GL00781

TECHNICAL NOTE

GEOTHERMAL ENERGY IN THE U.S. ARMY

by

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for limited distribution only

CORPS OF ENGINEERS

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I INTRODUCTION TO GEOTHERMAL SYSTEMS

A. Geothermal Systems: Pertaining to heat within the earth. (Dictionary of Scientific and Technical Terms, 1984).

The earth retains a vast amount of heat in its interior, but in general, this heat is too diffuse at the surface to be useful. Sources of heat in quantities that become useful are brought near the surface of the earth in tectonically active areas, characterized by recent volcanism and active-mountain building or areas with upwelling ground water (e.g. Texas Gulf Coast, South Dakota). Geothermal resources are defined as stored heat that is recoverable using current or near-current technology, regardless of cost (Reed, et al; 1982). The following categories of geothermal resources bases have been identified (Glasstone, 1982; Anderson and Lund, 1979; White and Williams, 1975; Reed, et al., 1982):

1. Hydrothermal Convection Systems: In hydrothermal convection systems the heat is transferred by convective fluid flow along faults, fracture zones and/or through permeable rocks. There are two common driving sources of heat — a relatively shallow igneous intrusion or the average temperature of the earth at a great depth. These sources also provide thermal input to drive the warm, less dense water upwards (see Figures 1 and 2; Anderson and Lund, 1979). Hot springs and geysers are surface manifestations of hydrothermal convection systems. These systems are referred to as vapor-dominated systems if steam is the dominant fluid in the fractured rock ($\geq$ 200°C, 390°F) and hot water systems if water is the dominant fluid.

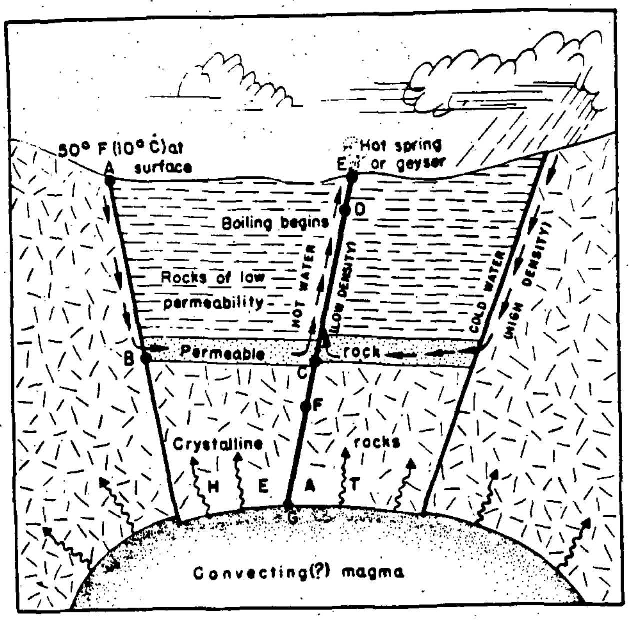


Figure 1. Schematic model of a hydrothermal convection system driven by an underlying young igneous intrusion (modified after White, 1968).

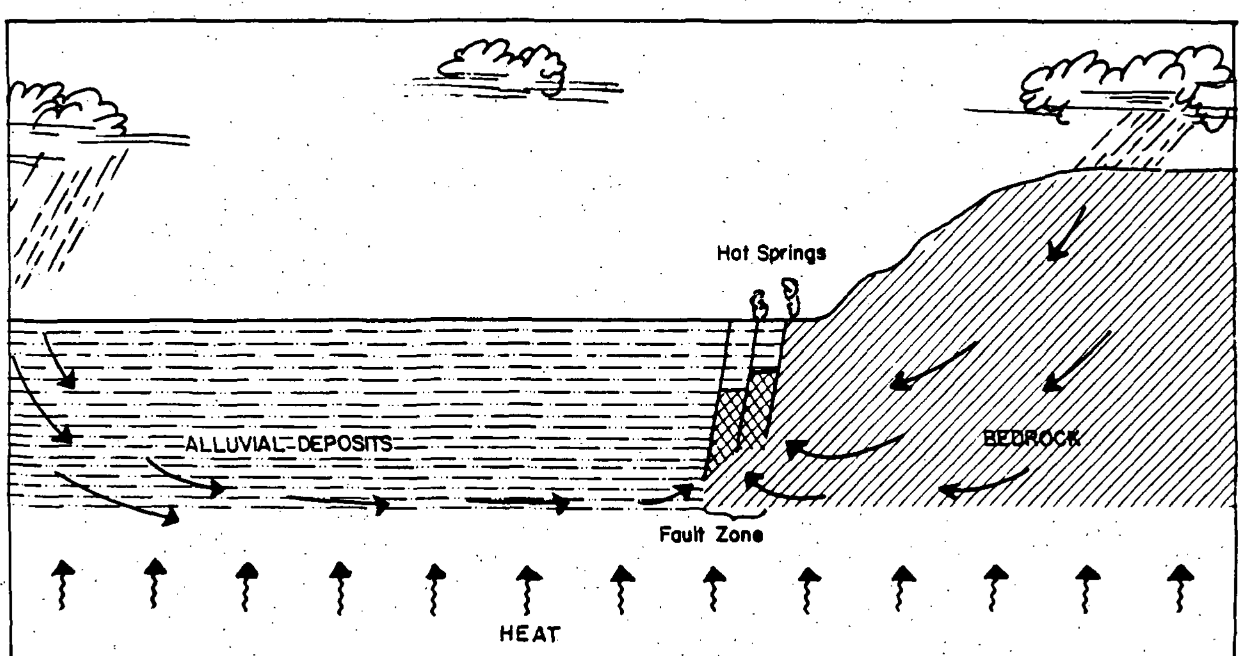


Figure 2. Schematic model of a hydrothermal convection system related to deep circulation of meteoric water without the influence of young igneous intrusions (Anderson and Lund, 1979).

Almost all of the geothermal resources which have been commercially utilized to date are hydrothermal convection systems.

2. Geopressured Resources: These resources occur in large, deep sedimentary basins such as those underlying the Texas/Louisiana gulf coast. Reservoirs contain high pressure/high temperature brines with dissolved methane. Geopressured resources are estimated to be quite large; however, technology has not yet been developed to simultaneously produce electricity and recover natural gas.

3. Hot dry rocks: Hot dry rock geothermal resources refer to hot, solid (vs. molten) rocks to which water does not have access. The source of heat may be a cooling intrusive igneous body. In order to utilize the geothermal resources, technology is currently being developed to fracture crystalline rock to provide a hydraulic conduit to and from the heat source and circulate water to recover heat.

4. Magma resorces: Magmatic activity occurs in tectonically active areas such as spreading ridges (rift zones), intraplate melting anomalies and subduction zones. The presence of relatively shallow molten or partially molten magma is associated with large amounts of heat being concentrated near the earth's surface. Technology for the extraction of heat from molten rock is only in the conceptual stages at this time.

5. Conduction-dominated systems:

"Beneath the vast majority of the land area of the United States, the vertical transport of heat in the upper crust is believed to be primarily by thermal conduction" (Sass and Lachenbruch, 1978). Conduction-dominated systems are defined by Sorey, et al. (1982) to include the presence of water in large regional or coastal plain aquifers: "In conduction-dominated systems, upward circulation of fluid is less important than the existence of high vertical temperature gradients in rocks that include aquifers of significant lateral extent. These conditions occur beneath many deep sedimentary basins throughout the United States." Figure 3 presents conceptual models for types of conduction-dominated systems (Sorey, et al. 1982). In the majority of the United States, the increase of temperature with depth is near normal at about 30°C/km (140°F/mile). Higher gradient areas such as eastern Washington and the Great Plains have large conductively heated aquifers with useable energy up to temperatures of 100°C (212°F). It will be at least several years before conduction-dominated geothermal resources of a normal geothermal gradient become economically viable to use.

To summarize, geothermal resources can exist in a variety of geological environments and water movement is necessary for current economical considerations. It is possible that several Army bases within the United States may have eonomical geothermal resources.

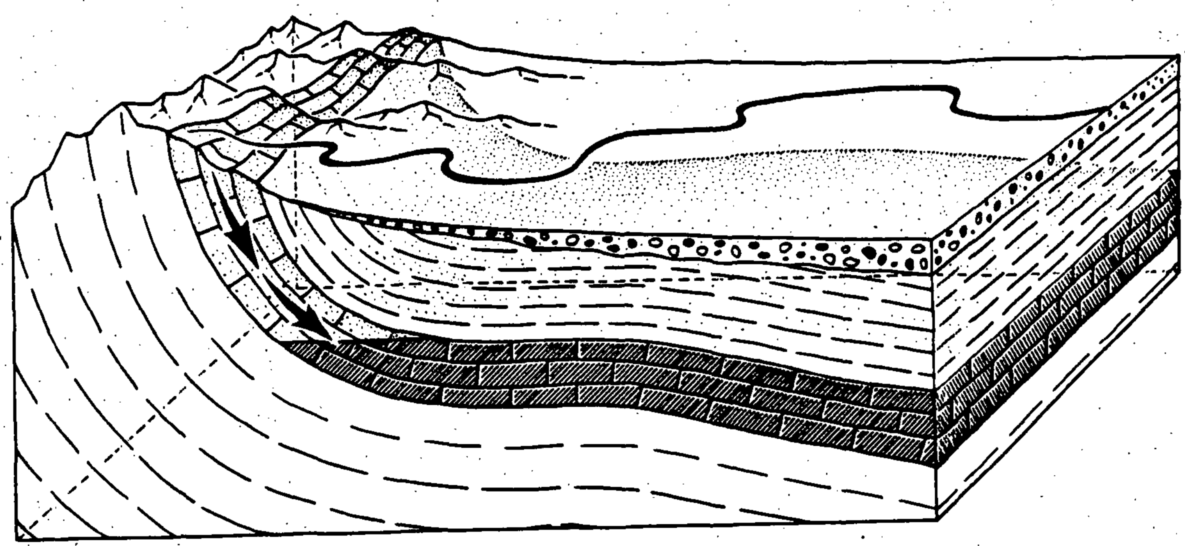
B. Applications of Geothermal Energy

There are three main applications of geothermally warm or hot water: 1) production of electricity, 2) space heating, and 3) industrial process heat. Figure 5 shows the approximate temperatures required for various geothermal uses (Anderson and Lund, 1979).

1. Electricity is presently produced from geothermal energy in several countries including Italy, New Zealand, United States, Iceland, Japan, the Phillipines and the USSR.

Currently, the United States produces over 1 gigawatt of electricity at The Geysers, California. There are three experimental units operating

A



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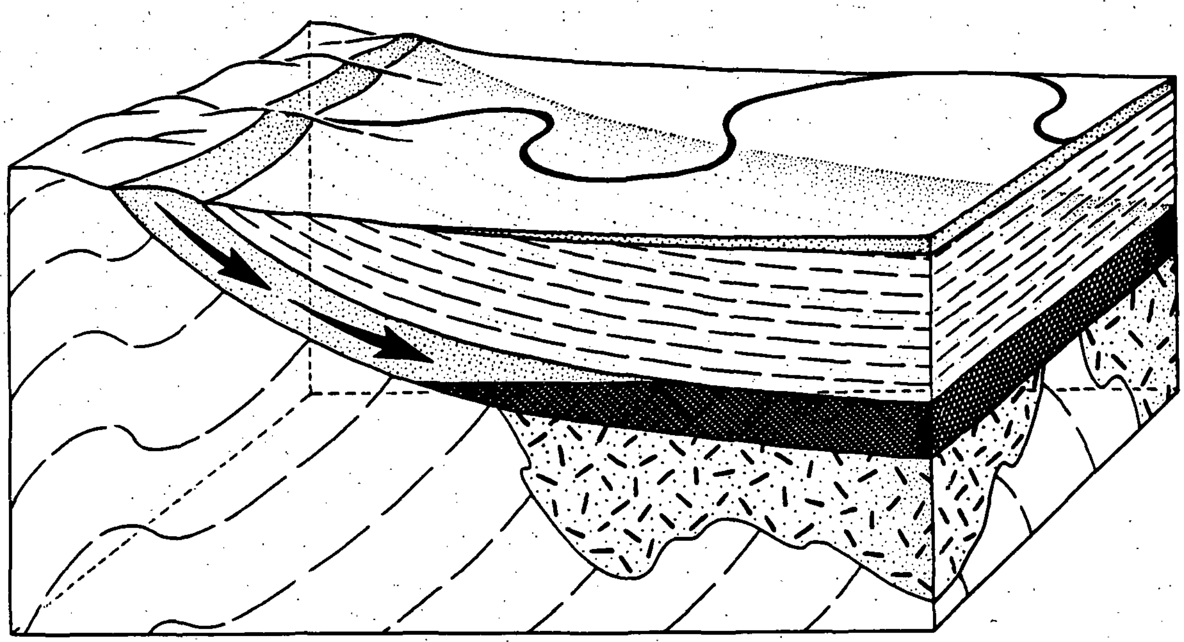


Figure 3. Conceptual models for types of conduction-dominated systems in which low-temperature geothermal resources in A) sedimentary basins and B) coastal plains occur. Arrows indicate direction of fluid circulation; shading shows location of reservoir containing low-temperature geothermal resources (Sorey, et. al., 1982)

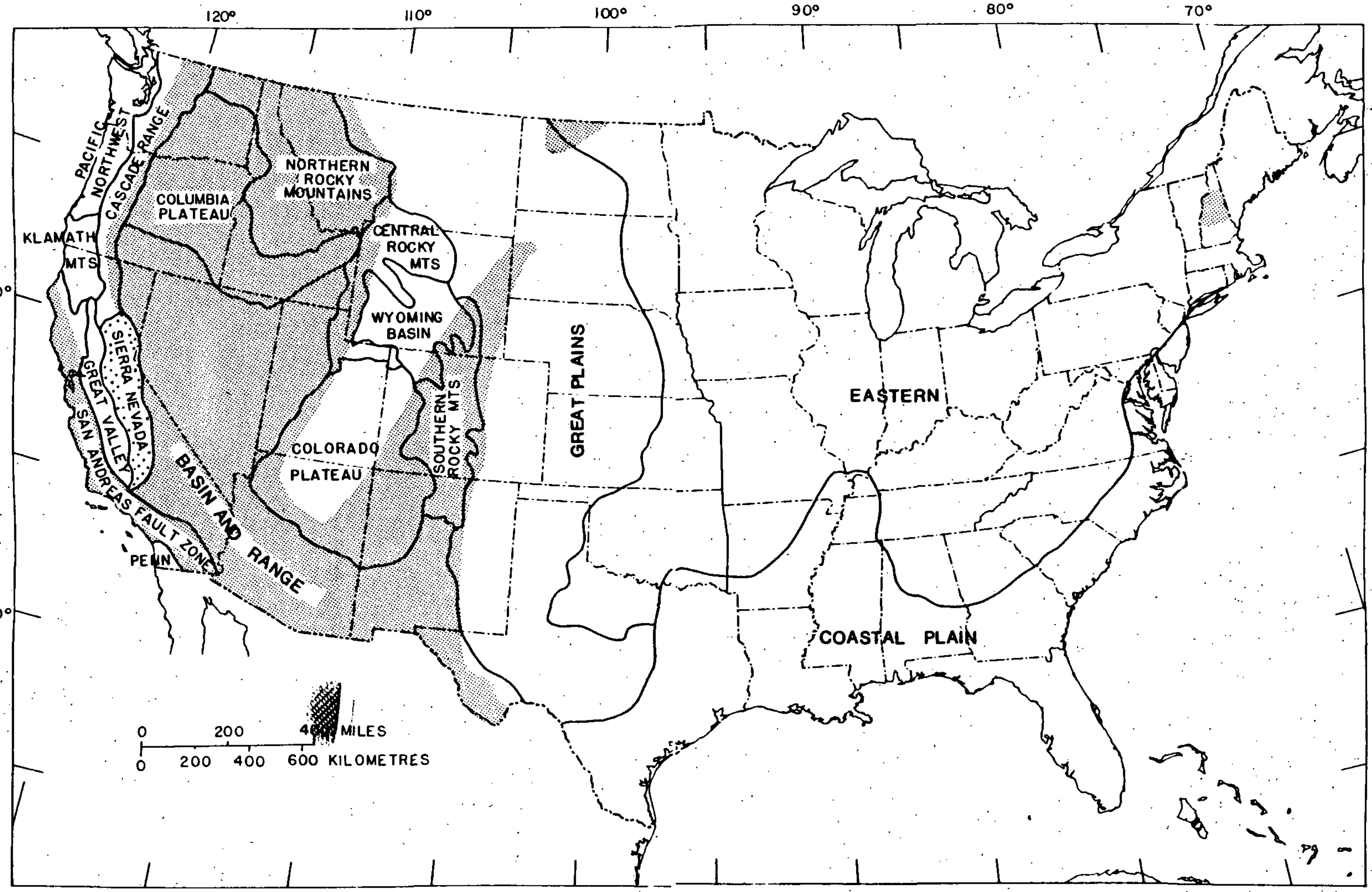


Figure 4. Map showing probable extent of hot (stippled), normal (white) and cold (dotted) crustal regions of the United States. Physiographic provinces do not necessarily represent heat flow provinces (Diment, et. al., 1975).

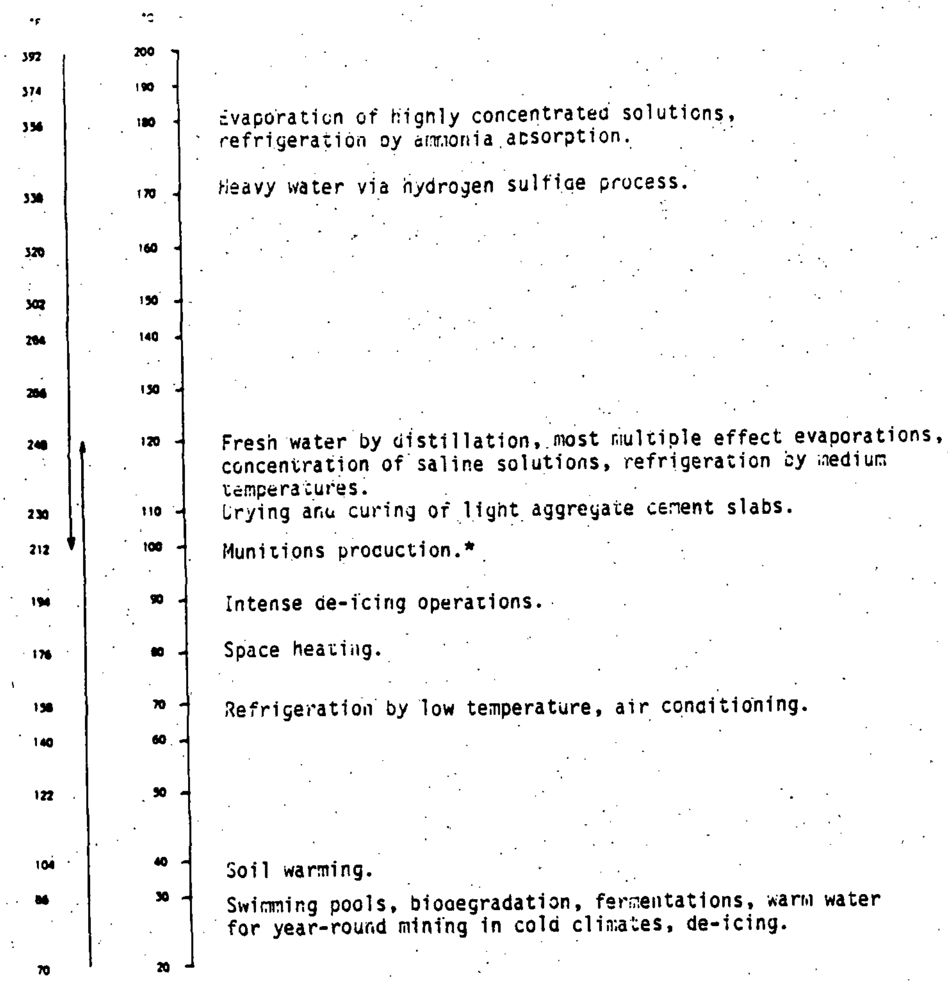
in the Imperial Valley of California, one unit in central Utah and one experimental unit in Hawaii (Reed, personal communication, 1985). The Navy is making preparations to begin producing electricity at China Lake, California in 1986.

2. Direct space heating applications of geothermal energy are much more widespread than the production of electricity. The DOE is currently funding 20 direct heat projects in the United States, eighteen are operating and two are under construction. The operating systems produce over 2.237 MJ per year ($534x10^9$ BTU/yr) (Reed, 1985). The vast majority of these projects are located in the western United States.

In areas where the seasonal heating demand is high, the most common space heating systems are forced air, circulating hot water and radiant heat. In addition, heat pumps are gaining in popularity. All of these systems are adaptable to geothermal energy; however, according to Anderson and Lund (1979) the forced-air system is the most adaptable.

Figure 6 illustrates the various temperature ranges required for heating and cooling methods.

3. As noted in Figure 5, agricultural and industrial processes can utilize geothermal water in the temperature range from 30-180°C (86-356°F).



*This is a tentative use of geothermal energy--Reed (1985, personal communication) reports knowledge of a dynamite factory which utilized 100 C geothermal water.

Figure 5. The approximate temperatures required for various geothermal uses (modified after Anderson and Lund, 1979)

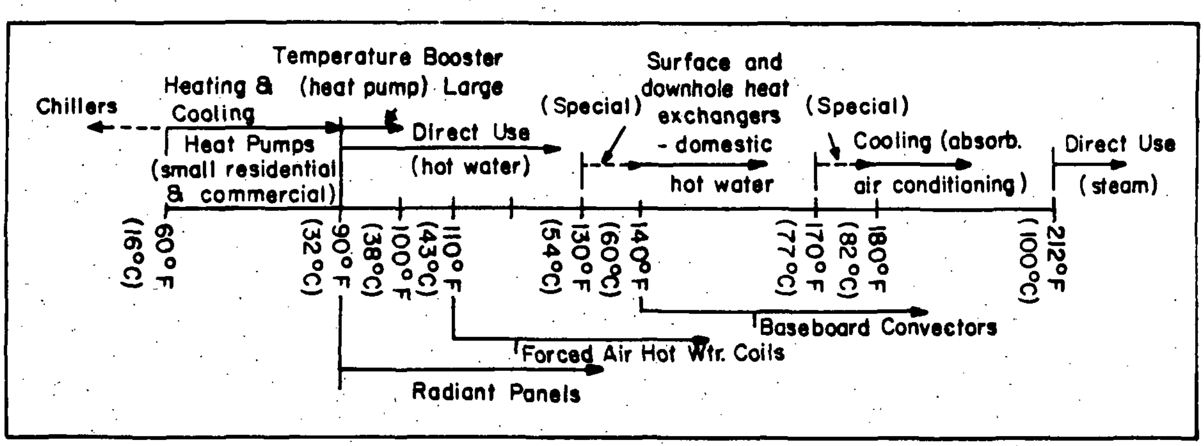


Figure 6. Temperature ranges for heating and cooling methods (Anderson and Lund, 1979).

II. FEDERAL AND DOD GEOTHERMAL INFRASTRUCTURES

Interagency Geothermal Coordinating Council:

The Interagency Geothermal Coordinating Council (IGCC) was officially formed in 1974 to facilitate cooperation among the various federal agencies with respect to geothermal energy. The council is at the Assistant Secretary level and, according to statute, the official DOD member is the Assistant Secretary of Defense for Manpower Reserve Affairs and Logistics. The DOD staff person on the working level who usually attends the IGCC meetings is Millard Carr: Because the Navy has been named the lead service in geothermal energy development, Mr. Carr is often accompanied by CPT Steve Quigley (NAVFAC) Assistant Commander for Energy and Environment. Dennis Hanneman (NAVFAC) and LCDR Tom Boothe (Navy Energy Office) also attended the meetings. NAVFAC maintains information on DOD geothermal activities for the council.

Interservice Geothermal Coordinating Working Group

The information available on this organization is very sketchy. The Working Group is mentioned by Millard Carr in the 1985 hearings before the House Appropriations Subcommittee on Military Construction. The Working Group has met only once, and no current Army Energy Office employee has participated in this group. In the 1985 MILCON Hearings, Mr. Carr states that the Working Group has a Defense Energy Program Policy Memorandum (DEPPM) in preparation which will provide central guidance and coordination; Mr. Carr has the primary responsibility for the authorship of the DEPPM, and has received input from the Navy.

Department of Energy

The Department of Energy through the Geothermal Division is the federal agency which has the most interest in geothermal energy. The formal working relationship between the DOE and DOD is established through the IGCC. More specific agreements have been established at working levels — for example, the Naval Weapons Center, China Lake, California and the San Francisco Operations Office of the Department of Energy work closely in resource assessment for the Navy under a Memorandum of Understanding (MOU) with the Navy Energy R&D Office (Breese, 1985, Personal Communication), and an agreement between the Air Force Systems Command and the DOE Idaho Operations Office exists to facilitate geothermal development at Ascension, Island.

The DOE, through its contract labs, has technical expertise in the areas of resource assessment and well development; the contract labs are available to the Army for consultation in these areas. The DOE has worked closely with the Navy at Twenty-Nine Palms, California, and with the Air Force in the Azores; Lackland AFB, Texas; Hill AFB, Utah; Ascension Island and Williams AFB, Arizona, to develop geothermal resources. During the Reagan administration the focus of DOE-Geothermal has changed from active assessment and development activities to developing new technologies for resource exploration, geothermal energy production and reservoir engineering. (The United States Geological Survey is still active in geothermal assessment programs and probably has the most expertise in this area).

The following is a brief list of DOE contractors and their respective areas of expertise:

Laboratory	Subject Area
Idaho National Engrg. Lab. (INEL)	Binary power system development, direct use applications
Univ. of Utah Research Inst. (UURI)	Resource assessment exploration
Sandia National Laboratories	Drilling technology, magma energy
Lawrence Livermore Laboratories	Seismic exploration
Univ. of California, Berkley	Reservoir Engineering, geophysics, computer modeling
Stanford University	Reservoir Engineering, well testing

III. EXISTING GEOTHERMAL ACTIVITY WITHIN THE ARMY

Hawthorne Army Ammunitions Plant (Hawthorne, NV)

Hawthorne Army Ammunitions Plant (HAAP) is the only U.S. Army site where significant activity has occurred to develop geothermal energy. In 1983 a geothermal exploratory well was drilled on base to confirm preliminary assessments that a widespread geothermal resource existed at depths of between 120 and 245 m (400-800 ft). The well was completed to a depth of 252 m (828 ft). Fluid temperatures in the well are lower than had been expected, being 53°C (127°F) when it was thought that temperatures of 80-90°C (175-195°F) would be encountered.* However, 53°C is adequate for space and domestic hot water heating. A maximum temperature of 54-1/2°C (130°F) was encountered at a depth of 53 m (175 ft).

It was concluded that capacities in excess of 0.063 m^3/s (1,000 gpm) are possible from properly designed geothermal wells in the area completed at depths of 120-180 m (400-600 ft). It is also thought that higher temperature fluids may exist in a region 1.5-3 km (1-2 miles) south of the well site.

Sierra Army Depot (Herlong, California)

Geothermal energy has been examined as part of the Energy Engineering Analysis Plan (EEAP) of the Sierra Army Depot. Known geothermal resources exist to the north of the depot in the Wendell-Amadee Hot Springs area. Currently, there is extensive exploration and development in the region (referred to as Susanville).

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* Dennis Trexler (1985) a geothermal consultant on this project felt that some of the hottest water may have been cut off by cementing the well to a depth of 146 m (480 ft).

It is thought that geothermal reservoir temperatures of 115°C (240°F) may exist at 1500 m (5000 ft) depth in the area, although geothermal resource production may be limited to fracture zones which are presently not known to continue beneath the base.

A preliminary economic evaluation of geothermal space heating at Sierra Army Depot by EG&G Idaho, Inc. (undated) indicates that a geothermal heating system would reduce heating costs and conserve conventional fuels. This evaluation assumed a temperature source of 118°C (245°F). The estimated resource exceeds the needs of the base by a large degree. According to David Wickward (1985) geothermal resources probably exist in the north end of the depot but are several miles from the present administration buildings. There is currently no activity to develop these resources.

The EEAP analysis for Sierra Army Depot (SAD) recommends a stepwise process for exploration for the resource based on investment-to-expected-return at each step as follows:*

1. Water Chemistry

Measure: Conduct water chemistry and temperature profile analyses of existing wells at SAD to establish a geothermometer for each.

Cost: $1000 - $2000 per well

Criteria for Continuing: Indication of at least 82°C (180°F) aquifer.

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* According to Reed (1985) the cost estimates for steps 1-3 are realistically closer to the low values quoted, for step 4 (Drill Well) the low value is more realistically estimated at $150,000.

2. Electrical Resistivity Tests

Measure: Conduct electrical resistivity analyses to establish contours.

Cost: $50,000 - $100,000

Criteria for Continuing: Anomalies similar to those of existing geothermal sources.

3. Heat Flow Profiles

Measures: Drill shallow wells (150 m, 500 ft) in areas identified by electrical tests and measure and plot heat flow profiles of new and existing wells.

Cost: $10,000 - $15,000 per well

Criteria for Continuing: Temperature gradient profiles indicating temperature increase with depth and predicted depth of acceptable temperature fluid.

4. Drill Well

Measure: Depending on level of certainty from previous tests drill either small diameter deep test hole or full size well holes.

Cost: $50,000 - $1,000,000 per hole depending on hole size, depth and material encountered.

White Sands Missile Range (White Sands, NM)

Preliminary analyses in the White Sands area and a stratigraphic well on base indicate a resource temperature greater than 90°C (194°F) at a depth of 1830 m (6000 ft). The Hueco Tanks area in Texas, located about 32 km (20 miles) from the present utilization site (Ft. Bliss), has a 90°C (194°F) resource at 465 m (1520 ft). Water at this temperature may be used in cooling applications (see Section IB).

A life cycle cost analyses conducted for the EEAP in 1983 for White Sands indicated that a conventional heating system would cost $7,051,595 compared to $9,637,681 for a geothermal heating system utilizing the deeper resource. This study made many assumptions about the geothermal resource, as the resource had not been thoroughly investigated.

A regional geothermal assessment indicated that a large low temperature resource is located near the post area (Icerman and Starkey, 1982). The New Mexico State University Energy Institute (NMEI) and White Sands Missile Range have made an agreement to drill temperature gradient holes on base to delineate and map the resource; the state of New Mexico is providing $30K in matching funds for the project. White Sands Missile Range is providing troop support to drill the holes and NMEI will provide temperature logs of the holes. The work is scheduled to begin sometime in 1985.

IV. PRELIMINARY ANALYSIS OF RESOURCE POTENTIAL AT ARMY FACILITIES

The following list was developed from 1) state geothermal maps prepared by the respective state Geological Surveys and produced by the National Geophysical Data Center of the National Oceanic and Atmospheric Administration and, 2) comments received by Dr. Duncan Foley (1983, 1985). Each map used varies in the form of presentation; however, each lists references, warm and hot water wells and springs, and indicates areas favorable for discovery of geothermal waters with gray shading. The specific meaning of gray shading is indicated after each state's name as noted in the list. For states that had no geothermal maps (central and eastern), Dr. Foley's comments are the primary source of information. It is noted that all U.S. Army bases were reviewed and only those with potential geothermal resources are listed.

ALASKA

(Lt. Gray: Favorable for discovery at shallow depths (< 1000 m, 3300 ft) of water sufficient for direct heat applications.)

Ft. Wainwright - Close to Eielsen AFB, Fairbanks, AK - The "Yukon Command Training Site" intersects the gray area associated with Chena and Circle Hot Springs. Hot Springs (NC - 34) adjacent to the NE Corner of the base yield water at 61°C (142°F).

Ft. Richardson, (Anchorage, AK) - Close to Elmendorf AFB (Anchorage, AK) - Volcanically active Mt. Spurr is nearby and a high geothermal gradient is indicated near the Cook inlet. Because anchorage is energy rich with oil, gas, coal and hydropower potential, little is known about the geothermal resources in this area. Department of Energy funded research in the next few years will expand the data base.

ARIZONA

(Gray: areas favorable for discovery and development of less than 100°C (212°F) resources).

Yuma Proving Grounds, (Yuma, AZ)--close to Marine Corps Air Station, Yuma, AZ - A well located just east of the northern point of the base (YU-11) has water of 44°C (111°F) at 310 m (1,020 ft.). A dry well just south (YU-34) shows a temperature of 60°C (140°F). Ten kilometers (6 miles) east of eastern edge of the station there are wells 20-500 m (65-165 ft.) deep which produce 30-45°C (86-113°F) water.

Yuma Facilities Engineering stated that they have water of about 38°C (100°F) from shallow wells (less than 1000 ft, 300 m) in a small cantonment area which contains 4-6 buildings. This area is about 25 km (15 miles) from where the hot water could be effectively utilized. Yuma received an unsolicited geothermal proposal through Huntsville (via Sacramento) which was rejected on the basis that a geothermal resource had not been verified on base.

The Navy has scheduled the nearby Yuma Marine Corps Air Station (YMCAS) for an advanced site survey in 1985, thermal gradient drilling in 1986 and site assessment in 1987. A Navy report on geothermal potential at YMCAS is due out in 1985.

CALIFORNIA

(Lt. Gray: Favorable for discovery at shallow depth (< 1000 m, 3300 ft.) of thermal water of sufficient temperature for direct heat applications. Dk. Gray: Known or inferred to be underlain at shallow depth by thermal water of sufficient temperature for direct heat applications).

Ft. Irwin (Barstow, CA) - Close to China Lake Naval Weapons Center, China

Lake, CA - In light gray area. Well on southern corner of base (SB-5, Paradise Springs) has 38°C (100°F) water, depth is unlisted.

A well located about 10 km away from west edge of base in Randsburg (SB-47 Magma Power Company well) yields 116°C (241°F) at 236 m (774 ft.). The Navy has contracted to make electricity at Coso Hot Springs at a location 45 km (28 miles) away (NW) from the NW corner of the base. The small town of Trona, CA (about 10 km from NW corner) has a few warm springs and several warm wells (SB-1: 30°C (86°F) depth unlisted; IN-14: 33°C (91°F) depth unlisted; IN-15: 32°C (90°F) at 91 m; IN-16: 58°C (136°F) at 183 m).

Sierra Army Depot (Herlong, CA) - The base is on parts of two dark gray areas. As of 1980 the possibility of producing electricity at a site adjacent to the base was being studied. The Wendell-Amadee Hot Springs which are located within 5 km (3 miles) of the NW corner of the base, discharge .06 m^3/s (950 gpm) at temperatures up to 96°C (205°F).

Sacramento Army Depot (Sacramento, CA) - near Mather AFB, McClellan. Low potential.

Camp Parks (Sub Presidio of S.F.) (Livermore, CA) - A 21°C (70°F) spring is located about 11 km (7 miles) SE, and at about 10 (6 miles) km north there is a spring at 21°C. In light gray area.

Ft. Baker (Sub. Presido, Salsilito, CA) - Close to Rocky Point Springs which has water in a well (MR-1) at 32°C (90°F). Light gray area on map.

Presidio of San Francisco - Light gray area on map.

Oakland Army Base - Light gray area on map.

Sharpe, Army Depot, (Stockton, CA) - Close to naval communications station Stockton, CA - Low potential.

Riverbank Army AMMO Plant (Riverbank, CA) - Low potential.

Ft. Ord (Seaside, CA) and Presidio of Monterey - Riverbank, CA - Close to Facility Point (Navy). 38°C (100°F) spring adjacent (MT-1 unnamed spring). In light gray area.

Ft. Hunter - Ligget (King City, CA, Sub Ft. Ord) - Dolans Hot Springs 15 km (9 miles) west (MT-5) has 37°C (99°F) water. In light gray area.

Camp Roberts (Paso Robles, CA semi-active) - Springs in vicinity at about 40°C (104°F). In light gray area — just outside dark gray area.

San Luis Obispo (San Luis, CA) - In light gray area. There is a hot springs well located 10 km (6 miles) south of base which produces 37°C (99°F) water.

U.S. Disciplinary Barracks (Lompoc, CA) - Close to Vandenberg AFB: In light gray area. Vandenberg has a 42°C (108°F) well.

Ft. MacArthur (Los Angeles, CA) - close to Navy Seal Beach Weapons Station, Long Beach Shipyard, Regional Medical Center (Long Beach) and Los Alimitos Air Station — the Naval Weapons Center is in a dark gray area. Wells adjacent to MacArthur have 28-31°C (82-89°F) temperatures. An oil well drilled in El Segundo had 218°C (424°F) water at 2540 m (8,330 ft.). The well apparently intersected a large fracture in the Newport-Inglewood fault zone — which served as a conduit for deep seated hot water.

The Navy has conducted a preliminary site survey in the Long Beach/ Seal Beach area (Higgins and Chapman, 1984). The report concluded that it is not currently economical to drill geothermal wells in this area; but recommends considering the conversion of all wells to geothermal wells in the future. To date, the Navy has not scheduled further geothermal activity in this area.

COLORADO

(Gray area: Area of significant lateral extent favorable for the discovery and development of low temperature sources (< 90°C, 194°F) geothermal water)

Ft. Carson (Colorado Springs, CO)

The Penrose artesian well located about 8 km (5 miles) from the southwest corner of the base produces 28°C (82°F) water, depth unlisted. The base does not intersect a gray area but is located less than 5 km (3 miles) from one on the southwest corner.

Fitzsimmons Army Medical Center (Aurora, CO)

Very low potential.

Rocky Mountain Arsenal (Denver, CO)

Low or no potential. The Rocky Mountains plant has a 28°C (82°F) spring.

GEORGIA: Hunter Army Airfield (Savannah, GA)

Low potential. Hunter is located on the Atlantic coastal plain and may have a 35-40°C (95-104°F) resource.

HAWAII

(Light gray: locations where geothermal resources exist, but evidence suggests that the probability for encountering a geothermal resource having a temperature greater than 200°C (392°F) within 3 km (2 miles) of the surface is 50% or less).

Schofield Barracks (Honolulu, HI) - close to Wheeler AFB and Navy Fleet Operations Control Center

Schofield Barracks intersects the light gray area associated with the Waianae Caldera. Extensive geochemical and geophysical studies recently conducted in the caldera suggest that a low to moderate temperature (< 150°C, 302°F) resource which was once though to exist probably does not (Reed, 1985).

Pohakula Training Area (Hilo, HI)

The western boundary of the training area is located about 7 km (4 miles) from the light gray area associated with Hualalai Volcano, which is considered an active volcano. According to Thomas, et al. (1980) it seems likey that the volcano has some geothermal potential, but the training site is not located over a rift zone which would be the hydrothermal conduit to bring hot fluid to the surface.

KANSAS

(Lt. Gray: Temperatures > 75°C (167°F) occur between 2-3 km (1 -2 miles). Dark Gray: most favorable for discovery and development of < 100°C (212°F) geothermal resources.)

Ft. Riley (Jct. City, KS) - Fort Riley is at the edge of a light gray area which is associated with the subsurface occurrence of the Precambrian Rice Formation. The Rice Formation may have an abundance of geothermal water in the deeper points (at least 500 m (1640 ft.) deep, chemical quality of water unknown).

Kansas Army Ammo Plant, (Parsons, KS) - Lies just outside of the dark gray area of the northwestern point of the Cherokee Basin (depth to basement is about 500-700 m, 1640-2279 ft.). The late Cambrian early Ordovician Arbuckle group is a likely source of 30-40°C (86-104°F) water of acceptable quality. Water from the Arbuckle group is used as public water supply in much of southeastern Kansas. A well drilled at the edge of the base yielded 30.7°C (88°F) at 550 m (1804 ft.).

NEVADA

(Dark gray: Areas with water temperature greater than 40°C (104°F) or where temperatures of 40°C may be encountered at depths less than 500 m (1640 ft.). Light gray: areas favorable for the discovery of thermal water at depths < 1000 m (3280 ft.) of sufficient temperature for direct heat applications.)

Hawthorne Army Ammunition Plant (Hawthorne, NV) - See comments in preceeding section.

Hawthorne Army Ammo plant intersects a dark gray area on the map. A shallow (< 300 m, 984 ft.) geothermal resource has been confirmed beneath the southern Walker Lake basin (which would probably underlie the base) with a large areal extent. Wells on base have reported the following temperatures and depths:

MN-4	51°C (124°F)	Depth unreported
5	46°C (115°F)	Depth unreported
5	24°C (75°F)	129 m
10	38°C (100°F)	138 m
13	23°C (73°F)	Depth unreported

A well located adjacent to the base, El Capitan Well, produces 97°C (207°F) water — its total depth is 350 m (1,150 ft.).

NEW MEXICO

(Dark Gray: Area most favorable for discovery and development of low temperature (less than 90°C, 194°F) geothermal resources).

Ft. Wingate Depot Activity (Gallup, NM) - One well located on base has a bottom hole temperature greater than 50°C (122°F) and thermal gradient between 40 & 50°C/km (168-198°F/mile). A well which is adjacent to the base, with bottom hole temperature less than or equal to 50°C, has a thermal gradient between 40 and 50°C/km.

Ft. Bliss Military Reservation - White Sands Missile Range (Las Cruces, NM) Close to Ordnance Missile Test Facility (White Sands, NM)-Holloman AFB (Alamogordo, NM) - See comments in previous sections, and under Texas.

These facilities lie south of the 20°C (68°F) groundwater isotherm indicating that naturally occurring groundwater is at 20°C or above (approximately the mean annual air temperature). Wells with temperatures of up to 71°C (160°F) are located on the Ft. Bliss MacGregor Gunnery Range. Geophysical data suggest that warm water may be rising along the Rio Grande Valley (the Rio Grande Rift Zone). Most of these military reservations are in the dark gray area. The Rio Grande Rift area is known to have particularly high heat flow, and contains several thermal anomalies.

OKLAHOMA

Ft. Sill (Lawton, OK): Low to no potential.

OREGON

(Lt. Gray: Region favorable for the discovery at shallow depth (< 1000 m, 3280 ft.) of thermal water sufficient for direct heat applications.)

Umatilla Ordinance Depot (Hermiston, OR) - Close to Boardman Bombing Range (Navy) - In light gray area. A well 6 km (4 mi.) away (Um4 - Hermiston City Well) has 24°C (75°F) water. Hermiston is in the geologic province known as the Columbia Plateaus. In this province deep wells in eastern Washington have penetrated warm water at intervals between 300-700 m (985-2300 ft.) and 800-1500 m (2625-4920 ft.). Fifteen hydrothermal-convection systems have been identified in the Oregon section of the

Columbia Plateaus. An inspection of data from Newcomb (1972) shows that wells on base range in depths from 90-210 m (300-700 ft.) and yield water from 16-22°C.

The Navy has an advanced site survey scheduled for nearby Boardman Bombing range in FY84 and site assessment for FY85. A Navy report on geothermal potential at Boardman Bombing Range is due out in FY85.

SOUTH CAROLINA

Charleston Army Depot (Charleston, SC)

Low to moderate potential. Water at 40-50°C (104-122°F) may exist at approximately 1 km depth.

TEXAS

(There are no gray areas defined on this map.)

Ft. Bliss (El Paso, TX) - See comments under NEW MEXICO and in previous sections.

The Hueco Tanks geothermal area located in Texas and New Mexico includes a large part of Ft. Bliss. In Texas, one well 137 m (450 ft) deep produces 58°C (136°F) water. Other wells produce water ranging from 33-38°C (92-100°F) at depths from 146-330 m (480-1,082 ft). Water quality is variable.

Warm water is furnished to the El Paso Utilities Canutillo well field and the Federal Correction Institution at LaTuna from a deep aquifer (274-323 m, 900-1060 ft) in the bolson along the Rio Grande. This is within 10 km of the southern boundary of Ft. Bliss.

Longhorn Army Ammunition Plant (Karnack, TX)

Low to no potential.

Saginaw Army Aircraft Plant (Ft. Worth, TX)

Three Cretaceous aquifers in the Dallas-Ft. Worth area, but not underlying Saginaw on the map, produce warm water. A well located close to the base (XU-19) produces 31°C (88°F) water at 389 m (1280 ft).

Ft. Sam Houston (San Antonio, TX) - Close to Lackland AFB.

Lackland AFB has 41°C (106°F) waters from approximately 1220 m (4000 ft.) depth. It is possible that similar, or perhaps warmer waters could be discovered at Ft. Sam Houston.

UTAH

(Gray area: favorable for discovery and development of local sources of low-temperature (> 90°C, 194°F) water.)

Utah Army Depot (Ogden, UT) - Hill AFB is 7 km (4 mi.) away - The Air Force is investigating the use of groundwater as a resource on Hill AFB. A geothermal exploration program funded by the DOE was conducted in the vicinity of Hill. A 993 m (3,260 ft.) test hole drilled in 1979 had a bottom hole temperature of 40°C (104°F). A well adjacent to what is assumed to be the depot (#10, Weber County - not clear on map) has a depth of 257 m (843 ft.),temperature of 24°C (750°F) and flow of .0189 m^3/s (250 gpm). In gray area.

Tooele Army Depot (Tooele, UT) - Warm Springs are less than 10 km (6 miles) away, the base is also adjacent to Tooele City Well which has 22°C (72°F) water at 216 m (709 ft.) (flow = .0205 m^3/s, 270 gpm). Another well, which is less than 5 km (3 mi.) from from base has 22°C (72°F) at 43 m (141 ft.) depth --this well lies on the edge of gray area.

Ft. Douglas, (Salt Lake City, UT) - In gray area. Several hot springs and warm wells in area (20°C - 70°C, 68-158°F range).

Dugway Proving Grounds, (Dugway, UT) - The Wendover Bombing and Gunnery Range is shown as having a hot springs at 61°C (142°F) in the southernmost section (Tooele City #33 S -- Wilson Health Springs). The Northwest corner of the range intersects at gray area. Bonneville Ltd. has a spring about 4 km (2 mi.) north of range at 88°C (190°F). The Navy did a preliminary investigation of geothermal resources at the Wendover Bombing range which borders the proving grounds on the west. It was concluded that the Wendover Range may have power producing capabilities and that Hill AF Range (to the north of Dugway) may have a resource suitable for direct heat applications (Whelan, undated).

VIRGINIA

Ft. Eustis (Newport News, VA) - Low potential.

Ft. Stony (Virginia Beach, VA) - Low potential.

Fts. Eustis and Stony are in the Norfolk area — the Navy has determined that a 46°C (115°F) resource exists at a depth of 2700 m (8232 ft) (Newman, 1983; Costain, et. al., 1984).

WASHINGTON

(Dark gray = known or inferred to be underlain by low-temperature to high temperature water low = < 100°C, 212°F high = > 150°C, 302°F.

Ft. Lawton (Seattle, WA)--Sub Ft. Lewis - close to Naval District Headquarters (Seattle), Torpedo Station (Key Point, WA), Strategic Weapons Facility Pacific (Bangor, WA) and the Regional Medical Center (Bremerton, WA). Bremerton Sulphur Spring has a temperature of < 20°C (68°F). Ravenna Park Sulphur Spring in Seattle is < 20°C. They are not in the gray area. The Navy has a preliminary site survey scheduled for FY85 in the Puget Sound area.

Yakima Firing Center (Yakima, WA) - Is located in the dark gray area. Several warm wells exist in the Yakima area with temperatures of 25-36°C (76-96°F) at depths of 300-480 m (980-1575 ft.). Several economic and engineering studies are being conducted to look at space heating for the municipality, high school, hospital, federal building etc.

Contact with the Yakima Engineering Office indicated that the Firing Range is in a distinctly different physiographic/geologic region than the areas which produce warm water. All of Yakimas Firing Centers' wells produce cold water.

V. ENVIRONMENTAL AND LEGAL CONSIDERATIONS

The following discussion is derived from Anderson and Lund (1979, Chapter 7) to which reference is made for more detailed information.

A. Environmental Issues

It should be assured that the use of land for the development of a geothermal resource is not in conflict with present land uses. (This is not a likely problem in direct utilization applications.) In addition, the appropriate state or federal agency should be contacted for assistance in planning to avoid potential problems with wildlife and natural vegetation.

Air quality may be an issue if electricity is produced, largely due to objectionable odors. High temperature geothermal fluids may contain small amounts of toxic substances such as hydrogen sulfide gas, mercury, arsenic or boron, although most negative effects affiliated with these impurities can be eliminated with proper plant design. For direct utilization of geothermal resources, closed loop systems will avoid the majority of these problems.

The main concern regarding water quality is that natural aquatic bodies may be degraded by geothermal fluids. If the fluid is toxic, it will be closely regulated by the state or federal government. In all cases, the system should be designed to prevent accidental discharge of geothermal fluid to water bodies.

Other environmental issues that may be of concern include the effects development may have on hot springs and other local geological features and/or archaeological resources.

B. Legal Considerations

The exploration, development and actual utilization phases of geothermal resource development all have significant legal considerations. It is of the utmost importance that competent legal assistance be employed at all of these phases.

Surface, mineral rights and in some cases water rights ownership need to be determined and proper permission obtained in order to gain access to the land for exploration purposes. State laws regarding whether the geothermal resource is considered a mineral or a water resource vary, and the cut off temperature between the two is often ambiguous. As a result, in many cases all three rights (surface access, mineral and water) need to be obtained.

The legal aspects of the development and production of geothermal resources are primarily affected by state water laws. This fact should be verified by contact with the state before proceeding with development. For most federal land exploration development and utilization leases must be obtained from the Bureau of Land Management.

Permits are usually required to provide for the transmission and use of geothermal resources. This may involve zoning compliance and the acquisition of rights-of-way. The Bureau of Land Management issues permits for the transmission of geothermal fluids on Department of Defense lands (Reed, 1985, personal comm.).

The disposal of geothermal fluids may be regulated in a variety of ways. Requirements will depend on local, state or federal laws — usually state water laws, as well as the quality of the geothermal fluids. It is likely that reinjection of the fluid will be required.

In summary, the legal issues, including the permitting processes required for geothermal resource development can be complex. In addition, laws regarding geothermal resources are still being changed in some states. It is imperative that sound legal guidance be given during all stages of geothermal development.

VI RECOMMENDATIONS

The following recommendations are made based on the research conducted to prepare this report. In order of priority the recommendations are:

1. That consideration be given to the development of the 53°C (127°F) geothermal resource already tapped at Hawthorne Army Ammunition Plant at Hawthorne, Nevada.

2. That consideration be given to initiating a resource investigation at Ft. Bliss, Texas. This would also include a consideration of potential applications, as the resource is likely to be at a temperature which is adequate for air conditioning.

3. That consideration be given to supporting a resource investigation at White Sands Missile Range (WSMR) White Sands, New Mexico. (This investigation may be made in conjunction with the Fort Bliss investigation.) This may take the form of providing financial support (30K) to WSMR so that the jointly funded geothermal energy study proposed by New Mexico State University may be carried out. The DOE may be approached to provide some support on this project.

4. That consideration be given to initiating a preliminary resource investigation at Sierra Army Depot in Herlong, California.

5. That a literature review similar to the one done for this report be conducted for U.S. Army bases located outside of the United States, focusing on countries where geothermal resources are known to occur. For example Italy and Japan are known to have abundant geothermal resources.

6. That more geological information be gathered regarding the following areas:

1) Ft. MacArthur, Los Angeles, California

2) Defense Depot, Ogden, Utah

3) Ft. Irwin, Barstow, California

4) Umatilla Army Depot, Hermiston, Oregon

5) Ft. Sam Houston, San Antonio, Texas

6) Yakima Firing Center, Yakima, Washington

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