and total gas recovery through the extensive fracturing it produces.

- 2. Provide a void volume for flashing water to steam. Several good producing wells have been abandoned when after 12 to 18 mo. of operation as the steam flow was choked off by the deposition of minerals from the water as it flashed to steam at the well bore. The proposed void volume might provide adequate space to make the well productive for 10 to 20 years. It may also be possible to change a wet well to dry steam production.
- 3. Provide a void and fractured region to permit reinjection of the condensed water and salts produced from the formation. In many areas (i.e., Salton Sea), it will be necessary to return all fluids into the formation from which they were produced as they contain too much mineral concentration for surface disposal. It is believed that a cavity in the producing formation could facilitate this underground disposal. Reinjection could also offer the advantage of providing continuing underground water replenishment in areas where water inflow is limited.

The principal problems raised in Plowshare Stimulation which require analysis are: the fate of the radioactivity in the geothermal water and whether this could present any hazard, and whether a nuclear explosion would be likely to destroy the natural system by shifting a key fault or some other such mechanism.

Gcothermal Theory

There are generally accepted theories on the origin of geothermal systems. A source of heat lies relatively near the surface of the earth, resulting from a recent intrusion of magmatic rock. These areas are often, but not exclusively, found in regions of young volcanic activity. A permeable rock filled by meteoric water at drillable depth is heated by the deeper heat source through conduction. The permeable rock must be overlaid with some impervious material, usually sedimentary material. This layer serves to cap the formation and retains the steam and/or hot water. There is evidence that some systems are self-sealing; the cap rock was formed by the deposition of minerals, notably silica, from leaks of fluids escaping from the hot aquifer.

Geothermal areas are often associated with grabens, geological depressions between major faults. Geochemical, gravity, magnetic, thermal conductivity, heat flow and microseismic techniques have been used with varying success to locate these areas. However, many companies believe drilling to be the only suitable exploration method.

The temperatures of these systems may be as high as 380°C, and they follow the Boiling Point with Depth Curve when producing dry steam. Once the producing formation is tapped with a bore hole, dry steam, steam and hot water or hot water will be produced. Shut off pressures range to 400-500 psig. The wells are generally produced at 100 to 150 psig to allow maximum flow for optimum power production. These steam flows average 100,000 lbs/hr (=45,500 Kg/hr) to as high as 660,000 lb/hr (=300 metric tons/hr).

Since the meeting in September 1970, further discussions have been held with the utilities, and we now expect their participation in the program by their sponsorship of the follow-on Plowshare Stimulation study.

Resource companies are beginning exploration programs and our talks with them offer hope for the location of a site suitable for an experimental program. These experiments will determine the economics and technical feasibility of the use of Plowshare in geothermal steam production.

It is hoped the Plowshare Geothermal program will lead to an understanding of how to extract the energy we need on the surface of the earth from the inexhaustible energy source that lies 20 to 50 Km. beneath our feet.