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POTENTIAL ENVIRONMENTAL ISSUES RELATED TO GEOTHERMAL POWER GENERATION IN OREGON

Rodney D. Wimer,* Phillip N. LaMori,** and Alan D. Grant*

Introduction

Geothermal energy, derived from the natural heat within the Earth, has been utilized for the generation of electricity since the dry steam field at Larderello, Italy, was tapped in 1904. In the United States, development of geothermal resources for electric power generation has progressed slowly since the first 11,000 kWe (kilowatts electrical) turbine was installed at The Geysers, California, in 1960. This field, with a present installed capacity of 502 MWe (megawatts electrical), is still the only geothermal resource that has been harnessed for commercial electricity production in this country.

Geothermal energy has historically been hailed by both developers and environmentalists as a clean energy resource. Bowen (1971, 1973), who was the first to attempt a detailed literature review of the environmental impacts of geothermal power production from vapor-dominated dry steam reservoirs, compared these impacts to those associated with more conventional coal and nuclear power generation. Recently Axtmann (1975) described the adverse environmental effects of chemical and thermal discharges from the Wairakei, New Zealand, geothermal power plant into the Waikato River. The Wairakei plant utilizes geothermal fluids from a liquid-dominated (hot water) reservoir to produce electric power.

This article discusses the present understanding of the nature and occurrence of geothermal resources in Oregon and emphasizes those critical environmental issues which must be addressed in public forums and ultimately in power plant design if significant utilization of this indigenous energy source is to become a reality. An emerging conversion technology known as the binary cycle, which will be demonstrated in 1980 in a 50-MWe plant near Heber in the Imperial Valley of California, is also described. The binary conversion process, which

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*Portland General Electric Company, Portland, Oregon
**Electric Power Research Institute, Palo Alto, California

isolates the geothermal fluids in a closed system for eventual reinjection into the reservoir, has the potential to mitigate several adverse environmental impacts often attributed to geothermal power generation. The suspected liquid nature and thermodynamic quality of Oregon's geothermal resources may dictate utilization of the binary cycle for electric power generation.

Geothermal Resources in Oregon

Nature and occurrence of geothermal resources

Geothermal resources can be grouped into two broad classes which are largely defined by the nature of the heat source responsible for the observed upper crustal thermal anomaly: (1) igneous-related geothermal systems characterized by intrusions of magma into the upper crust, and (2) geothermal systems which are not related to igneous intrusions but which generally occur in sedimentary rocks in areas of high regional heat flow (Muffler, 1975). The first class can be further subdivided into three resource types: (a) magma, (b) hot dry rock, and (c) hydrothermal convection systems. Hydrothermal convection systems are further broken down into two main types depending on the nature of the dominant pressure-controlling phase in the geothermal reservoir: (a) vapor-dominated systems, wherein liquid water and vapor coexist in the reservoir with vapor as the continuous pressure-controlling phase; and (b) hot-water systems characterized by liquid water as the continuous, pressure-controlling fluid phase (White, Muffler, and Truesdell, 1971). The vapor-dominated reservoir systems are considered extremely rare; indeed, The Geysers, California, is the only large system of this type extensively drilled to date in the United States. The Mud Volcano system in Yellowstone National Park and Mt. Lassen Volcanic National Park may also be underlain by vapor-dominated reservoirs (Renner, White, and Williams, 1975).

Geothermal resource potential

Over 200 thermal springs and wells have been identified to date in Oregon (Bowen and Peterson, 1970). Most of these springs occur within two distinct geologic environments: (1) the structurally deformed and moderately altered Tertiary strata of the Western Cascades; and (2) individual grabens of the Basin and Range province of southeastern Oregon, usually adjacent to or astride major normal faults. Those thermal springs for which geochemistry data indicate subsurface temperatures greater than 90°C (194°F) are shown in Figure 1. The chemical compositions of these hotter spring systems indicate minimum reservoir temperatures ranging from 90°C (194°F) to 207°C (405°F) and further suggest that reservoirs supplying these thermal springs are of the hot-water type, with generally high contents of alkalis, chloride, and silica (Mariner and others, 1974, 1975). Hot springs which are surface manifestations of vapor-dominated systems are generally acidic

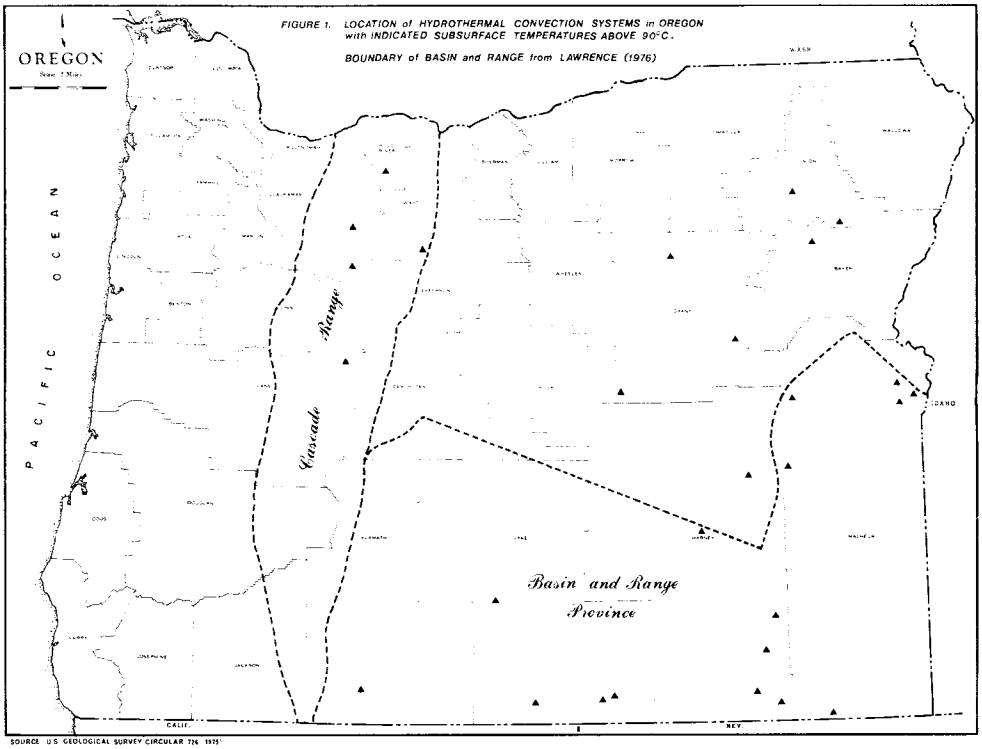

FIGURE 1. LOCATION of HYDROTHERMAL CONVECTION SYSTEMS in OREGON with INDICATED SUBSURFACE TEMPERATURES ABOVE 90°C.
BOUNDARY of BASIN and RANGE from LAWRENCE (1976)

SOURCE U.S. GEOLOGICAL SURVEY CIRCULAR 726 1975

(pH as low as 2 or 3), low in chloride content (generally less than 50 ppm), and high in sulfate.

Although Oregon contains over 200 thermal springs and has been the site of more Tertiary and Quaternary volcanism than any other western state, the geothermal resource potential of this State is essentially unknown. In 1975 the U.S. Geological Survey (White and Williams, eds., 1975) made a preliminary estimate of the U.S. geothermal resource potential based on incomplete information. That survey indicated a total of about 30.4 x 10^{18} calories of recoverable thermal energy suitable for nonelectrical applications and 1,336 MWe (at a 30-year plant life) of electric power generation potential from all identified hydrothermal resources in Oregon (see Table 1).

These estimates, developed from a small data base, translate into the equivalent electrical energy generated by slightly more than one nuclear plant the size of Trojan. Note, however, that these are minimum estimates which will probably be continually revised upward as knowledge of the nature and occurrence of Oregon's geothermal resource improves through regional and site-specific exploration programs. The above estimates do not include possible concealed hydrothermal resources, igneous-related systems, and resources in above-average conductive heat-flow environments. As techniques are developed to evaluate and utilize these resource

Table 1. Estimated Potential Electric Energy from Identified High Temperature[1] Hydrothermal Convection Systems in Oregon

Spring Name	Subsurface Temperature (°C)	Volume (km^3)	Stored Heat (10^{18} cal)	Recovery Factor e_r	Electrical Potential[2]
Mickey H.S.	210	12	1.4	0.025	154
Alvord H.S.	200	4.5	0.5	0.025	57
Hot Lake	180	12	1.2	0.02	107
Vale H.S.	160	100	8.7	0.02	770
Neal H.S.	180	4	0.4	0.02	37
Lakeview	160	16	1.4	0.02	123
Crumps Spring	180	8	0.8	0.02	70
Weberg H.S.	170	2.25	0.2	0.02	18
Total					1336

[1] High temperature systems are those with estimated subsurface temperatures greater than 150°C, which is presently considered the minimum threshold for electric power generation.

[2] Electrical potential assumes commercial power generation at a 30-year plant life.

Source: U. S. Geological Survey Circular 726 (1975)

types, the total energy potential will probably increase significantly.

Geothermal Power Conversion Cycles

Dry steam cycle

At The Geysers, California, a dry steam (vapor-dominated) resource, the first unit in 1960 consisted of an 11 MWe turbine, a direct contact condenser, and a cooling tower. Power production was accomplished in a manner similar to conventional fossil-fired plants. Noncondensible gases naturally occurring in the steam were vented to the atmosphere through gas ejectors above the condenser and in the cooling tower exhaust. Excess cooling tower fluids were discharged to local streams. Natural dry steam was produced by drilling a well into the subsurface instead of by burning nonrenewable fossil fuel. A schematic diagram of The Geysers-type dry steam conversion process is shown in Figure 2.

Development at The Geysers field proceeded slowly in the early years, primarily because of uncertainties regarding the longevity of the resource. The pace of development increased, however, as the longevity of the resource was established and more reserves were located. This increased rate of development resulted in accompanying environmental concerns and required the establishment of mitigation procedures to control environmental problems. The

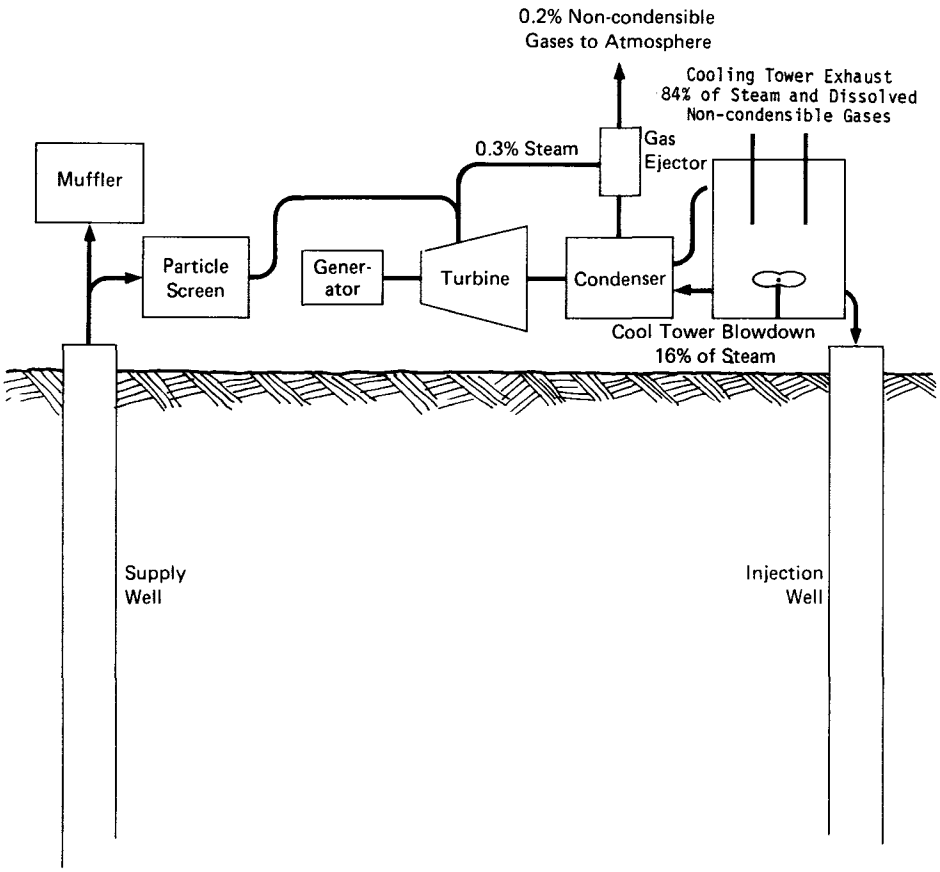

Figure 2. Geysers-type dry steam power production cycle.

once-through discharge of cooling tower blowdown into local streams was soon stopped and the excess condensate was disposed of in reinjection wells. Venting of wells prior to production and during power plant shutdown had originally resulted in high noise levels, but the development of effective muffling devices greatly reduced these noise emissions to allowable levels. Concern over the release of hydrogen sulfide (H_2S) in the noncondensible gas stream led to the development and testing of several processes to reduce such emissions. The Stretford process, which chemically converts H_2S to elemental sulphur, can reduce H_2S emissions by over 90 percent and is now planned for all new units and will be retrofitted to existing units (Pacific Gas and Electric Co., 1975).

The dry steam geothermal resource, while easily exploitable, is an uncommon occurrence. Thus, The Geysers field is not a truly representative model of the environmental impacts associated with

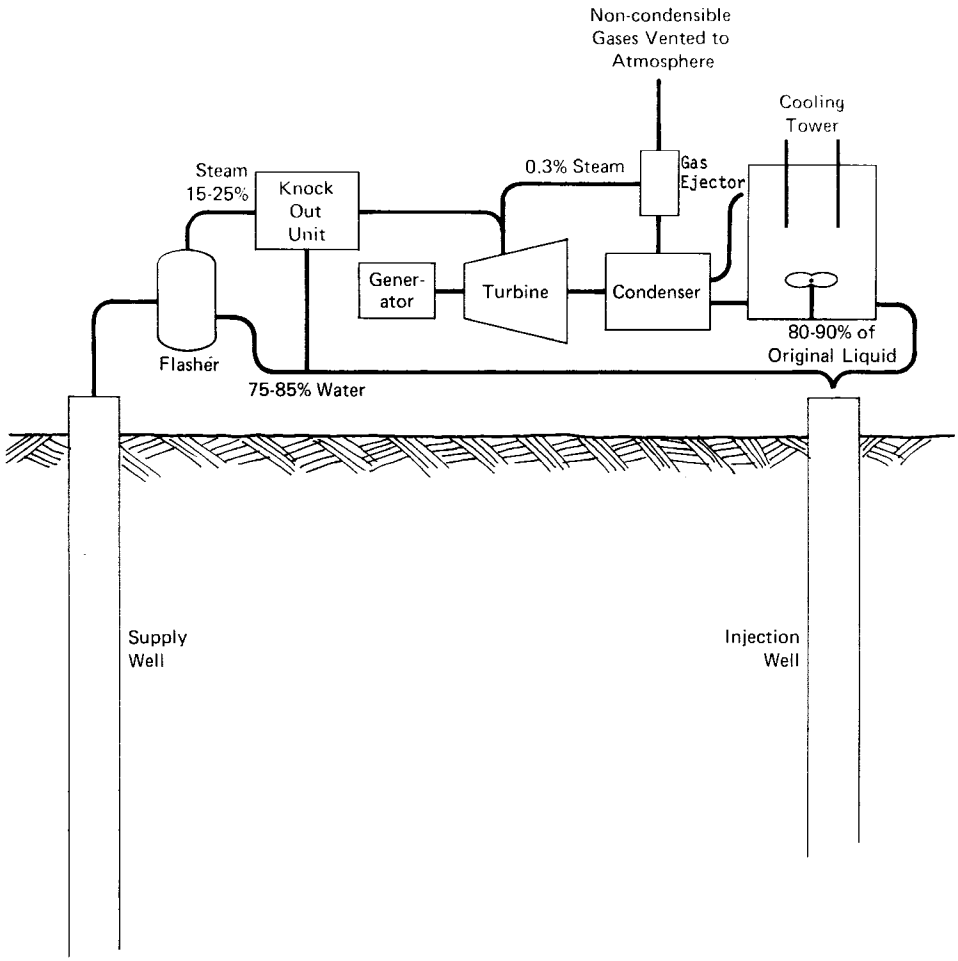

Figure 3. Flashed steam power production cycle.

geothermal power production because over 95 percent of the world's hydrothermal geothermal resources are believed to be of the hot-water (liquid-dominated) type. The more common hot-water resources will be exploited by one of two power conversion cycles: the flashed steam cycle or the binary cycle.

Flashed steam cycle

The flashed steam geothermal power cycle (see Figure 3) is similar to the dry steam cycle, except that a flasher and water knock-out unit are required. Flashing results in significantly larger quantities of fluid to be eventually reinjected into the

geothermal reservoir. A primary requirement of the flashed steam cycle is fluid temperature high enough to provide economic quantities of steam (generally above 400°F). The environmental concerns associated with the flashed steam cycle are similar to those accompanying the dry steam cycle, although noise emissions from venting wells is not a problem. Presently, worldwide power generation capacity using the flashed steam cycle totals approximately 500 MWe from about a dozen widely scattered locations, none of which are in the United States. The power plants in Cerro Prieto, Mexico, and Wairakei, New Zealand, utilize the flashed steam process and are the two largest power producers, with 75-MWe and 190-MWe of installed capacity, respectively.

Binary cycle

The binary power cycle (see Figure 4) has been proposed for power production where geothermal resource temperatures are too low for economic utilization of the flashed steam cycle or where the produced fluid contains undesirable amounts of dissolved solids or noncondensible gases. In the binary cycle the geothermal fluid is maintained in a closed loop from the production to the reinjection wells and therefore should not result in environmental degradation. The thermal energy contained in the geothermal fluid is transferred to a low-boiling-point working fluid which expands through a turbine to generate power and is then condensed and recirculated. The spent geothermal fluid is pumped from the plant to reinjection wells for ultimate disposal back into the reservoir.

The main advantages of the binary cycle over the flashed steam cycle are the closed-system operation and the ability to extract energy from the total produced fluid. This latter factor makes the more complicated and somewhat higher capital-cost binary cycle economically competitive with other geothermal power production options. The major disadvantages of the binary cycle include the increased capital costs, requirements for additional heat exchangers, and the probable need for supplemental cooling water supplies.

The binary conversion cycle has yet to be demonstrated in a commercial-sized power plant in the United States. However, the San Diego Gas & Electric Co. is sponsoring a 50-MWe binary cycle demonstration plant jointly with the Electric Power Research Institute (EPRI) and several other utilities. This plant is to be constructed at the Heber thermal anomaly in the Imperial Valley of California and is presently scheduled for operation in late 1980. Successful demonstration of the binary cycle conversion technology at the Heber plant will encourage development and economic utilization of geothermal resources with temperatures ultimately as low as 150°C (300°F).

Environmental Impacts of Geothermal Exploration and Field Development

As with all forms of power generation, environmental impacts are associated with the conversion of geothermal energy to elec-

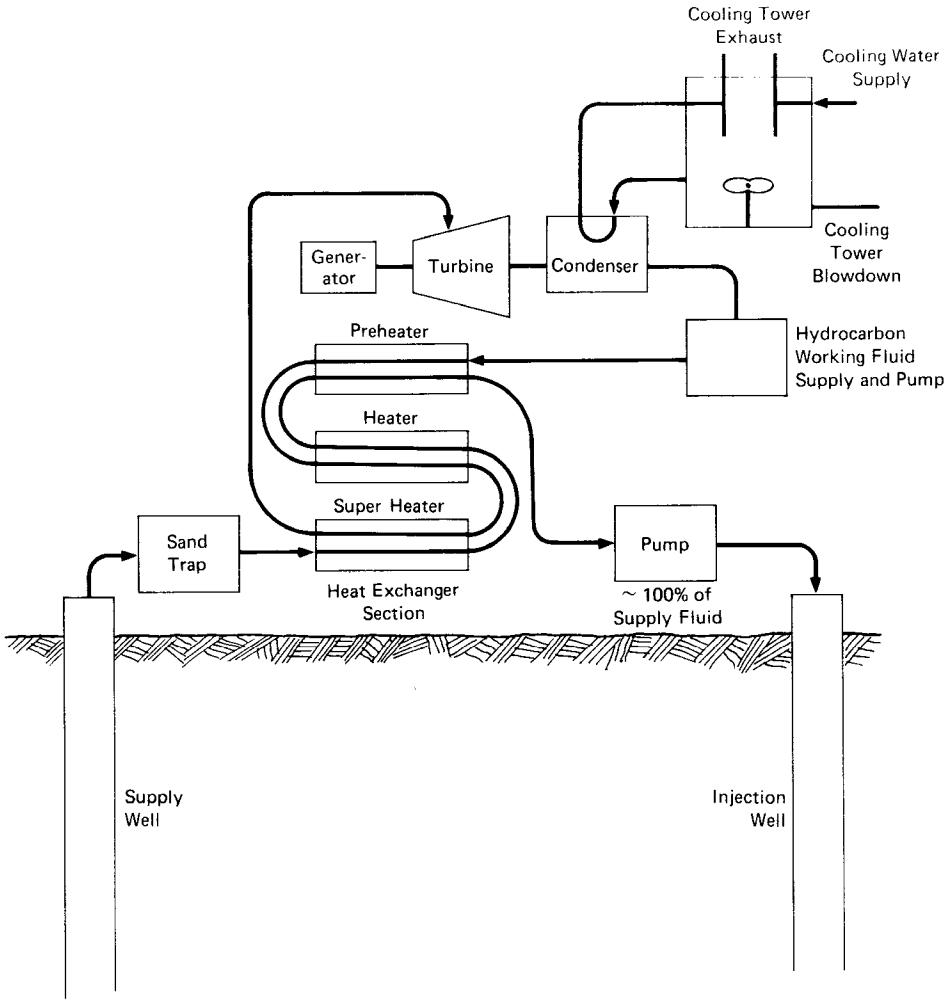

Figure 4. Binary power production cycle.

trical energy. The list of environmental concerns relative to the development and utilization of geothermal resources includes many of those impacts attributed to other forms of power generation (e.g. air quality, land use). Others, such as subsidence and possible induction of earthquakes, are unique to the geothermal industry. Furthermore, the types and magnitudes of environmental impact associated with geothermal power production will be dependent upon the nature of the reservoir system being developed (i.e. vapor-dominated vs. hot-water systems) and will be site specific. Unlike fuel cycles of coal or nuclear alternatives, the entire fuel cycle of a geothermal plant is concentrated at the

point of resource extraction. This geographic concentration results in economic and land use advantages over the often expansive and geographically dispersed fuel cycle steps associated with coal and nuclear options but presents constraints with respect to power plant siting.

The environmental impacts associated with geothermal power production can be categorized according to the three separate stages of resource development: (1) resource exploration, (2) test drilling and field development, and (3) power plant construction and operation. The first two stages are discussed below; the third stage is discussed in the section entitled Potential Environmental Impacts of Binary Cycle Power Generation in Oregon.

Exploration

Environmental impacts in the exploration phase resulting from geological, geophysical, and geochemical investigations are transitory and are generally of small magnitude. These investigations are usually conducted on the ground, although aircraft are used for transportation, airborne geophysical techniques, and aerial photography.

Existing roads are used whenever possible; but surficial investigations may require off-road vehicular travel. Little road construction would be required in the Oregon Cascade Range because of the numerous existing Forest Service and logging roads in the area. Gravity, magnetic, and microseismic surveys are conducted with portable equipment which can usually be backpacked into areas that are inaccessible to vehicles. Seismic and electrical resistivity surveys might result in minor temporary surface disturbances from vehicular movement, depending on the particular technique employed.

Shallow holes (generally less than 500 feet deep) are sometimes drilled during the exploration phase for temperature-gradient measurements and heat-flow determination. Small truck-mounted rotary drill rigs are generally used, and drill cuttings or chips are removed by introducing a jet of air during drilling. The extracted cuttings tend to form a small conical pile above the drill hole and are easily removed upon completion of drilling. The hole is usually plugged, covered, and rehabilitated after the temperature-gradient measurements have been monitored over a period of several months. Since these shallow holes are usually drilled adjacent to existing roads, they result in little surface disturbance.

Test drilling and field development

Adverse environmental impacts from geothermal energy utilization may occur during the test drilling and field development phase. Activities in this phase include: (a) test hole drilling to delineate reservoir boundaries; (b) fluid sampling for determination of the reservoir's physical and chemical properties; (c) production testing to determine the flow rate, composition, temperature and

enthalpy of fluids and gases, recharge characteristics, reservoir pressures, and hydrodynamic properties; and (d) the drilling and testing of production wells to supply geothermal fluids to the power plant if favorable results are obtained during initial reservoir tests.

Potential adverse environmental effects during the test drilling and field development phase can be grouped into four categories: land use conflicts, air pollution, water pollution, and noise. Land use conflicts and water pollution appear to be of greatest concern. The magnitude of these impacts will vary according to the type of resource being exploited (e.g. vapor-dominated vs. hot-water reservoirs), topography, type and extent of vegetation cover, and subsurface geologic and hydrologic conditions.

Land use conflicts: Various land use disturbances occur during drilling and field development from access-road construction and well-site preparation. These impacts range from temporary nuisance conditions such as blowing dust to the disturbance of vegetative cover and displacement or loss of wildlife habitats.

The amount of land disturbed is dependent upon the number and spacing of production wells required to supply fluids to the power plant, which in turn are functions of topography and the physical characteristics, extent, and thermodynamic quality of the geothermal reservoir. For example, during early development of The Geysers dry steam field, the average well density was one well per five acres (Budd, 1973). The recent initiation of directional drilling at The Geysers has greatly reduced land requirements, and three production wells are now being located on individual well pads. Present plans for the 50-MWe binary cycle demonstration plant to be constructed near Heber, California, provide for the location of all 12 directionally drilled production holes on a single pad. This optimum well spacing can only be achieved under very special circumstances, such as the pressurized sedimentary reservoirs of moderate primary permeability in the Imperial Valley. Such compact spacing through directional drilling may not be possible in Oregon, where geothermal reservoirs will probably produce from secondary permeability zones (faults, fractures, joints, etc.) in volcanic rocks of varying lithologies. Land requirements for the surface installations (pumps, piping, etc.) necessary to transport the geothermal fluids to the power plant are also directly related to well spacing and terrain conditions.

Geothermal field development does not preempt multiple land usage of the impacted area. For example, the Larderello field in Italy is in an area where farms, vineyards, and orchards are adjacent to production wells, pipelines, and power plants (Bowen, 1973, p. 201-202.)

Water pollution: During the drilling and field development phase the most serious potential water and air pollution problems will occur if there is a well blowout. A blowout occurs when well

bottom-hole pressures build up and become sufficient to overcome the well's hydrostatic weight. Well blowouts, which were occasionally a major problem in the early development of The Geysers field, were apparently instigated by slope instabilities resulting from heavy precipitation, rugged terrain, and altered surficial geologic units. Well blowouts appear to be controlled completely now through improved drilling and casing techniques and the implementation of stringent federal and state regulations requiring blowout prevention equipment on each wellhead. Blowouts are still a potential hazard, however, in the test drilling and field development stage.

Ground water contamination can occur during the drilling of production wells through use of improper drilling and cementing procedures. Adverse impacts could result from the loss of formation integrity, permitting the upward migration of generally poor quality geothermal fluids under high pressure into shallow aquifers. Avoidance of such adverse impacts is possible through use of proper well completion and operation practices, along with the design and implementation of appropriate well monitoring programs.

Atmospheric pollution: Atmospheric pollution is not a major problem during the drilling and field development stage. Release of hydrogen sulfide and other noncondensible gases could occur when production wells into vapor-dominated reservoirs are being blown for cleanout of rock particles and other debris, but such releases would occur only over a period of several weeks. Uncontrolled releases should generally not occur from wells drilled into liquid-dominated reservoirs.

Noise: High-frequency and high-intensity noise emissions can occur during drilling and testing of geothermal wells, particularly in vapor-dominated reservoir systems when compressed air is used as the drilling medium instead of mud. When the production well is being blown for cleanout, sudden release of compressed air and natural steam can also result in objectionable noise levels. The development of muffling devices, such as those in use at The Geysers, has resulted in noise emissions being held within acceptable limits during testing of geothermal wells. As most prospective geothermal resource areas in Oregon are in regions of low population density, noise emissions from geothermal developments should have no significant adverse effects on the general populace. Furthermore, noise is generally not a problem with flowing fluid wells.

Potential Environmental Impacts of Binary Cycle Power Generation in Oregon

The types and magnitudes of environmental impacts associated with the construction and operation of geothermal power plants are dependent upon differences in reservoir type and upon the conversion process used to convert the thermal energy contained in pro-

duced fluids to electrical energy (direct steam, flashed steam, or binary cycle). Nonresource-related and site-specific differences in topography, climate, geology, hydrology, vegetation, and land use are also of importance.

As geothermal reservoirs in Oregon will probably be medium temperature (325°-400°F) and of the hot-water type (see Geothermal Resources in Oregon), this discussion assumes utilization of the binary conversion process. Depending on the chemical and thermodynamic quality of individual reservoir systems, greater thermal efficiencies may be realized through utilization of the flashed steam process. However, the environmental impacts associated with the utilization of the direct and flashed steam conversion technologies are well documented in the literature (Bowen, 1973; Axtmann, 1975; and Mercado, 1975).

In the binary conversion process, the hot geothermal fluids which are used to heat and vaporize a low-boiling-point working fluid, such as isobutane, are isolated in a closed system and reinjected into the reservoir. Therefore, the adverse environmental impacts associated with power generation utilizing the binary cycle are potentially fewer and of less magnitude than those associated with existing direct and flashed steam technologies. These potential impacts are described below; and, to the extent possible, differences in the magnitudes of each, assuming hypothetical sites in both the Cascade Range and in eastern Oregon, are estimated.

Impacts on land

The land use requirements of a binary cycle geothermal power plant are primarily dependent upon the number and spacing of production and reinjection wells and upon the acreage required for cooling towers, the turbine-generator building, isobutane and condensate storage tanks, and shops and warehouse facilities. At the Heber 50-MWe demonstration plant site these power block facilities will require 4 to 6 acres, and the total development including well locations and necessary buffer zones will involve 20 acres. Figure 5 shows an artist's conception of the Heber facility. Slightly larger sites might be required in Oregon, where reservoir differences may necessitate location of separated production wells.

In Oregon, geothermal power plants must be located within areas designated as suitable for such purposes in the Oregon Nuclear and Thermal Energy Council's (now the Energy Facility Siting Council) "Statewide Siting Task Force Report" (1974). Many natural resource areas, including wilderness, roadless, historic, botanical, and research natural areas; wildlife refuges; and geologic areas are presently withdrawn as potential geothermal plant sites by this legislation. Several Known Geothermal Resource Areas (KGRA's) in the Cascade Range are within or immediately adjacent to areas designated as unsuitable and thus will probably not be developed for electric power generation unless the earlier designation is reviewed and changed.

Subsidence and induced seismic activity resulting from fluid withdrawal and reinjection are other potential land use impacts of geothermal development. Prolonged withdrawal of fluids from liquid-dominated reservoirs in sediments is a potentially serious problem. The Wairakei field in New Zealand is the only geothermal field in which documented ground movement has been reported. The area affected is greater than 65 km^2 and the total maximum vertical movement since 1956 has been approximately 4 m (Axtmann, 1975, p. 801). Although the risk of subsidence can be greatly reduced through reinjection of the geothermal fluids, they are presently not reinjecting at the Wairakei field. With the binary cycle, almost the entire volume of withdrawn fluids will eventually be returned to the reservoir and subsidence should not be a problem.

In Oregon, subsidence is not expected to occur in the generally competent volcanic formations of the Cascade Range (U. S. Forest Service, 1977). The risk of subsidence may be greater in the Basin and Range grabens, particularly those in which the geothermal fluids are contained in reservoirs within the generally thick sedimentary fill.

Whereas the reinjection of geothermal fluids reduces the likelihood of subsidence, high pressure injection into geologic units that are in hydraulic communication with an active fault should be avoided because such injection may trigger minor earthquakes. Present experimental evidence suggests, however, that the potential for inducement of minor earthquakes can be greatly reduced by not injecting along an active fault and by controlling injection pressures and fluid flow rates (Healy and others, 1968; Raleigh and others, 1976).

New transmission corridors will be needed to interconnect the potential geothermal resource areas of southeastern Oregon with the regional grid system. As much of this region is arid, sparsely populated, and nonforested, no major adverse environmental impacts should result from construction of new 230-kV or 500-kV transmission lines. If capacity is available on transmission lines that already cross the Cascade Range, they could be used to transmit the electrical energy from geothermal power plants. Additional lines would be required, however, to connect any future geothermal plant with the existing system.

Impact on water

Geothermal plants, because of their low thermal efficiency (11 to 16 percent vs. 32 to 34 percent for a nuclear plant and 36 to 40 percent for fossil-fuel plants), require rejection of large amounts of waste heat per kilowatt of plant capacity. Geothermal plants which use either the direct or flashed steam conversion cycles provide their own cooling water and generally do not require supplementary sources. After passing through the turbine, the natural steam is condensed, piped to the cooling towers, and recirculated back to the condensers for cooling. The excess condensate not evaporated through the cooling tower is reinjected

into the geothermal reservoir where it originated, thus prolonging useful production from the field.

On the other hand, geothermal power plants utilizing the binary cycle may require large amounts of supplemental cooling water from outside sources because the geothermal fluids usually remain in a closed system; and since the total extracted volume, excluding losses, is reinjected into the reservoir, it is not available for cooling tower water supply. In some cases, it may be desirable and possible to use some geothermal fluid for power plant cooling water.

Consumptive water requirements for a 50-MWe binary cycle geothermal power plant utilizing a wet cooling tower will probably range from 1,000 to 2,000 gallons per minute, depending on the total amount of waste heat to be rejected (Holt/Procon, 1976). Assuming an 80 percent annual plant factor, this would result in the need for obtaining 1,300 to 2,600 acre-feet of water annually from either surface or regional ground water supplies, or perhaps the geothermal reservoir itself. For a 200-MWe geothermal field, the total consumptive water requirements would be increased to between 5,000 and 10,000 acre-feet annually.

Cooling water requirements of binary cycle plants could be reduced substantially through use of either a combination wet-dry or dry cooling tower technology. For example, the consumptive water requirements of a wet-dry cooling tower are 40-70 percent of those for a conventional wet tower, depending on design (Olesen and Budenholzer, 1972). Dry cooling towers require no makeup to the circulating water system but do require a much greater land area than evaporative towers and may result in reduced generator output during hot summer days. Wet-dry and dry cooling towers would also require much higher initial capital investments than the more conventional wet cooling towers and higher auxiliary power to operate fans and pumps.

The availability of cooling water may be a limitation to geothermal development in certain water-short areas. This could seem particularly true for portions of southeastern Oregon such as the Alvord Valley and Glass Buttes. Cooling-water supplies may be more readily available in the Cascade Range because of normally high precipitation and runoff amounts and the expected presence of large amounts of ground water.

Thermal and chemical pollution of possible nearby natural surface water bodies should not be a problem with binary cycle geothermal power plants under normal operation. Waste heat rejection in most cases will be accomplished by evaporation to the atmosphere in either wet or wet-dry cooling towers, spray ponds, or cooling reservoirs. Blowdown from the cooling towers can be routed to an evaporation pond or reinjected into the geothermal reservoir.

Improper injection of geothermal effluents back into the reservoir could cause contamination of shallow ground-water aquifers. Because of higher temperatures, geothermal effluents are expected to be of poorer quality than these ground-water supplies, parti-

cularly in the concentration of dissolved solids and certain trace elements such as mercury, arsenic, and boron. If proper injection well drilling and completion practices are followed and if a shallow ground-water aquifer surveillance program is implemented in the area surrounding the reinjection field, contamination of domestic supplies can be obviated.

Impact on the atmosphere

Air quality impacts from geothermal power plants are of two main types: (1) those associated with the discharge of water vapor from cooling towers, and (2) those associated with the release of noncondensible gases, primarily hydrogen sulfide.

The discharge of water vapor to the atmosphere from wet evaporative cooling towers results in the development of a steam plume above the tower. Under adverse meterological conditions, this steam plume could descend to the ground and cause localized fogging and icing problems on plant structures and nearby roads; but this problem should not occur frequently under normal atmospheric conditions. The use of wet-dry or dry cooling towers would greatly reduce or, in the case of the latter, eliminate these adverse impacts.

Geothermal fluids, both liquid and steam, may contain noncondensible gases including carbon dioxide (CO_2), hydrogen sulfide (H_2S), methane (CH_4), and ammonia (NH_3). The gas of principal concern is H_2S, because of its potential danger to plant and animal life (see California Division of Oil and Gas, and others, 1975), high corrosiveness, and objectionable "rotten egg" smell. With the direct and flashed steam technologies, such as those in use at The Geysers and Cerro Prieto, Mexico, respectively, the noncondensible gases have been vented to the atmosphere through air ejectors above the condensers and rapidly diluted under favorable meterological conditions. Under adverse meterological conditions, however, concentrations of H_2S in air can exceed ambient air quality standards. An H_2S abatement program presently underway at The Geysers will provide technology for controlling hydrogen sulfide to within acceptable levels (see, for example, Allen and McCluer, 1975).

Development and utilization of the binary conversion process should greatly reduce, or eliminate altogether, the discharge of noncondensible gases. As the binary cycle operates as a closed system with a single-phase liquid flow, the noncondensible gases will remain in solution and be reinjected into the reservoir without release to the environment. If the produced fluids are in a two-phase flow and steam flashing occurs at the wellhead, the noncondensible gases will concentrate in the steam phase and be removed and treated in a separator following the steam condenser.

Socioeconomic and aesthetic impacts

Socioeconomic impacts, both beneficial and adverse, will result from development and utilization of geothermal energy in Ore-

gon. Major benefits will include economic stimulation through the development of an indigenous energy resource and increased electrical system reliability through dispersed power plant siting and a broader generation resource mix. Changing land use patterns, population growth, and accompanying stresses on certain community facilities may result from power plant construction and operation, but the magnitude of these impacts will depend on the existing community structure of those areas affected.

Construction of a geothermal plant will employ on the order of 200 workers at all levels over a period of several years. Some of this labor could be drawn from local communities, especially for such jobs as plumbing, welding, and operation of heavy equipment. A permanent operational staff of between 10 and 20 will be needed. Several additional permanent workers would maintain the wells, piping, pumps, and equipment in the geothermal field itself.

A significant positive impact would result from increased county revenues due to real estate and ad valorem taxes. Furthermore, geothermal power generation in portions of eastern Oregon could aid in diversification of the economy, which is currently dependent upon the primary sector. Such diversification would result in the introduction of additional employment opportunities.

The aesthetic impact of a geothermal power plant will depend on existing land uses, type and extent of vegetation, topography, and geographic location. As Figure 5 shows, a binary cycle plant is not obtrusive in appearance, although this is certainly a matter of individual judgment. The largest and tallest structures are the mechanical draft cooling towers, which are approximately 15 m (50 feet) high. In the Cascade Range, most if not all of the power plant and field facilities could be easily harmonized with the forested landscape, and from a distance the steam plume above the cooling tower is all that would be visible from most vantage points. In the generally nonforested landscape of southeastern Oregon the plant would be much more visible, although potential geothermal occurrences are somewhat remote from major population centers and high-use recreation areas.

Conclusions

Based upon our present, albeit sketchy, knowledge, potential geothermal resources in Oregon are likely to be of the liquid-dominated (hot water) type with estimated temperatures of the hotter reservoir systems approaching 200°C (392°F). The binary cycle appears to be the most favorable conversion process for electric power generation from geothermal systems with temperatures in the range of 150°C (302°F) to 210°C (410°F). Utilization of the binary cycle, which isolates the geothermal fluids in a closed system, will greatly reduce the adverse environmental impacts generally attributed to geothermal energy based on the uncommon Geysers model. Air pollution impacts resulting from the release of hydrogen sulfide and other noncondensible gases will be nonexistent during normal plant operation. With the application of

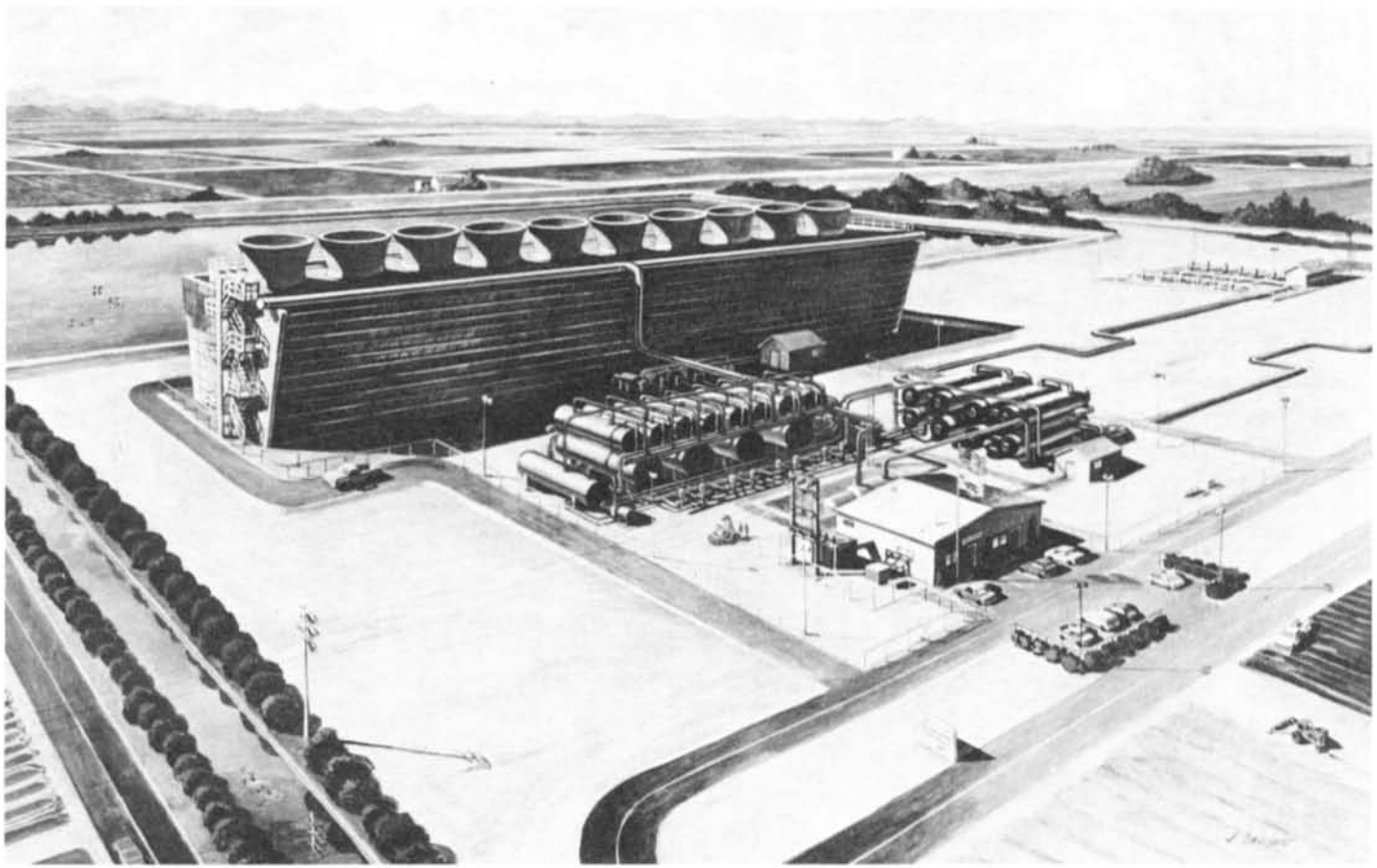

Figure 5. Artist's Conception of the Heber 50-MWe Binary Cycle Demonstration Geothermal Power Plant.

directional drilling techniques to tap geothermal reservoirs, land requirements and the concomitant impact of surface installations can be reduced. Reinjection of the geothermal effluents will eliminate the need to discharge these fluids to surface waters and reduce the possibility of subsidence. When accomplished properly, deep reinjection will not adversely impact domestic ground water supplies. Improved drilling and casing techniques and the utilization of blowout-prevention equipment on the wellhead will greatly reduce the probability of well blowouts during the drilling and reservoir testing phase.

The greatest and most significant uncertainty in geothermal energy utilization for electric power generation in Oregon is associated with the existence or availability of commercial reservoirs which can produce large volumes of fluids for at least 30 years. The next most significant uncertainty is the availability of water for binary power plant condenser cooling. In this regard, it appears desirable to conduct hydrological studies of surface and ground waters in potential geothermal areas parallel with exploration. The need for cooling water is probably not a major obstacle to geothermal development, but the availability of cooling water warrants careful consideration in the early stages of resource evaluation.

If commercial geothermal reservoirs are present in Oregon, the binary cycle will enable their utilization for power generation in an environmentally compatible manner. Furthermore, if these reservoirs can be developed economically, geothermal power may eventually become an important supplement to Oregon's present hydropower, nuclear, and fossil generation resources mix. The important advantage is that geothermal energy would be a fuel resource indigenous to Oregon and not imported from out of state.

Acknowledgments

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References

Allen, G.W., and McCluer, H.K., 1975, Abatement of hydrogen sulfide emissions from The Geysers Geothermal Power Plant: Proceedings of second U.N. symposium on the development and use of geothermal resources, May 20-29, 1975, San Francisco, Calif., U.S. Govt. Printing Office, p. 1313-1316.

Axtmann, R.C., 1975, Environmental impact of a geothermal power plant: Science, v. 187, p. 795-803.

Bowen, R.G., 1971, Electricity from geothermal, nuclear, coal sources - an environmental impact comparison: The Ore Bin, v. 33, no. 11, p. 197-209.

Bowen, R.G., 1973, Environmental impact of geothermal development: *in* Kruger, P., and Otte, C., eds., Geothermal energy: Stanford Univ. Press, Stanford, Calif., p. 197-215.

Bowen, R.G., and Peterson, N.V., compilers, 1970, Thermal springs and wells in Oregon: Oregon Dept. Geol. and Mineral Indus., Misc. Paper 14 (map).
Budd., C.F., Jr., 1973, Steam production at The Geysers Geothermal Field: *in* Kruger, P., and Otte, C., eds., Geothermal energy: Stanford Univ. Press, Stanford, Calif., p. 129-144.
California Division of Oil and Gas, and Oregon Department of Geol. and Mineral Indus., 1975, Proceedings of workshop on environmental aspects of geothermal resources development, November 20-22, 1974, prepared through NSF grant no. AER 75-06972, 123 p.
Healy, J.G., Rubey, W.W., Griggs, D.T., and Raleigh, C.B., 1968, The Denver earthquakes: Science, v. 161, p. 1301-1310.
Holt/Procon, 1976, Energy conversion and economics for geothermal power generation at Heber, Calif., Valles Caldera, New Mex., and Raft River, Idaho - case studies: Prepared for the Electric Power Research Institute by the Ben Holt Co. and Procon Inc., EPRI ER-301, November, 1976, 114 p.
Lawrence, R.D., 1976, Strike-slip faulting terminates the Basin and Range province in Oregon: Geol. Soc. America Bull., v. 87, p. 846-850.
Mariner, R.H., Presser, T.S., Rapp, J.B., and Willey, L.M., 1975, The minor and trace elements, gas, and isotope compositions of the principal hot springs of Nevada and Oregon: U.S. Geol. Survey open-file report, 27 p.
Mariner, R.H., Rapp, J.B., Willey, L.M., and Presser, T.S., 1974, The chemical composition and estimated minimum thermal reservoir temperatures of selected hot springs in Oregon: U.S. Geol. Survey open-file report, 1974, 27 p.
Mercado, S.G., 1975, Cerro Prieto geothermoelectric project; pollution and basic protection: Proceedings of second U.N. symposium on the development and utilization of geothermal resources, May 20-29, 1975, San Francisco, Calif., U.S. Govt. Printing Office, p. 1385-1398.
Muffler, L.J.P., 1975, Tectonic and hydrologic control of the nature and distribution of geothermal resources: Proceedings of second U.N. symposium on the development and use of geothermal resources, May 20-29, 1975, San Francisco, Calif., U.S. Govt. Printing Office, p. 499-507.
Olesen, K.A., and Budenholzer, R.J., 1972, Economics of wet/dry cooling towers show promise: Electrical World, December 15, 1972.
Oregon Nuclear and Thermal Energy Council, 1974, State-wide siting task force report: Salem, Oreg.
Pacific Gas and Electric Co., 1975, Amended environmental data statement - Geysers Unit 13: Filed with the California Public Utilities Commission March 1975.
Raleigh, C.B., Healy, J.H., and Bredehoeft, J.D., 1976, An experiment in earthquake control at Rangeley, Colo.: Science, v. 191, p. 1230-1236.
Renner, J.L., White, D.E., and Williams, D.L., 1975, Hydrothermal convection systems: *in* White, D.E., and Williams, D.L., eds., Assessment of geothermal resources of the United States - 1975: U.S. Geol. Survey Circ. 726, p. 5-57.
U.S. Forest Service, 1977, Draft environmental statement for geothermal development in the Breitenbush area: USAFSR6DES (Adm) 773, Pacific Northwest Region, Portland, Oreg., p. 70.
White, D.C., Muffler, L.J.P., and Truesdell, A.H., 1971, Vapor-dominated hydrothermal systems compared with hot-water systems: Econ. Geology, v. 66, p. 75-97.
White, D.E., and Williams, D.L., eds., 1975, Assessment of geothermal resources of the United States: U.S. Geol. Survey Circ. 726, 155 p.

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GEOTHERMAL OPEN-FILE REPORT RELEASED

The Department has released Open-file Report O-77-2, "Geothermal Gradient Data," by Donald A. Hull, David D. Blackwell, Richard G. Bowen, Norman V. Peterson, and Gerald L. Black. The 135-page report contains a brief text, maps, and tables and graphs showing geothermal data collected in Oregon by the authors between September 1975 and December 1976. The report is available in the Department's Portland, Baker, and Grants Pass offices at a cost of $5.00 per copy.

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STUDY OF GROUND EFFECTS OF EARTHQUAKES IN PORTLAND NOW AVAILABLE

Copies of "A Preliminary Geological Investigation of the Ground Effects of Earthquakes in the Portland Metropolitan Area, Oregon" (1974), by Paul Hammond, G.T. Benson, Dan J. Cash, L.A. Palmer, Jan Donovan, and Brian Gannon, may be purchased for $4.00 at the Department's Portland office. The publication, which summarizes Portland's earthquake history and discusses potential geologic hazards related to earthquakes, contains six Portland area maps: a preliminary tectonic map, a lineation map, a map showing the crack analysis of lineations in East Portland, a slope map, a landslide map, and a map showing potential geologic hazards related to earthquakes.

* * * * *

NEW BUREAU OF MINES STATE LIAISON OFFICER APPOINTED

On April 1, 1977, John M. West became the new Bureau of Mines State Liaison Officer in Oregon, replacing Walter E. Lewis, who retired. Mr. West, a native Oregonian, has served the Bureau as minerals resource investigator in Spokane; nonmetallic commodity specialist in Washington, D.C.; foreign minerals specialist, doing studies on South Asia and the Far East; commodity specialist on boron, mercury, and diatomite in San Francisco; and gold specialist in Washington, D.C. As Liaison Officer he will strengthen Federal-State cooperative efforts to solve supply and environmental quality problems associated with the development of mineral resources and provide information and assistance related to Federal programs conducted or administered by the Bureau of Mines. West's business address is: Suite 7, Standard Insurance Building, 475 Cottage Street N.E., Salem, Oregon 97301; telephone (503) 399-5755.

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