DOE/EV/06200--T1-Vol.1

DOE/EV/06200--T1-Vol.1

DE83 002536

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

**EVALUATION OF NOISE
ASSOCIATED WITH GEOTHERMAL-
DEVELOPMENT ACTIVITIES**

**Final Report
for the period
31 July 1979 - 30 April 1982**

**Marshall Long, Ph. D., P. E.
Richard Stern, Ph. D.**

**Marshall Long/Acoustics
1629 Stanford Street
Santa Monica, CA. 90404**

NOTICE

**PORTIONS OF THIS REPORT ARE ILLEGIBLE. It
has been reproduced from the best available
copy to permit the broadest possible avail-
ability.**

**Prepared for the
Department of Energy
Office of Environment
Under Contract DEAC-0179-EV06200**

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DISCLAIMER

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

GEOHERMAL NOISE

ABSTRACT

This report was prepared for the purpose of ascertaining the current state of noise generation, suppression, and mitigation techniques associated with geothermal development. It includes a description of the geothermal drilling process as well as an overview of geothermal development activities in the United States. The report considers noise sources at the well site, along geothermal pipelines, and at the power plants. All data presented are measured values by workers in the field and by Marshall Long/Acoustics. One particular well site was monitored by Marshall Long/Acoustics for a period of 55 continuous days, and includes all sources of noise from the time that the drilling rig was brought in until the time that it was moved off site. A complete log of events associated with the drilling process is correlated with the noise measurements including production testing of the completed well. Data are also presented which compare measured values of geothermal noise with federal, state, county, and local standards. A section on control of geothermal noise is also given. Volume I of this document presents summary information while Volume II presents all measured values.

GEOHERMAL NOISE

VOLUME I

Abstract

List of Figures

List of Tables

List of Photographs

1.0 Introduction

1.1 Overview of Geothermal Development

1.1.1 Energy Production

1.1.2 Direct Use

2.0 Geothermal Activity

2.1 Current Geothermal Activity

2.2 Future Geothermal Activity

3.0 Geothermal Noise Sources

3.1 Well Site

3.1.1 Site Preparation

3.1.2 Drilling Rig Erection and Dismantling

3.1.3 Well Drilling Operations

3.1.3.1 Mud Drilling Operations

3.1.3.2 Air Drilling Operations Without Steam Production

3.1.3.3 Air Drilling Operations With Steam Production

3.1.3.4 Well Cleanout and Production Testing

3.1.3.5 Well Maintenance

3.2 Steam Pipelines

3.2.1 Pipeline Construction

3.2.2 Steam Passage

3.3 Power Plants

3.3.1 Plant Construction

3.3.2 Plant Operations

3.3.2.1 Start Up, Normal Operations

3.3.2.2 Temporary Shutdown

3.3.2.3 Long Term Shutdown

3.4 Direct Use Facilities

4.0 Long Term Noise Monitoring

5.0 Noise Control Standards

5.1 Federal Standards

5.1.1 Environmental Noise Standards

5.1.2 Occupational Noise Standards

5.2 State Standards

5.2.1 Alaska

5.2.2 Arizona

5.2.3 California

5.2.4 Colorado

5.2.5 Hawaii

5.2.6 Idaho

5.2.7 Louisiana

5.2.8 Montana

5.2.9 Nevada

GEOTHERMAL NOISE

- 5.2.10 New Mexico
- 5.2.11 Oregon
- 5.2.12 Texas
- 5.2.13 Utah
- 5.2.14 Washington
- 5.2.15 Wyoming
- 5.3 County and Community Standards
 - 5.3.1 Deschutes County, Oregon
 - 5.3.2 El Paso City, Texas
 - 5.3.3 Imperial County, California
 - 5.3.4 Inyo County, California
 - 5.3.5 Lake County, California
 - 5.3.6 Lake County, Oregon
 - 5.3.7 Mono County, California
 - 5.3.8 Pershing County, Nevada
 - 5.3.9 Salt Lake County, Utah
 - 5.3.10 Sonoma County, California
- 5.4 Use Permits
- 6.0 Compliance With Current Noise Standards
 - 6.1 Environmental
 - 6.2 Occupational
- 7.0 Control of Geothermal Noise
 - 7.1 Well Site Preparation, Plant Construction Noise
 - 7.2 Drilling Noise
 - 7.3 Venting Noise
 - 7.4 Plant Noise
- 8.0 Conclusion
- Data Sources
- Bibliography
- Acknowledgements

GEOHERMAL NOISE

VOLUME II

- 1.0 Data Sheets for Noise Associated With Geothermal
Development Activities
- 2.0 Geothermal Well Drilling Daily Noise Levels

GEOTHERMAL NOISE

List of Figures

- 2.1 Geothermal Electrical Capacity of the United States
- 3.1 Union Oil Company of California Geothermal Well Site (DX63), The Geysers, California
- 3.2 Octave Band Spectra of Caterpillar Tractors at 50 Ft. (Source # 1)
- 3.3 Octave Band Spectra of Caterpillar Scraper Model 657 at 50 Ft., Average of 5 Measurements (Source # 1)
- 3.4 Range of Noise Levels Generated by Site Preparation Equipment at 50 Ft.
- 3.5 Octave Band Spectrum from 23 Diesel Powered Construction Equipment Units at 50 Ft. Rated Power: 45-770 HP; Engine Speed: 1100-2700 RPM (Source # 3)
- 3.6 Noise Levels Due to Rigging Up at 100 Ft.
- 3.7 Octave Band Spectrum Due to Mud Drilling Operations at 100 Ft.
- 3.8 Octave Band Spectra Due to Air Drilling Operations at 100 Ft.
- 3.9 Sound Field Distribution for a Free Venting Well
- 3.10 Octave Band Spectrum from Unmuffled Steam Discharge at 100 Ft.
- 3.11 Octave Band Spectral Attenuation of Mufflers for Steam Discharge
- 3.12 Portable Rock Muffler
- 3.13 Octave Band Spectrum of Steam Discharge Through a Portable Rock Muffler With Different Flow Volumes at 100 Ft.
- 3.14 Fluid Kinetics Corporation High Capacity Silencer
- 3.15 Octave Band Spectrum from a Fluid Kinetics Corporation Model BOS 96/130 Portable Blow Off Silencer at 4,000,000 #/hr at 100 Ft.
- 3.16 Octave Band Spectra from 1/4 In. Bleed Lines at 100 Ft.
- 3.17 Octave Band Spectrum Due to Drag Valves
- 3.18 Range of Noise Levels Produced by Construction Equipment
- 3.19 Octave Band Spectrum of Noise Produced By a Steam Turbine in the Interior of a Power Plant at 10 Ft.
- 3.20 Octave Band Spectrum of Noise Produced by a Condenser in the Interior of a Power Plant at 10 Ft.
- 3.21 Octave Band Spectrum Produced by Steam Jet Gas Ejectors at 10 Ft.
- 3.22 Octave Band Spectrum at the Exterior of the Turbine Building at 10 Ft.
- 3.23 Octave Band Spectrum from Cooling Towers at 100 Ft.
- 3.24 Power Transformer Radiation Pattern
- 3.25 Octave Band Spectrum of Noise Produced by Power Transformers Along a Major Lobe at 100 Ft.
- 3.26 Day-Night Noise Level Contours from a Geothermal Power

GEOTHERMAL NOISE

- Plant
- 3.27 Union Oil Company of California's Geothermal Power Plant Blow-off Silencer
- 3.28 Octave Band Spectrum of Noise Produced by Free Venting of Steam Through a Pit Type Rock Muffler With 800,000 #/hr Steam Discharge at 100 Ft.
- 3.29 Day-Night Noise Level Contours in the Vicinity of Power Plant Unit # 13, Plant Tripped, Stacking Steam
- 4.1 The Geysers Area
- 4.2 Long Term Noise Monitoring at 120 Ft. Day 1-5
- 4.3 Long Term Noise Monitoring at 120 Ft. Day 6-10
- 4.4 Long Term Noise Monitoring at 120 Ft. Day 11-15
- 4.5 Long Term Noise Monitoring at 120 Ft. Day 16-20
- 4.6 Long Term Noise Monitoring at 120 Ft. Day 21-25
- 4.7 Long Term Noise Monitoring at 120 Ft. Day 26-30
- 4.8 Long Term Noise Monitoring at 120 Ft. Day 31-35
- 4.9 Long Term Noise Monitoring at 120 Ft. Day 36-40
- 4.10 Long Term Noise Monitoring at 120 Ft. Day 41-45
- 4.11 Long Term Noise Monitoring at 120 Ft. Day 46-50
- 4.12 Long Term Noise Monitoring at 120 Ft. Day 51-55
- 4.13 Long Term Noise Monitoring at 120 Ft. 24 Hour L_{eq} , L_{dn}
- 5.1 Noise Level Curves, Inyo County, California

GEOTHERMAL NOISE

List of Tables

- 2.1 Drilling Activity for States with Geothermal Wells Over 2000 Ft.
- 3.1 Noise from Mud Drilling Operations at 100 Ft.
- 3.2 Noise from Air Drilling Operations Without Steam at 100 Ft.
- 3.3 Noise from Air Drilling Operations With Steam at 100 Ft.
- 3.4 Noise from Steam Discharge from Jets at 100 Ft.
- 3.5 Noise from Steam Discharge from Bleed Lines at 100 Ft.
- 3.6 Noise Generated by Drag Valves at 100 Ft.
- 3.7 Noise Data Measured in the Interior of a Power Plant Building
- 3.8 Noise Generated by Steam Jet Gas Ejectors at 10 Ft.
- 3.9 Noise Exterior to Power Plant Buildings at 100 Ft.
- 3.10 Noise Generated by Cooling Towers at 100 Ft.
- 3.11 Noise Generated by Power Transformers at 100 Ft.
- 3.12 Noise From Power Plant Rock Mufflers at 100 Ft.
- 6.1 Noise Levels from Geothermal Operations as a Function of Distance (dBA)
- 6.2 Unacceptable Zones in the Vicinity of Geothermal Operations Without Ear Protection (Ft.)

GEOTHERMAL NOISE

List of Photographs

- 3.1 Typical Geothermal Drilling Rig
- 3.2 Drilling Rig Equipment
- 3.3 Mud and Holding Tanks
- 3.4 Drilling Rig, Mud Pumps, and Diesel Engine-Electrical Generators
- 3.5 Blooie Line and Silencer. Marshall Long/Acoustics Monitoring Truck in the Background
- 3.6 Blooie Silencer Venting Steam
- 3.7 Rock Muffler Located at Well Site
- 3.8 Cooling Tower
- 3.9 Above Grade Rock Muffler at Power Plant Unit # 13
- 4.1 Marshall Long/Acoustics Monitoring Truck at Union Oil Company of California's Well Site, DX 63, at The Geysers, California

1.0 Introduction

Geothermal power is a promising resource in a world where the availability of fossil fuel energy depends more often upon world politics than on the laws of supply and demand. Since the technical and emotional issues associated with nuclear power are currently preventing full exploitation of this form of energy, the earth's heat may provide much of the supplemental power needed for the next few generations. The amount of geothermal energy available in the United States has been estimated to be 2400 quadrillion Btu. Last year only 80 quadrillion Btu were used in the United States. Considering the efficiency of converting the geothermal energy into electricity it has been estimated that the currently available geothermal energy is equivalent to 14 billion barrels of oil. In addition, geothermal energy is a renewable resource.

Although it is one of the most environmentally clean and safe sources of energy, a few problems still remain. One of these problems is the noise associated with development activities which has both environmental and occupational implications. Health hazards associated with occupational noise are relatively easy to control through the use of personal hearing protection. Not so with environmental noise for while there are little if any health hazards associated with the noise levels at distances greater than 100 ft. from a typical source, there is still potential for annoyance. Legal obstacles, arising often from environmental issues and based on both objective and subjective factors, can easily delay the development of this much needed resource.

Local governments have become concerned and are becoming increasingly active in regulating geothermal development through environmental controls. When local officials and their constituents are convinced that environmental problems may exist and are not convinced that they can or will be solved, the development of geothermal resources may be delayed by long and difficult permitting processes. The problem has been compounded by some geothermal developers who have justified the fears of the local residents.

Currently there are techniques available to accurately assess noise impact and to control it. The environmental problems arising from noise production can be easily solved if care is taken at the drilling site and at the power plant to quiet the sources of noise, and where that is not possible, to isolate acoustically the community from geothermal activities. A diffusion of this knowledge to all

interested parties can only speed geothermal development.

1.1 Overview of Geothermal Development

For many years hot springs which spontaneously appeared at the surface of the earth have attracted people to "take the waters" in an effort to improve health. Cooking and mineral extraction have also been attempted. It was not until recently that the full potential of geothermal energy was realized and consequently in the past twenty years the development of geothermal resources has been greatly accelerated. Over fifty nations throughout the world are active in geothermal development or are considering the prospect of becoming active.

When molten rock (magma) lies close enough to the surface of the earth it heats the layers of rock above it which in turn heats water trapped within the rock layers. The physical state of the resource fluid depends on several conditions and these conditions necessitate different energy development methodologies. If the pressure in the rocks is high enough and the temperature low enough the water remains liquid. Since there are many dissolved minerals present in the water a well tapping this geothermal reservoir would yield a superheated brine. When the liquid is brought to the surface and the pressure of the brine is reduced it flashes into a mixture of steam and hot water which can then be used for a variety of purposes. If the pressure in the rocks is lower or the available heat high enough the water is turned into steam in the ground and a well tapping this reservoir would yield steam directly. Wells which produce either steam, brine, or a combination of both can be used to generate power. They can also be used directly i.e. without first converting the thermal energy into electrical energy. Another form of energy resource has been termed geopressured-geothermal. This form occurs in the United States principally in the northern Gulf of Mexico. The energy available in geopressured-geothermal areas is not limited to thermal energy. Because of the abnormally high fluid pressures that result from the compartmentalization of the standard shale beds in which the liquid is contained, hydraulic (mechanical) energy is available as well as chemical energy in the form of dissolved natural gas, primarily methane.

1.1.1 Energy Production

Because it is difficult to transfer hot steam or brine

GEOHERMAL NOISE

over long distances for direct use and because frequently steam and brine gathering fields are in remote areas, the most practical means of utilizing geothermal energy is to convert it into electrical energy. Energy in this form may be sent anywhere in the United States and therefore any city or town may benefit from the development of geothermal resources.

In the United States the first commercial geothermal electric power complex was started at The Geysers about 65 miles north of San Francisco, California. Although attempts were made over 60 years ago to obtain geothermal energy it was not until 1956 that six steam producing wells were successfully drilled. Four years later Pacific Gas and Electric built the first power plant, Unit #1. The net output of that plant is 11 megawatts (MW) and it is still in operation. There are now fifteen units operating in the area producing about 902 MW. All these plants use the dry steam available at The Geysers. In the Imperial Valley of California where highly saline brine is produced, several flash steam plants have been built. There are no other energy producing plants on-line in the United States. Nearly all the geothermal steam being produced in the United States was developed in The Geysers area by Union Oil Company of California - Magma Power Company - Thermal Power Company. Thermogenics and Aminoil USA also supply steam to power plants in The Geysers area. The power producing plants in this area are owned by Pacific Gas and Electric. In the Imperial Valley of California the two operating power plants are owned primarily by Southern California Edison and San Diego Gas and Electric.

1.1.2 Direct Use

For years geothermal energy has been used for space heating. Both closed-loop systems and direct utilization of hot brine have been employed. The closed loop system uses a heat exchanger placed in the well itself with a secondary fluid which transports the heat to the end user. In direct utilization, the hot brine is circulated through the system to transport heat directly to the end user.

There are nine cities in the United States which use geothermal energy for space heating. Klamath Falls, Oregon (with over 400 wells) and Boise, Idaho are the largest users of geothermal energy for space heating. The Oregon Institute of Technology, for example, uses the heat from 3 wells to warm approximately 500,000 sq. ft. of floor space at a savings per year of over \$250,000 compared to conventional fuel heating. In the city of Boise a full geother-

GEOHERMAL NOISE

mal program has been developed for the metropolitan area. On a more limited and isolated scale, seven institutions use the energy to heat their buildings. Idaho is the largest user of direct heat. Eleven of the fifteen states with known geothermal resource areas (KGRA) use geothermal heat directly, compared to only one state, California, converting the heat to electricity.

There are numerous projects throughout the United States that use direct heat in agriculture (typically greenhouses) in areas too cold to heat by conventional means and in aquaculture (growing catfish, trout, and freshwater prawns). In other locations geothermal energy is used to pasteurize milk or dehydrate vegetables, principally onions. Refining sugar, producing ethanol and cooking potatoes are other direct uses which are employed in the United States. There are numerous applications in the chemical processing industry which are currently under study. The direct use of geothermal energy is the fastest growing application of the resource.

2.0 Geothermal Activity

The known geothermal resource areas in the west are spread over fifteen states. Nine of these states already have wells. In eleven of the states there is direct use of geothermal energy. One state, California, is producing electricity.

Since 1940 the rate of increase in worldwide geothermal energy as measured in megawatts of electrical power has increased by about 7 percent per year. There is a commitment over the next few years (until 1983) to increase the rate to about 19 percent per year. With increased pressure to develop alternative sources of energy the rate will probably be at least 19 percent per year, and probably will be higher. For the United States the rate of increase since the first plant went on-line in 1960 has been 24.8 percent per year. Plants under construction or committed to be built between now and 1984 will maintain this rate. For a 24.8 percent increase per year in output capacity the amount of energy needed and therefore the number of producing wells must double every 3.2 years. Added to this number is one additional well which must be drilled about every one and one-half years per plant to replace the loss of steam as depletion of reservoirs takes place. Existing plants are returning the condensed and cooled liquid back into the reservoir since one limit on the rate at which energy may be taken from the ground depends on the amount of liquid in the reservoir which is available to be heated. These injection wells must also be drilled.

The implication of this amount of activity is that many wells will have to be drilled in the coming years and the location of these wells may not be in isolated areas. As the location of drilling operations approaches communities, whether they are rural, suburban or urban, the environmental effects of drilling and production, including noise, will become more noticeable. One purpose of this report is to present the most accurate data available on noise produced by geothermal operations so that problems which may arise can be clearly defined and mitigated.

2.1 Current Geothermal Activity

The western states that have known geothermal resource areas are Alaska, Arizona, California, Colorado, Hawaii, Idaho, Louisiana, Montana, Nevada, New Mexico, Oregon, Texas, Utah, Washington, and Wyoming. Texas and Louisiana have geopressured-geothermal activity while the rest of the

GEOHERMAL NOISE

states have only geothermal wells. A summary of geothermal drilling activity for the years 1975 - 1980 is shown in Table 2.1. The table shows the number of wells spudded (started) during the year and those wells which were successful in producing usable geothermal energy. Since noise is produced whenever a well is drilled, for whatever purpose, the table also includes observation holes and injection holes. Only wells which have been drilled deeper than 2000 ft are included in this table since the source of these data did not include wells whose depth was less than 2000 ft. The total footage drilled for all wells completed in 1980 including those wells whose depth was less than 2000 ft was 866,006 ft for a total of 207 wells.

There are 18 geothermal electric plants in operation in the United States (California) with a combined capacity to produce 927 MW of electrical power. This is sufficient power to supply about 43% of the present electrical needs of the City of Los Angeles. There are also 187 projects in operation that use direct heat.

2.2 Future Geothermal Activity

Perhaps the best indicator of future geothermal activity lies in the rate at which output power capacity is scheduled to become available. The steady rate of increase for the United States has been 24.8 percent per year with a doubling every 3.2 years. The available output capacity proposed for the next few years continues at this rate with a leveling off predicted to begin after 1984. Clearly this rate of increase cannot be maintained indefinitely. Many of the plants scheduled for the next years are well into the planning and construction stages. By the end of 1984 the electrical output capacity is expected to be about 2009 MW (from 39 plants) compared to our current capacity of 927 MW (and 18 plants) which could supply all the power needs of the City of Los Angeles. This represents an increase of 117 percent in four years. The rate of increase in well drilling activity over the past few years has been about 20% per year. Based on 207 wells drilled in 1980 it is estimated that during the years 1981 to 1984 inclusive over 1300 new wells will be drilled with a combined depth of over 5.4 million feet. Fig. 2.1 shows the geothermal capacity of the United States between 1960 and 1980. The projected capacity between 1981 and 1989 is indicated by the dotted line, based on the power plants proposed and now under construction. There are also 129 projects for direct use of geothermal energy planned. Thus prospects are extremely bright for the use of geothermal resources.

TABLE 2.1
Drilling Activity for States with Geothermal Wells Over 2000 Ft. Deep

YEAR	1975		1976		1977		1978		1979		1980		TOTAL	
STATE	D	P	D	P	D	P	D	P	D	P	D	P	D	P
California	34	26	48	32	41	24	41	27	49	34	53	47	266	190
Hawaii	1	1	0	0	0	0	2	0	0	0	1	1	4	2
Idaho	2	2	4	2	3	0	5	1	2	0	3	2	19	7
Louisiana											3	0	3	0
New Mexico	2	1	0	0	1	1	1	1	4	4	5	1	13	8
Nevada	6	2	6	2	3	0	4	1	15	4	15	2	49	11
Oregon	1	0	1	0	0	0	2	0	4	1	5	0	13	1
Texas											2	2	2	2
Utah	6	5	6	3	4	0	3	0	3	1	0	0	22	9
TOTAL	52	37	65	39	52	25	58	30	77	44	87	55	391	230

D = Well started
P = Well producing

Figure 2.1 Geothermal Electrical Capacity of the United States

3.0 Geothermal Noise Sources

There are many noise sources that are associated with the development of geothermal energy. In general they may be divided into three categories: 1) sources associated with the well site, 2) sources associated with the steam or brine pipelines and 3) sources associated with the geothermal energy user (such as the power plants for energy conversion into electricity or direct use). In the sections which follow data will be reported on geothermal noise sources. The reported values are the most accurate and representative of the data currently available. The data consist of measured sound pressure levels (SPL) which have been converted to a standardized distance of 100 feet by adding a correction for geometric spreading and are reported as A-weighted (dBA) or C-weighted (dBC) depending on the filtering network used. Spectra are given as unweighted octave band sound pressure levels. The source of the data is stated for each measurement. Volume I of this report contains summary information while Volume II contains more detailed information concerning the measurements.

3.1 Well Site

A typical well site at the Geysers is illustrated in Fig. 3.1. Located on the well site are the drilling rig with its associated structure and base, pipe racks to hold the drilling string, mud pumps and a mud mixing tank, diesel powered electrical generators which supply power to the mud pumps and the draw works, a blooie line and muffler, diesel powered air compressors, and if necessary water tanks. A drilling rig is illustrated in Photograph 3.1. There are additional buildings such as an office, a change building for the employees, and a parts supply unit.

Noise is generated at the well site in four distinct time periods. First there is noise associated with the preparation of the site. Second, noise is produced when the drilling rig is brought onto the site and erected and at the end of drilling operations, when it is dismantled and removed. Pad preparation and rig erection last for only a few days. The third period includes well drilling operations, which typically last for about 60 days. During this time noise is caused principally by the engines used in the drilling operations, brake noise, noise caused by impact (from pipes and chains), noise from unlubricated mechanisms, and noise created by the venting of steam and air. Finally there is noise associated with well mainte-

Figure 3.1 Union Oil Company of California Geothermal Well Site (DX 63), The Geysers, California

Photograph 3.1 Typical Geothermal Drilling Rig

GEOHERMAL NOISE

nance, the fourth period, which includes the time between the end of production testing of the well and the time that the well is connected to a user facility when the products of the well begin being used.

3.1.1 Site Preparation

Site preparation for a single well pad consists of clearing an area (approximately 300 ft. by 200 ft.), leveling the ground and providing a firm base for the drilling rig, engines and ancillary equipment. A sump hole must be dug to receive the cuttings and other waste products. Finally access roads must be provided (about 25 ft. wide) to the well pad. During site preparation, truck and other vehicular traffic to and from the site is heavy. Typical equipment for use in site preparation includes:

- a. Crawler tractor (D8 class)
- b. Scraper
- c. Water truck
- d. Motor grader
- e. Backhoe
- f. Heavy and light trucks

Noise measurements on vehicles are normally performed at a distance of 50 feet and are reported as such in this document. The A-weighted and C-weighted sound pressure levels (SPL) of two models of Caterpillar tractor Class D8 and a Caterpillar scraper have been recently studied (Source #1). The noise generated by the tractors was measured for typical operating conditions with the tractor pushing dirt up a 9% slope. Two different D8H model tractors were utilized. The first was with an open exhaust stack and exposed engine. The overall SPL for this condition was 89 dBA and 95 dBC. The second tractor had a muffler and a partially enclosed engine and under these conditions the SPL was 83 dBA and 90 dBC. Data were recorded with the tractors moving uphill and downhill and the reported values are the average of the two measurements. The noise generated by a Model D8K tractor was 80 dBA and 88 dBC under the same test conditions. The spectra produced by these three vehicles is illustrated in Fig. 3.2.

Noise generated by large Caterpillar Type 657 scrapers was also examined. Scraper noise was measured for vehicle passbys at 50 ft. under full load conditions, uphill and downhill on a 7% grade. There are two engines on these machines, one on each end. The spectra are averages of five separate passbys. The spectra produced by the scrapers are illustrated in Fig. 3.3. Their overall SPL was 83 dBA and 89 dBC.

Figure 3.2 Octave Band Spectra of Caterpillar Tractors at 50 Feet (Source #1)

Figure 3.3 Octave Band Spectra of Caterpillar Scraper Model 657 at 50 Feet, Average of 5 Measurements (Source #1)

GEOTHERMAL NOISE

Additional measurements have been made of noise generated by tractors and backhoes leveling a site and excavating a sump for geothermal operations (Source # 2). An SPL of 77 dBA was measured for that operation. An International Scraper Model 295, also used for pad preparation, was measured to have SPLs of 88, 92, 84, 91 dBA for loading, unloading, walking unloaded, and walking unloaded uphill respectively, all at 50 ft.

During site preparation only a given number of vehicles operate at any one time and not all operate in a manner which produces maximum noise at any given instant. Estimates of sound levels produced during site preparation must therefore take a duty cycle into account. Noise produced by construction equipment is well documented in the literature. Figs. 3.4 and 3.5 summarize these findings (Source # 3). The data in Fig. 3.4 have been extended to include more recent findings (Source # 4). The noise levels of the tractors and scrapers reported here fall within the limits shown in Fig. 3.4 except for the tractor with exposed engine and open exhaust stack. Noise from this configuration has extra loud high frequency components as would be expected from an unmuffled and exposed combustion engine and the spectrum from this vehicle also lies outside the limits shown in Fig. 3.5. The SPL of the combination of tractor and backhoe is also indicated in Fig. 3.4 along with the SPL of the International scraper.

3.1.2 Drilling Rig Erection and Dismantling

The erection of a drilling rig and the placement of the generator, mud pumps, air compressors and remaining equipment takes approximately three to four days. The time depends on whether rigging up activities occur continuously or take place only during daylight hours. Fig. 3.6 illustrates the noise levels which occurred on 12 December, 1981 at a distance of 120 feet from the wellhead of Union Oil Company's geothermal well DX63. Section 4.0 of this report describes the monitoring equipment and setup used by Marshall Long/Acoustics to make these measurements. The monitoring period began 63 hours before spud in. The well is located in The Geysers, Sonoma County, California. Most of the rigging up activity occurred during the daylight hours. The equivalent continuous sound level (L_{eq}) for each hourly period is plotted as well as the maximum and minimum values of the noise level which occurred each hour. The 24 hour L_{eq} was 64.2 dBA with a day night noise level (L_{dn}) of 67.1 dBA. Examination of the measurements made at the same site on the following day when the activities were continuous gave a 24 hour L_{eq} of 65.7 dBA while the L_{dn} was 71.6 dBA.

Figure 3.4 Range of Noise Levels Generated by Site Preparation Equipment at 50 Feet

Figure 3.5 Octave Band Spectrum from 23 Diesel Powered Construction Equipment Units at 50 feet Rated Power: 45-770 HP; Engine Speed: 1100-2700 RPM (Source #3)

Figure 3.6 Noise Levels Due to Rigging Up at 120 Feet

3.1.3 Well Drilling Operations

In the drilling process some major pieces of equipment used are: a large block and tackle (travelling block) which holds the drill string, a draw works which is a winch mechanism for raising and lowering the drill string, and a rotating table which rotates the drill string. Attached to the end of the traveling block by a hook is the swivel, a ball and socket mechanism which allows the drill pipe to spin freely without turning the entire system. The swivel connects to a kelly, a 40 ft. section of pipe, hexagonally shaped, which is inserted through a drive bushing. The drive bushing has 4 extending prongs which lock into the rotary table located on the derrick floor. The rotary table is power driven by the draw works and rotates the drill string.

Drilling fluid (mud) is circulated through the drill string via a large high volume pump called the mud pump through several pipes and a large hose (rotary hose) which is attached to the drill string above the swivel mechanism. For details of drilling rig equipment see photograph 3.2.

Drilling procedures can be divided into three parts: 1) the actual drilling process, 2) running drill pipe into the hole (RIH), and 3) pulling pipe out of the hole (POH). The overall drill pipe assembly is made up of 30 ft. long sections of pipe called joints. Each joint has an internally threaded flange at one end and an externally threaded flange at the other. The device which does all the cutting is located on the lower end of the drill pipe assembly and is called the bit. Three rotating spiked cones are situated at the end of the bit and perform the actual digging. Drill mud is circulated through the drill pipe to cool the bit, flush out all loosened particles, and aid in preventing the hole from sloughing.

To drill, weight must be applied to the end of the bit while it rotates. This is done by allowing the weight of the drill collars, part of the drill string, to rest on the bit. The drill string is supported by the block and tackle which is adjusted up and down through the winch. By releasing the winch line using a hand brake, the drill assembly pushes down on the bit using as much of its weight as the block will allow, while the drill assembly rotates. Caution must be taken against applying too much force to the bit, otherwise the pipe could crack or the bit could lose its efficiency. As a result, pressure is being constantly applied and lifted off the brake to attain a con-

Photograph 3.2 Drilling Rig Equipment

GEOTHERMAL NOISE

stant amount of force on the bit.

When drilling at large depths, the bit tends to veer off a straight path. A survey must be done periodically with respect to depth to locate the position of the bit. A directional device is lowered through the drill pipe to the bottom by means of a cable. The instrument records its position using compass points as reference. Intentional curving of the pipe can be achieved by using a "turbo" drill. A turbo drill can curve the path of the bit to any predetermined position.

Debris and cuttings from the hole are flushed out with water mixed with drilling mud. Mud is circulated under high pressure through the drill pipe by pumps. The mud travels down the hole and is ejected through the bit. The mud washes the particles up as it cools the bit. Heavier cuttings are collected in a junk sub which is a special section of the pipe which extends, basket-like, above the bit and along the drill assembly. The lighter particles are lifted up the hole with the mud and removed through an outgoing mud line. This line empties into a holding tank where heavier particles such as sand drift to the bottom and are separated out. The residue eventually drops into a large pit and is removed. The upper surface of the holding tanks flows off onto two shaker screens into tanks below where it is remixed and eventually forced by pumps through the drill pipe again. Photograph 3.3 shows the mud tanks and holding tanks.

The RIH or POH modes designate the processes of running in and pulling out the drill pipe from the hole. Both operations are quite similar. The major equipment used includes the block and cable winch system, power tongs, a chain winch for RIH and the draw works and rotary table system for POH. At the end of the block there is a clamp which locks into a joint of the pipe just below the flange. The pipe is stored on both sides of the derrick on racks.

When the pipe is run into the hole the pipe is lowered until it reaches the floor of the derrick. At the bottom of its descent, the block is stopped and a special lock is thrown into the hole to effectively reduce its diameter. The drill pipe is immobilized and the block is unlatched from the stand. To add a new piece of pipe to the string a worker located near the top of the derrick secures a new stand to the block. The driller using the winch brake lever raises the block and lowers it down over the drill string. To make a connection, a worker will wrap a chain several times around the flange of the drill string. The new stand is manually placed on top of the lower stand. By flinging the chain, it will wrap around the upper stand.

Photograph 3.3 Mud and Holding Tanks

GEOHERMAL NOISE

The chain winch then pulls the chain in and the upper pipe screws into the flange. To achieve a tight seal two pairs of tongs, a tool which acts like a 6 ft. pair of pliers, are clamped onto both stands, above and below the connecting point. Each tong has a cable attached to the end of it so that a torque can be applied to both of them to tighten the two stands together. The driller then raises the block, the lock becomes uprooted and is pulled away and the pipe is lowered into the hole.

In POH the process is virtually the same as RIH, only in reverse. The block clamps onto the flange and raises the drill string out of the hole. The lock is thrown into the hole at the top of the block's ascent. A tong is placed above the flange and breaks the tight seal between the two stands. The rotary table then unscrews the two pipes, and the upper stand is placed on the racks.

Well drilling operations begin with the spudding in of the well. The power to rotate the drill string and cutting tools is supplied by special drilling power plants. During the first portion of the well drilling operations mud is used as a circulating fluid. The mud is a mixture of water (93%) and Bentonite (6%), a compound of sodium, aluminum, silicon, oxygen, and hydrogen, plus other materials (1%). The entire drilling process consists of drilling, reaming, cleaning, and cementing special casings in the well hole. The latter are used to prevent the hole from collapsing and to also prevent water contamination. Occasionally broken tool bits must be recovered. There are special measurements which are made during drilling operations to monitor and then adjust the direction of the hole. For geothermal wells, temperature must also be carefully monitored. During the entire operation the drilling string is often raised and lowered to change the tools which are unique to each specific operation.

When the hole begins to penetrate rock formations which may contain steam, compressed air is used as the circulating fluid rather than mud. As more steam is encountered less compressed air is needed since the steam acts to supplement the air. During drilling operations mud is used for about two thirds of the time while air is used for the remaining one third.

The final phase of well drilling operations occur with well cleanout and production testing. This phase involves venting steam to the atmosphere at several different pressures and measuring the flow velocity with an orifice meter. The results of these measurements are used to determine whether well drilling operations will continue further. They are also used to determine whether the well can

GEOHERMAL NOISE

be used commercially in a steam gathering facility or if not, the method of abandoning the well. The free venting of steam also cleans the debris out of the well.

3.1.3.1 Mud Drilling Operations

A typical well site is illustrated in Fig. 3.1. The configuration shown illustrates the latest method of obtaining the power necessary to carry out drilling operations. Diesel engines are used to supply mechanical power to electric generator units which in turn furnish electrical power to drive the mud pumps, the draw works, ancillary equipment, and are used to power the remainder of the site. The advent of the silicon controlled rectifier (SCR) has made practical this form of power train. Photograph 3.4 shows the drilling rig, mud pumps, and diesel engine-electrical generator units.

Older configurations use diesel powered mud pumps and draw works. Noise from these older units is much louder than that produced by diesel electric rigs. For example, the A-weighted SPL of a recently measured all diesel powered rig was 87 dBA at 100 ft. (Source # 1). Because varying engine loads cause the level and the spectrum of the sound to change frequently, this type of noise is more annoying to receptors. The older method is phasing out and therefore this study has concentrated on the more recent configuration.

The noise of drilling operations using diesel engines to supply power to an electrical rig has been reported by a number of authors and is summarized in Table 3.1. The dominant source of noise for this operation comes from the diesel engines themselves. Mixed in are additional noises from the mud pumps, the turntable, braking noise, chain and pipe slapping, noise from unlubricated metal parts and also from the draw works. The range of sound pressure levels reported in the literature and measured in this study varies from 70 to 80 dBA (except the one measurement taken above the drilling rig). The average SPL for mud drilling was 76 ± 5 dBA. Since the C-weighted sound pressure levels are about 10 dB higher than the A-weighted levels, the range of C-weighted levels is about 80 to 90 dBC. The average C-weighted level is 86 ± 2 dBC. A range of values has also been given in the literature (Source # 4) as 69 to 79 dBA which is entirely consistent with our recent measurements. The octave band sound pressure levels are shown in Fig. 3.7.

It should be noted that the mud drilling operations are used in developing steam producing wells and brine

Photograph 3.4 Drilling Rig, Mud Pumps and Diesel
Engine Electrical Generators

TABLE 3.1

Noise from Mud Drilling Operations at 100 Ft.

Test Nr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
dBA	80	79	73	74	77	88	70	80	71	74	78	70	79	72	77
dBC	89	88	83	86	87										
63 Hz	88	83	81	82	80										
125 Hz	84	86	78	82	85										
250 Hz	78	81	74	78	78										
500 Hz	79	75	72	72	73										
1000 Hz	75	76	70	71	73										
2000 Hz	69	68	64	66	70										
4000 Hz	64	63	57	55	63										
8000 Hz	55	55	51	43	55										
Source	1	1	1	1	2	1	1	1	1	1	5	6	7	8	8
Data Nr	5	6	6	7	8	9	9	9	10	10	11	12	13	14	14

2. Air intake side, RIH

4. POH

6. Measured above rig

8. Side opposite diesel engine

3. Opposite air intake side, RIH

5. Average of 3 locations, 3 Cat D379 engines

7. Side opposite diesel engine

Figure 3.7 Octave Band Spectrum Due to Mud Drilling Operations at 100 feet

GEOTHERMAL NOISE

producing wells. For the brine producers there are no air drilling operations and the sound levels discussed in this section apply to the entire well drilling operation.

3.1.3.2 Air Drilling Operations Without Steam Production

When the drill string begins to encounter the steam bearing formations, compressed air is used as the circulating fluid to cool the tool bit and bring cuttings and debris to the surface. Large trailer-mounted engines and air compressors are used for this operation. The noise produced by the air compressors and their engines is added to the noise created by the electrical generators and their engines. The fact that the mud pumps have been turned off does not appreciably affect the overall sound pressure level. The compressor-engine units have approximately the same power as the generator-engine units. A summary of the noise produced by air drilling operations before steam is reached is given in Table 3.2. The spectral data of the air compressor and engine is also approximately the same as the electrical generator and its engine. In addition, most of the A-weighted sound levels are within the 70 to 80 dBA SPL range established for the generator-engine units (excluding test # 4 and 5). It is not clear why tests # 4 and 5 are 10 dBA above all the other tests. The average SPL of the remaining six is 78 dBA. This value is 2 dB greater than that specified for the generator-engine units alone. Thus if both the generators and compressors are operating, it would be expected that the overall level would increase by about 2-3 dB.

3.1.3.3 Air Drilling Operations With Steam Production

The drilling of a geothermal well does not stop when steam is first encountered. Drilling operations continue until sufficient quantities of steam have been found or the operation is abandoned. Steam is vented to the air during drilling operations through a blooie line and blooie (centrifugal) silencer. Photograph 3.5 illustrates a blooie line and blooie silencer. Photograph 3.6 shows a blooie silencer venting steam. Blooie silencers operate both to quiet the steam noise and to remove particles from the steam flow. They are used both dry and wet i.e. with cooling water injected upstream from the unit. The effectiveness of a silencer depends on the volume of steam, the size of the silencer and the volume and point of injection of the cooling water. During air drilling operations the sound generated by the steam flow becomes the

TABLE 3.2

Noise from Air Drilling Operations Without Steam at 100 Ft.

TEST NR	1	2	3	4	5	6	7	8	9	10	11
dBA	80	77	82	90	92	76	79	74	76	76	80
dBC	93										
63 Hz	93										
125 Hz	86										
250 Hz	80										
500 Hz	77										
1000 Hz	75										
2000 Hz	69										
4000 Hz	61										
8000 Hz	53										
Source	9	1	7	10	10	10	10	10	10	10	10
Data Nr	15	16	17	18	18	18	18	18	18	18	18

4. Two compressors operating
 6. Two compressors operating
 8. One compressor operating
 10. Two compressors operating

5. Two compressors operating
 7. Two compressors operating
 9. One compressor operating
 11. Two compressors operating

Photograph 3.5 Blooie Line and Silencer. Marshall Long/
Acoustics Monitoring Truck in Background.

39

Photograph 3.6 Blooie Silencer Venting Steam

GEOHERMAL NOISE

dominant source of noise.

Data for air drilling operations with steam production with and without blooie silencers, and with and without water injection are given in Table 3.3.

The range of sound pressure levels for air operations with a blooie line alone is 95-108 dBA (100-110 dBC) with an average value of 103 ± 6 dBA (105 ± 4 dBC). Adding a blooie silencer without water injection produced noise levels in the range of 87-108 dBA with an average value of 92 ± 10 dBA, a reduction of about 11 dBA. By injecting water upstream of the silencer the range of measured sound pressure levels was lowered to 80-108 dBA with an average value of 88 ± 13 dBA, a further reduction of about 4 dBA. The large standard deviations should not be construed as disqualifying the data but rather showing the varied conditions under which measurements were made. For example, much of the effectiveness of water injection comes from introducing the water well upstream of the blooie silencer and also is strongly dependent on the volume of water used.

It is more useful to study sets of measurements made under similar conditions varying only one parameter at a time. This was done in a few cases where sets of measurements were recorded on the same well. A reduction of 12 dBA was shown when a blooie silencer was added to a blooie line, with an additional reduction of 11 dBA when water was injected (Test # 1, 5, 16). Another well also showed a reduction of the noise level by 11 dBA with water injection (Test # 10, 17). Fig. 3.8 shows the range and average values of the noise spectra associated with air drilling operations with steam production. The data includes measurements of noise from a blooie line alone, a blooie line with a blooie silencer, and a blooie line with silencer and water injection.

TABLE 3.3

Noise from Air Drilling Operations With Steam at 100 Ft.

TEST NR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
dBA	87	89	96	97	102	87	108	100	84	72	83	105	108	95	102	108	97	80
dB C	92	95								84	91	107	110	100	103			97
63 Hz	84	90								80	84	98	104	93	94			
125 Hz	87	90								80	86	102	104	93	97			
250 Hz	80	80								76	85	97	106	95	90			
500 Hz	86	85								68	82	98	91	90	95			
1000 Hz	82	82								66	78	100	91	90	91			
2000 Hz	83	78								64	74	98	92	91	95			
4000 Hz	83	74								60	69	91	85	84	95			
8000 Hz	75	68								48	56	90	73	72	86			
Source	1	1	1	11	11	11	11	11	7	12	12	12	12	12	12	1	1	1
Data Nr	19	20	20	21	21	21	22	22	23	24	24	24	24	24	24	25	25	26

1. 170,000 #/hr, 90 deg to silencer, no water	2. 170,00 #/hr, 120 deg to silencer, no water
3. 170,000 #/hr, 120 deg to silencer, no water	4. 170,000 #/hr, water injection
5. 170,000 #/hr, no water	6. 170,000 #/hr, water injection
7. 160,000 #/hr, water injection	8. 160,000 #/hr, water injection
9. Water injection	10. 200,000 #/hr, blooie line w/water, muffler
11. 200,000 #/hr, blooie line w/muffler, no water	12. 199,000 #/hr, blooie line, no muffler
13. 199,000 #/hr, blooie line, no water, muffler	14. 100,000 #/hr, blooie line, no water, muffler
15. 180,000 #/hr, blooie line, no water, muffler	16. 160,000 #/hr, blooie silencer, no water
17. 160,000 #/hr, blooie silencer, w/water	18. 160,000 #/hr, Shell muffler, w/water

Figure 3.8 Octave Band Spectra Due to Air Drilling Operations at 100 Feet.

3.1.3.4 Well Cleanout and Production Testing

After drilling is completed the wells must be cleaned out and tested to determine their suitability for commercial steam production. They are usually vented to the atmosphere for about a day. Venting may take place with or without a muffler but it is usually done with a muffler. The directivity and sound pressure levels due to a free jet are illustrated in Fig. 3.9.

At one time free venting directly to the atmosphere was common but recent environmental standards have discouraged this practice. The current method of testing wells is either by venting them through the existing blooie silencer or through a portable silencer of some type such as Aminoil USA's portable rock muffler. Several other types of mufflers have been tested for venting over a number of years. A compilation of jet noise measurements both with and without mufflers is given in Table 3.4.

While some of the commercial mufflers have been quite successful in reducing noise from free venting, a problem which is common to all of them occurs because of the contents of the stream which emanates from a geothermal well. Included in the steam flow are particles of rock and dirt, sometimes of considerable size, which quickly tear up many types of mufflers. As a result most geothermal development companies have designed their own mufflers which have included sacrificial impact plates in a conventional design or simply a container of rocks. These mufflers are more resistant to destruction by the particles in the flow.

When a well is vented the noise created is produced by the high speed flow of the steam itself. Noise due to a free jet (air flowing from a pipe is referred to as a free jet) is directional and very dependent on the jet velocity. The sound pressure level increases rapidly with velocity according to the formula $8 \log V$. This means that for every doubling of the velocity, the sound level increases 24 dB. The size of the exit area of the jet is also an important factor in determining the spectral distribution of the sound as well as the level. The larger the diameter the louder will be the sound and the lower will be the frequency spectrum of the noise.

Fig. 3.10 shows the octave band noise levels due to unmuffled jets from Table 3.4. The sound pressure level associated with free jets averages 108 ± 13 dBA and 111 ± 7 dBC

Figure 3.9 Sound Field Distribution for a Free Venting Well
(Overall Unweighted SPL, dB)

TABLE 3.4

Noise from Steam Discharge from Jets at 100 Ft.

TEST NR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
dBA	111	113	108	110	113	76	81	86	114	125	90	95	102	110	111	81	123	122	86	99	82	102	85	112
dB C	110	113	109	112	112									109	111	87	123	122	86	99	81	103	86	111
63 Hz	81	83	91	91	91									74	82	72	92	91	81	75	70	82	75	90
125 Hz	88	90	94	94	96									83	90	80	104	96	80	86	70	91	76	94
250 Hz	98	100	95	95	100									91	92	79	108	106	76	90	69	94	74	98
500 Hz	101	103	100	89	102									103	106	80	108	112	74	93	67	97	72	104
1000 Hz	108	110	103	91	106									105	107	79	118	116	74	94	70	98	73	106
2000 Hz	103	105	103	94	108									102	104	78	120	119	75	92	77	96	78	106
4000 Hz	98	100	102	96	105									102	100	75	116	115	70	90	77	90	81	102
8000 Hz	100	103	99	93	100									96	96	69	109	108	60	86	70	82	79	92
Source	4	12	13	9	10	1	1	1	7	7	10	10	10	4	4	4	4	4	4	4	4	4	4	12
Data Nr	27	28	29	30	31	32	32	32	33	33	34	35	36	37	37	37	38	38	38	39	39	40	40	41

1. 10 in. valve, 150-175,000 #/hr	3. 100,000 #/hr
4. Fully opened, 125 dBA when partly opened	5. 150,000 #/hr
6. 3 in. line, horizontal, 180 deg. from exit	7. 3 in. line, horizontal, 90 deg. from exit
8. 3 in. line, horizontal, 45 deg. from exit	11. 6 in. orifice, 4 in. choke, production test
12. 3 in. orifice, 3 in. choke, production test	13. 4 in. orifice, 4 in. choke, production test
14. 10 in. valve, 100,000 #/hr, no muffler	15. 10 in. valve, 100,000 #/hr, no muffler
16. AP multiple perforated exhaust tube muffler	17. 160,000 #/hr, no muffler
18. 250,000 #/hr, no muffler	19. Kittell muffler
20. 140,000 #/hr, valve 1/4 open	21. Delta muffler
22. 205,000 #/hr, valve full open	23. 218,000 #/hr, valve full open
24. 270,000 #/hr, open well	

TABLE 3.4 (cont'd)

Noise from Steam Discharge from Jets at 100 Ft.

TEST NR	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
dBA	83	110	108	122	84	118	119	117	92	114	116	97	97	83	127	108	110	105	94	84	112	122	99	103
dBC	84	112	109									99	100						92					
63 Hz	78	105	97									90	97						79					
125 Hz	76	105	99									90	92						76					
250 Hz	74	103	98									92	85						76					
500 Hz	70	105	102									90	86						73					
1000 Hz	78	104	102									87	89						82					
2000 Hz	77	102	103									94	94						84					
4000 Hz	73	99	100									83	83						89					
8000 Hz	62	101	101									66	68						90					
Source	12	12	12	12	12	12	12	12	12	12	12	15	15	13	16	16	16	16	7	7	1	1	1	1
Data Nr	41	41	41	42	42	42	42	43	43	43	43	44	44	45	46	46	46	46	47	48	49	49	49	49
25.	150,000 #/hr, rock muffler											26. 170,000 #/hr, long conical muffler												
27.	270,000 #/hr, short conical muffler w/center											28. 270,000 #/hr, open well												
29.	150,000 #/hr, rock muffler											30. 170,000 #/hr, long conical muffler												
31.	270,000 #/hr, short conical muffler w/center											32. 270,000 #/hr, open well												
33.	150,000 #/hr, rock muffler											34. 170,000 #/hr, long conical muffler												
35.	270,000 #/hr, short conical muffler w/center											36. portable rock muffler												
37.	portable rock muffler											38. silencer												
39.	no muffler											40. muffler												
41.	no muffler											42. muffler												
43.	portable muffler											44. well cleanout, cyclonic muffler												
45.	conical 3 deg. diffuser, 90 deg. from exit											46. conical 3 deg. diffuser, 60 deg. from exit												
47.	conical 3 deg. diffuser, 180 deg. from exit											48. conical 3 deg. diffuser, 180 deg. from exit

Figure 3.10 Octave Band Spectrum from Unmuffled Steam Discharge at 100 Feet.

GEOTHERMAL NOISE

at 100 ft.

The principle source of noise during venting of geothermal wells is the pressure fluctuations caused by the turbulent eddies in the high velocity steam stream. The most practical way to reduce the noise is to decrease the velocity of the stream. Some methods which have been used include slow expansion of a pipe diameter (called a diffuser), injection of water into the stream which decreases the volume of the stream and thus reduces the velocity, use of baffle silencers which reduce the stream through an expansion chamber from one pipe size to that of a larger size, and finally through the use of rock mufflers which reduce the steam velocity by causing the steam to impact directly onto a bed of rocks and subsequently discharge through a large open area.

Commercial mufflers, including those which are designed specifically for large scale blow off, tend to have absorbent material on the interior of the muffler along with a diffuser which forces the flow to expand through small holes. The holes shift the spectrum of the noise to higher frequencies by making the turbulent eddies smaller. The high frequency noise is then attenuated by passing it through an absorbent tube. The flow exits through a larger pipe which again slows the flow by allowing it to expand into a greater area. Effectiveness of these types of mufflers is limited basically by the expansion ratio which can be achieved between the input pipe and the exit pipe. Noise is created again by the flow once the stream has left the muffler. Unless the muffler has slowed the flow to the extent that the velocity is not the dominant noise producing factor these mufflers are relatively ineffective since they do not treat the fundamental problem.

The large exit diameter employed in these types of mufflers once again shifts the frequency of the noise downward. The test results shown in Table 3.4 indicate that it is very difficult to suppress the low frequency components of jet noise since a pure expansion, by its very nature, involves a very large exit diameter. For a typical commercial silencer an attenuation of only 11 or 12 dB at 63 Hz is all that is usually attained. A Kittell muffler 7223-BLR-30 is typical of the commercial mufflers which are designed specifically for steam venting. It can provide attenuation better than 40 dB for frequencies higher than 700 Hz but is limited to about 11 dB at 63 Hz. This type of muffler, in spite of the difficulties it encounters with particles in the flow, can do much to alleviate noise created by a steam jet.

GEOHERMAL NOISE

Fig. 3.11 illustrates the attenuation of sound obtained through the use of several types of mufflers. The overall attenuation for each of the mufflers shown is summarized as follows:

Delta-PSMV Muffler	12 dBA	13 dBC
Delta P Multiple Perforated Exhaust	29 dBA	23 dBC
Rock Muffler (early design)	30 dBA	27 dBC
Kittell Muffler	51 dBA	36 dBC

Also shown in this comparison is an early Union Oil Company version of a rock muffler which consisted of a pipe blowing steam into a trench filled with rocks. This rock muffler design, although effective, has been improved considerably since that time.

A portable muffler based on the original design principle has been constructed by Aminoil USA and is shown in Fig. 3.12. Steam is allowed to vent through a conical diffuser into the end of a muffler. The flow impacts a bed of rocks which reduces the velocity of the flow and decreases the size of its turbulent eddies. A lower flow velocity produces less noise and the smaller eddies shift the frequency of the sound to a range which has a higher rate of attenuation.

The overall sound pressure level of the noise associated with the testing of steam production with the jet venting into the Aminoil USA portable rock muffler is 75+6 dBA and 78+7 dBC at 100 ft. On the average, rock mufflers of this type can be expected to reduce the noise level of a free venting jet by about 20 dBA. The spectrum associated with noise from a jet venting into a portable rock muffler is given in Fig. 3.13. The sound levels produced are dependent on the rate of the volume of steam blown through the mufflers. Two comparative measurements illustrate this point. With 360,000 #/hr of steam, noise levels are about 74 dBA. With 150,000 #/hr of steam the level drops down to about 61 dBA, a reduction of 13 dBA. One weakness with this particular silencer design is that the tapered diffuser actually increases the flow velocity since the flow is supersonic and causes a higher noise level inside the tapered section.

Another type of commercial muffler which has been used successfully in abating steam blow off noise is that manufactured by the Fluid Kinetics Corporation. This silencer consists of a box which can be mounted on a truck bed and contains a diffuser incorporating two right angle bends for the flow. Particles which happen to be in the stream will impact on a replaceable plate which minimizes the wear and tear on the functioning parts of the silencer.

Figure 3.11 Octave Band Spectral Attenuation of Mufflers for Steam Discharge

Figure 3.12 Portable Rock Muffler (Aminoil USA)

Figure 3.13 Octave Band Spectrum of Steam Discharge Through a Portable Rock Muffler with Different Flow Volumes at 100 Feet.

GEOHERMAL NOISE

The diffuser is designed as pictured in Fig. 3.14 and consists of a branchwork of perforated pipes in the bottom of the box with a light overlay of Scoria rock, and vertical panels above which are designed to absorb the high frequency sound. Data measured by the manufacturer are shown in Fig. 3.15 for steam blow off at the Commonwealth Edison Company, Collins Station Unit # 5 in Morris, Illinois. Two of these units were used to vent 4,000,000 #/hr at 830 psig initial pressure with an overall SPL of 86 dBA at 100 ft. This type of muffler is convenient in that it can be carried about on the back of a truck and used in well testing as well as in a permanent installation. Unfortunately all truck mounted mufflers radiate sound from the sides of the muffler itself and therefore remain a contributing noise source. This type of muffler can be most effective in solving some types of acoustical problems.

In summary the noise due to steam blow off at the wellhead has in the past been the most dominant source of noise associated with geothermal activities. During drilling and testing of wells commercial silencers and rock mufflers can provide geothermal developers with the tools needed to reduce noise levels to quite satisfactory values. The installation of these mufflers is a matter of timing in the development process. Clearly it is not in the interest of a developer to build a rock muffler before drilling a well since there is no way of knowing whether the well will produce steam. During the initial stages of drilling and testing, portable mufflers either employing rocks or more conventional designs must be used for the sake of economy. Once wells have been confirmed as productive, a rock muffler may be built to service a group of such wells and noise due to venting will be reduced accordingly. Photograph 3.7 illustrates a small, above grade rock muffler at a well site.

3.1.3.5 Well Maintenance

From the time that the well is completed to the time that steam is sent to a user facility, the well may be vented through a small bleeder line to the atmosphere. This process is often necessary to prevent the well from being "lost". Steam condensing to water on the sides of the well and flowing back down due to gravity may build up enough hydrostatic pressure to counteract the pressure of the steam thereby shutting off the flow. By allowing the steam to bleed, the likelihood of having to clean out the well, a costly operation, is diminished. Bleeding also keeps the temperature of the well more stable. Thus there is less tendency for the walls of the well to deteriorate due to thermal expansion and contraction. Bleed lines, if

Figure 3.14 Fluid Kinetics Corporation High Capacity Silencer

Figure 3.15 Octave Band Spectrum from a Fluid Kinetics Corporation Model BOS 96/130 Portable Blow Off Silencer at 4,000,000 #/hr at 100 Feet.

Photograph 3.7 Rock Muffler Located at Well Site

GEOHERMAL NOISE

allowed to vent freely to the atmosphere are a significant source of noise at the well site after drilling operations have ceased. Data concerning muffled and unmuffled bleed lines are given in Table 3.5.

An open bleed line of 1 inch diameter produces sound pressure levels of about 92 dBA. A commercial muffler has been used to reduce the A-weighted sound pressure level by 33 dB while a rock muffler can reduce the level by 44 dB to 48 dB. An open 1/4 inch bleed line will produce levels of about 72 ± 5 dBA and 70 ± 5 dBC. The spectra of an open 1/4 inch bleed line, the same line with a commercial muffler and the line with a rock muffler are shown in Fig. 3.16. The reduction in sound pressure level for the commercial muffler is about 7 dBA and 8 dBC. For the rock muffler the reduction is about 41 dBA and 31 dBC. It is clear that the rock muffler is more than adequate for the attenuation of noise generated by bleed lines. The average sound pressure level for noise generated by bleed lines and attenuated by rock mufflers is 55 ± 16 dBA.

The next period of interest begins when the steam is finally sent to the user facility. During the time that the well is supplying steam little noise is generated other than that associated with small condensate bleed lines. However there are times when free venting may occur at the well site. This may happen when a valve must be changed at the wellhead. Valve changes are necessary when the primary valve has become worn. This event occurs at intervals of about two years. Replacement takes place in a period which does not usually exceed 4 hours during which the steam must be freely vented. To replace the main valve, the well is allowed to vent unmuffled while the valve is removed. First, two bolts are removed from the flange plates under the valve and replaced by cables which are deadheaded to the valve flange through the bolt holes. The cables are drawn tight and the remaining bolts are removed. The valve can be lifted by a crane from the pipe against the back pressure of the cables. Once the old valve is removed the new valve is seated by reversing the process. The data listed in Section 3.1.3.3, well cleanout and production tests applies during these conditions.

Occasionally conditions may occur at the well site which also may create large amounts of noise. If a well begins to lose its steam generating capacity due to physical changes in the well hole, emergency measures may necessitate free venting to recover the well. Again the data contained in Section 3.1.3.3 apply.

TABLE 3.5

Noise Due to Steam Discharge from Bleed Lines at 100 Ft.

TEST NR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
dBA	55	76	92	59	44	61	76	76	91	76	65	67	67	72	74	66	71	73	56	32	75	66	59	39
dBC	65									74	63	65	70	69				72	55	41	74	64	60	
63 Hz	55											46	51					44	41	33	47		41	
125 Hz	59											49	57					42	41	35	45	47	47	
250 Hz	60											53	58					43	34	29	48	42	37	
500 Hz	58											47	56					43	39	29	54	38	44	
1000 Hz	59											60	60					50	47	29	55	40	46	
2000 Hz	50											63	62					59	51	21	59	49	49	
4000 Hz												66	63					66	51	20	69	61	54	
8000 Hz												64	63					72	50	21	74	66	54	
Source	9	4	4	4	4	13	13	13	13	4	4	4	7	7	1	1	1	16	16	16	16	16	16	12
Data Nr	50	51	51	51	51	52	52	53	53	54	54	54	55	56	57	57	57	58	58	58	59	59	59	60

1. 1 in. bleed, rock muffler
 3. 1 in. bleed, unmuffled
 5. 1 in. bleed, rock muffler
 7. 1/2 in. bleed, rock muffler
 9. 1/2 in. bleed, rock muffler
 11. 1/4 in. bleed, unmuffled
 13. rock muffler
 18. 1/4 in. bleed, open
 20. 1/4 in. bleed, rock muffler
 22. 1/4 in. bleed, factory muffler
 24. rock muffler

2. 1/4 in. bleed, unmuffled
 4. 1 in. bleed, commercial muffler
 6. 1/2 in. bleed, rock muffler
 8. 1/2 in. bleed, rock muffler
 10. 1/4 in. bleed, unmuffled
 12. 1/4 in. bleed, unmuffled
 14. rock muffler
 19. 1/4 in. bleed, homemade muffler
 21. 1/4 in. bleed, open
 23. 1/4 in. bleed, homemade muffler

TABLE 3.5 (cont'd)

Noise Due to Steam Discharge from Bleed Lines at 100 Ft.

TEST NR	25	26	27	28	29	30	31	32	33	34	35	36
dBA	47	60	44	43	52	56	82	85	78	80	52	55
dBC				48	57	62						
63 Hz												
125 Hz												
250 Hz												
500 Hz												
1000 Hz												
2000 Hz												
4000 Hz												
8000 Hz												
Source	12	12	12	4	4	4	13	13	13	13	13	13
Data Nr	60	61	61	62	62	62	63	63	63	63	63	63

25. rock muffler

27. rock muffler

29. rock muffler

31. bleed line

33. bleed line

35. bleed line with silencer

26. rock muffler

28. rock muffler

30. rock muffler

32. bleed line

34. bleed line

36. bleed line with silencer

Figure 3.16 Octave Band Spectra From 1/4" Bleed Lines at 100 Feet

3.2 Steam Pipelines

When the well is completed the steam must be transported from the well site to a user facility. This is accomplished through the use of large pipes wrapped with thermal insulating material which connect the wells to the primary facility and often to alternate facilities.

There are two periods in the lifetime of a steam pipeline which may be identified. The first occurs when the pipeline is being constructed and the second occurs during normal use of the pipeline.

3.2.1 Pipeline construction

The sounds of bulldozers, trucks, welding rigs, cranes and other construction equipment will be heard primarily during the daylight hours for a period of time which depends on the location of the well and the location of the power plant. The construction period of a steam pipeline is measured in weeks rather than in days or months. Noise levels generated by construction equipment during this period are indicated in Fig. 3.18 (Section 3.3.1).

When a new pipeline is connected to an existing pipeline system (referred to as commissioning the new pipeline) steam must be vented to clear the line. This event usually occurs only once during the initial startup of the pipeline.

3.2.2 Steam passage

The pipelines carrying steam from the wells to the plant produce only moderate levels of noise. All the pipes are lagged (wrapped) with thermal insulating material typically including aluminum or steel sheet metal cladding which also acts to reduce noise. The measured noise levels adjacent to an 18 inch pipe wrapped with an absorptive blanket and cladding is about 60 dBA at 10 ft. At 100 ft. the level is about 50 dBA. The change in sound pressure level at a rate of only 3 dBA per doubling of the distance is due to the fact that the pipeline is considered to be a "line source of sound" (Data # 64, Source # 1).

During normal operation of the pipeline it sometimes becomes necessary to close down the plant for a long period of time. When the facility restarts there can be an eight hour period when the pipelines are cleared and open venting to the atmosphere may occur, with noise levels as indicated in Section 3.1.3.4. Planned shutdowns for overhaul and

GEOHERMAL NOISE

maintenance of the plant are usually scheduled every two years with unplanned shutdowns occurring about twenty five times a year. Occasionally the rock catchers at the well are cleared. During this short period unmuffled venting of steam will occur.

Although the noise produced by steam passing through the pipeline is relatively low there are places in the pipeline system where high levels of sound are produced. These occur at valve locations and where orifice plates are placed in the pipeline to determine steam velocity. An orifice plate consists of a thin circular plate with a large hole in the center which is placed inside the pipeline. If the pressure is measured both upstream and downstream of the plate the flow velocity may be calculated. A limited amount of data is available concerning orifice plate noise. At a distance of 10 ft. from the center of the pipeline and 30 ft. downstream from the plate a sound pressure level of 117 dBA was measured. At 130 ft., 280 ft. and 1500 ft. downstream and 10 ft. from the center of the pipe noise levels of 83, 80 and 57 dBA were measured. (Data # 65, Source # 17.)

Placed outside the fenced-in area of the power plant may be one or more drag valves in the main steam lines. These valves are emergency pressure relief devices which automatically activate if the pressure in the steam line becomes too high. They allow steam to pass through to a rock muffler if available or directly to the atmosphere. The sound pressure levels caused by the drag valves alone is given in Table 3.6 and their associated spectrum in Fig. 3.17. Drag valves are no longer in use by Union Oil Company. Fisher "V-ball" valves are now in service which dump the steam directly to rock mufflers.

3.3 Power plants

A typical power plant using steam as its source of energy is constructed on about 215,000 square feet of ground which has been leveled, paved and fenced. On the site are a turbine building (housing the turbine and condenser system), a cooling tower, a hydrogen sulfide treatment plant, and the power transformer and switching system, plus extra buildings as necessary for the operation of the plant. In addition there is a provision for venting the steam in case the plant must be shut down and the steam stacked (vented to the atmosphere). Usually a large rock muffler is used for this purpose.

The operation of a power plant is as follows. Geothermal steam is fed to a steam turbine which in turn

TABLE 3.6

Noise Generated by Drag Valves at 100 Ft.

TEST NR	1	2	3	4	5	6
dBA	83	85	89	74	93	91
dBC	89	89	93	94		92
63 Hz	77	85	92	51		85
125 Hz	73	76	82	50		79
250 Hz	87	81	83	52		74
500 Hz	82	80	81	57		81
1000 Hz	79	79	82	67		84
2000 Hz	76	79	82	70		86
4000 Hz	75	76	79	68		86
8000 Hz	74	77	79	56		76
Source	12	12	12	1	17	18
Data Nr	66	66	66	67	68	69

1. 1/4 load, down 7MW, 128 psig line press.
3. Full load, down 27 MW, 145 psig, line press.
5. 12 in. valve, 20 psig 150,000 #/hr.

2. 1/2 load, down 14 MW, 130 psig line press.
4. Valve at input to rock muffler
6. Venting 800,000 #/hr

Figure 3.17 Octave Band Spectrum Due to Drag Valves

GEOHERMAL NOISE

drives an electrical generator. The spent steam then flows to a condenser where it is condensed. A small portion of the geothermal steam from the wells is also used to drive the gas ejector system which removes the non-condensable gases at the condenser and exhausts them to a hydrogen sulfide treatment unit from which they are vented to atmosphere. The steam in the condenser is condensed by means of cooling water obtained from the large cooling tower in the facility. Part of the condensate becomes cooling tower make-up water and the balance is reinjected into the geothermal reservoir.

3.3.1 Plant Construction

The construction of a power plant for geothermal use is no different from the construction of any other type of power plant. The highest noise levels occur during site preparation when large earth moving equipment is used. During this period some blasting may be required for excavation. Fig. 3.18 (Source # 3) lists the range of sound pressure levels associated with construction equipment and Fig. 3.5 (Section 3.1.1) shows the spectra of several pieces of equipment. Typical measured noise levels at 50 ft. associated with plant construction are (Source # 3):

a) Ground Clearing	84 $\pm$ 7 dBA
b) Excavation	89 $\pm$ 6 dBA
c) Foundations	78 $\pm$ 3 dBA
d) Erection	87 $\pm$ 6 dBA
e) Finishing	89 $\pm$ 7 dBA

3.3.2 Plant Operations

There are three operating conditions which may be associated with plant operations. The first condition begins with plant start-up and exists during all normal operations when the plant is producing electricity. The second condition occurs when the plant is shut down temporarily and while it is no longer producing electricity, the steam is stacked (vented to the atmosphere). The third condition occurs when the plant is shut down on a more permanent basis for maintenance and overhaul of components. During this period the plant is not producing electricity and the steam is either routed to another facility or the supply wells are shut down at the well sites.

Figure 3.18 Range of Noise Levels Produced by Construction Equipment

3.3.2.1 Start-up, Normal Operations

At plant start-up the main source of noise is the free venting steam as each of the pipelines is cleared of debris and tested. These noise levels have been discussed in Section 3.1.3.4. During normal operations when the plant is producing electricity there are four sources of noise: the turbine contained within the plant enclosure, the steam ejectors associated with the condenser, the cooling tower, and the main transformer.

Sound pressure levels produced in the interior of the power generating building have been measured and are shown in Table 3.7. The spectrum associated with the turbine is shown in Fig. 3.19. The average sound pressure level is 98 ± 8 dBA at 10 ft. Both the turbine and the condenser produce high noise levels on the interior of the turbine building. A condenser room was measured to have a sound pressure level of 96 dBA at 10 ft. from the condenser. The spectrum of the noise in the condenser room is shown in Fig. 3.20. Typically operators working in the turbine building are provided with sound proofed offices which reduce the noise levels in their normal working environment.

Much of the noise produced by the condenser system is associated with the steam jet gas ejectors. These are supplied with a small portion (about 5%) of the geothermal steam and act as gas pumps to withdraw the non-condensable gases from the condenser thereby maintaining a vacuum in the condenser and high efficiency in the turbine. The average sound pressure level of a steam jet gas ejector is 89 ± 3 dBA and 90 ± 2 dBC at 10 ft. Table 3.8 lists measured values while Fig. 3.21 illustrates the spectrum. Note that measurement distances given in this table and figure are standardized to 10 ft. Path treatment where mineral wool and lead has been installed on the exterior surfaces of the ejectors produce noise level reductions of approximately 24 dBA (Source # 18, Data # 79)

The walls of the turbine building reduce the exterior noise to about 66 ± 7 dBA (71 ± 6 dBC) at 100 ft. The spectrum of the exterior noise from the turbine and condenser building is shown in Fig. 3.22. The associated sound pressure levels exterior to the turbine building at 100 ft. is given in Table 3.9.

A large cooling tower is used to provide cool water to the condenser unit thereby converting the steam to water

TABLE 3.7

Noise Measured in the Interior of Power Plant Buildings

TEST NR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
dB A	91	96	110	97	96	100	94	92	121	103	101	90	94	92	94
dB C	94	99													
63 Hz	86	88													
125 Hz	86	90													
250 Hz	86	90													
500 Hz	88	91													
1000 Hz	87	94													
2000 Hz	84	89													
4000 Hz	79	84													
8000 Hz	65	71													
Source	1	1	18	18	18	18	18	18	18	18	18	13	13	13	13
Data Nr	66	67	68	68	68	69	69	69	70	70	70	71	71	71	71

1. Turbine room

3. Turbine room, 20% load

5. Turbine room, 100% load

7. Turbine room, 50% load

9. Turbine room, 20% load

11. Turbine room, 100% load

13. Turbine room

15. Turbine room

2. Condenser room

4. Turbine room 50% load

6. Turbine room, 20% load

8. Turbine room, 100% load

10. Turbine room, 50% load

12. Turbine room

14. Turbine room

Figure 3.19 Octave Band Spectrum of Noise Produced by a Steam Turbine in the Interior of a Power Plant at 10 Feet

Figure 3.20 Octave Band Spectrum of Noise Produced by a Condenser in the Interior of a Power Plant at 10 Feet

TABLE 3.8

Noise Generated by Steam Jet Gas Ejectors at 10 Ft.

TEST NR	1	2	3	4	5	6	7
dBA	90	85	85	88	93	91	88
dBC	91	88	87	92			
63 Hz	85	84	81	82			
125 Hz	81	81	79	82			
250 Hz	81	78	79	80			
500 Hz	80	77	76	81			
1000 Hz	80	77	75	83			
2000 Hz	83	79	76	85			
4000 Hz	87	80	78	87			
8000 Hz	81	74	78	82			
Source	13	13	13	13	13	13	13
Data Nr	76	76	76	77	77	78	78

Figure 3.21 Octave Band Spectrum Produced by Steam Jet Gas Ejectors at 10 Feet

Figure 3.22 Octave Band Spectrum at the Exterior of the Turbine Building at 100 Feet.

TABLE 3.9

Noise Exterior to Power Plant Buildings at 100 Ft.

TEST NR	1	2	3	4	5	6	7
dBA	57	65	77	61	72	69	64
dBC	67	71	80	67			
63 Hz	65	68	67	61			
125 Hz	62	63	76	61			
250 Hz	56	60	71	59			
500 Hz	59	62	69	59			
1000 Hz	51	59	71	54			
2000 Hz	48	59	70	54			
4000 Hz	44	57	70	52			
8000 Hz	37	50	62	45			
Source	13	13	1	13	1	13	13
Data Nr	80	80	81	82	83	84	84

GEOHERMAL NOISE

after it has passed through the steam turbine. A cooling tower consists of a series of cascading water falls along the sides of the tower. Air is drawn through the falling water by a series of large rotating fans on the roof of the structure. The water is cooled by evaporation and is sent to the condenser to be used to condense the geothermal steam into water which is then routed to the cooling tower. Photograph 3.8 illustrates a cooling tower.

There are two sources of noise associated with the cooling tower. The first is the noise generated by the cooling fans. This noise radiates from the exhaust stacks as well as through the side louvers. The second source of noise is from the falling water. The decrease of noise with distance from the side of a cooling tower is not as simply calculated as with most other noise sources associated with geothermal development. Near the sides of the tower the generation of noise is closely approximated by a plane source of sound and therefore the noise remains relatively constant with distance until a distance of about $1/3$ the height of the tower is reached. Then the tower is best described as an acoustical line source and the noise decreases approximately 3 dB for every doubling of the distance from the tower. When a distance of $1/3$ the length of the tower is reached the tower begins to assume the characteristics of a point source and the noise decreases at about 6 dB per doubling of distance. Of the two noise sources, the fan and the falling water, the fan noise dominates at large distances and it is the sound of the fan which is radiating through the louvers that is heard the loudest. Because of the complicated radiation pattern of the cooling tower only data in the near field will be given i.e. measurements which have been made in the region where the signal is constant or is decreasing at the rate of 3 dB per double distance. These values and the associated spectrum are given in Table 3.10 and Fig. 3.23 respectively. The average sound levels are 78 ± 6 dBA and 86 ± 3 dBC at 100 ft.

The last principal source of noise connected with normal operations is the power transformer. Transformers have highly directional noise characteristics such as those illustrated in Fig. 3.24. Noise from power transformers are given in Table 3.11 with the spectrum measured along a principal lobe given in Fig. 3.25. The average sound pressure level from a limited number of measurements is 65 ± 7 dBA at 100 ft.

A typical day-night noise level contour around a geothermal power plant is shown in Fig. 3.26

Photograph 3.8 Cooling Tower

TABLE 3.10

Noise Generated by Cooling Towers

TEST NR	1	2	3	4	5	6	7	8	9	10	11
dBA	81	83	83	81	85	79	75	78	76	64	75
dBC	86	89	87	87		80					
63 Hz	81	82	84	80		75					
125 Hz	80	84	80	81		73					
250 Hz	79	81	78	81		75					
500 Hz	76	77	75	76		67					
1000 Hz	72	75	73	73		66					
2000 Hz	73	75	75	73		63					
4000 Hz	76	79	78	74		65					
8000 Hz	77	79	79	77		67					
Source	13	13	13	13	13	1	1	1	1	1	1
Data Nr	85	85	85	86	86	87	88	88	88	89	89

1. Units 7 & 8, 20 ft.
3. Units 9 & 10, 20 ft.
5. Power plant, 5 ft.
7. Unit 11, 80 ft.
9. Unit 11, 100 ft.
11. Unit 7 & 8, 80 ft.

2. Unit 11, 20 ft.
4. Power plant, 10 ft.
6. Unit 11, center of cooling tower
8. Unit 11, 50 ft.
10. Unit 7 & 8, 100 ft.

Figure 3.23 Octave Band Spectrum from Cooling Towers at 100 Feet

Figure 3.24 Power Transformer Radiation Pattern

TABLE 3.11

Noise Generated by Power Transformers at 100 Ft.

TEST NR	1	2	3
dBA	73	63	59
dBC	79		
63 Hz	65		
125 Hz	60		
250 Hz	75		
500 Hz	76		
1000 Hz	57		
2000 Hz	50		
4000 Hz	45		
8000 Hz	36		
Source	1	1	1
Data Nr	90	91	91

1. PG & E Unit 11, on center line of transformer 2. PG & E Unit 11, on center line of transformer
 3. PG & E Unit 7 & 8

Figure 3.25 Octave Band Spectrum of Noise Produced by Power Transformers Along a Major Lobe at 100 Feet

Figure 3.26 Day-Night Noise Level Contours from a Geothermal Power Plant

3.3.2.2 Temporary Shutdown

Occasionally geothermal power plants are purposefully shut down for short periods of time, or accidentally shut down (tripped) due to a system malfunction. Under these conditions it is not practical to reduce the steam being delivered to the plant by shutting down the wells or re-distributing the steam to other power plants. Thus some method of venting the steam must be used which does not produce excessive noise. The volume of steam can be as high as one million pounds per hour. Several types of mufflers have been used for silencing the escaping steam. One of the most successful of these has been a rock muffler built by Union Oil Company. Fig. 3.27 details the construction of this muffler, which is basically a pit filled with light basalt rocks into which steam is blown through small holes in a branchwork of pipes. Table 3.12 illustrates the sound pressure levels associated with rock mufflers discharging steam during the time that a power plant was tripped. The spectrum is given in Fig. 3.28. The average sound pressure level is 60 ± 8 dBA at 100 ft.

Recently plants have been designed with rock mufflers encased in a concrete shell rather than located below grade. Such a muffler is shown in Photograph 3.9. Noise levels from this type of rock muffler located above grade are comparable to rock mufflers located in the ground. Some developers have located smaller versions of this type of muffler at well sites or groups of well sites so that production testing and cleanout can be accomplished through a permanently installed muffler.

Under conditions that the plant is tripped, noise from the turbine and the steam jet ejectors will not be present. Noise from the cooling tower may still exist, however. A contour of the day night noise level, L_{dn} , from Pacific Gas and Electric Unit # 13 power plant under a temporary shut down is shown in Fig. 3.29.

3.3.2.3 Long Term Shutdown

During long term shutdowns there is little noise produced at the power plant other than that associated with maintenance and overhaul operations. The steam is either shut off at the wells to conserve the resource or is redistributed to other plants which can use the additional steam, thus preserving the overall steam output of the fields.

Figure 3.27 Union Oil Company of California's Geothermal
Power Plant Blow-off Silencer

TABLE 3.12

Noise from Power Plant Rock Mufflers at 100 Ft.

TEST NR	1	2	3
dBA	69	53	59
dBC	77		
63 Hz	74		
125 Hz	72		
250 Hz	66		
500 Hz	61		
1000 Hz	65		
2000 Hz	60		
4000 Hz	52		
8000 Hz	36		
Source	19	19	19
Data Nr	90	91	91

1. PG & E Unit 9 & 10, 800,000 #/hour
3. PG & E Unit 9 & 10, 800,000 #/hour

2. PG & E Unit 9 & 10, 800,000 #/hour

Figure 3.28 Octave Band Spectrum of Noise Produced by Free Venting of Steam Through a Pit Type Rock Muffler with 800,000#/hr Steam Discharge at 100 Feet

87

Photograph 3.9 Above Grade Rock Muffler at Power Plant Unit #13

Figure 3.29 Day-Night Noise Level Contours in the Vicinity of Power Plant Unit #13, Plant Tripped, Stacking Steam

GEOHERMAL NOISE

3.4 Direct Use Facilities

Because of the varied forms that a direct use facility may take it is difficult to quantify "typical" noise. Each plant will have the normal noises associated with its own operations. The noise from pumps, heat exchanger systems and flow regulating equipment may be the only additional noise that can be attributed to geothermal development. Thus no measurements will be given for these specialized and individualized plants.

4.0 Long Term Noise Monitoring

Because average sound pressure levels and spectra do not adequately describe the noise associated with geothermal development, Marshall Long/Acoustics equipped a vehicle with an acoustical monitoring unit so that the noise produced from drilling a geothermal steam well could be monitored on a continuous basis. The operation lasted for 55 days and measurements were taken from rigging up to production testing with the drilling rig in place. All specific activities were identified and correlated with the noise recorded thus producing a history of the noise generated at Union Oil Company's well site DX 63 from midnight, 11 December 1981 to 4 February 1982. Photograph 4.1 shows the Marshall Long/Acoustics monitoring vehicle in place at Union Oil Company's well site, DX 63, at The Geysers, California.

The basic monitoring equipment consisted of a Digital Acoustics, Inc. Model DA607P v.03 integrating environmental noise monitor. A Genrad 1560-P5 ceramic microphone and 1560-P40 preamplifier was used to detect the noise. The microphone was mounted on a mast extending above the vehicle and fixed inside a specially designed, acoustically transparent cage which protected the microphone from the weather. The microphone was calibrated every few weeks with a Bruel and Kjaer type 4230 calibrator. Its calibration remained constant within 0.1 dB over the period of the measurements. The monitoring equipment was powered by two heavy duty 12V batteries which continually charged the 6V battery contained within the monitoring unit itself. The batteries were adequate to supply power throughout the entire monitoring operation. The vehicle was covered with foam rubber to reduce the sound of rain hitting the metal surface of the truck during inclement weather and to eliminate reflections of sound from the body of the vehicle.

Photograph 4.1 Marshall Long/Acoustics Monitoring Truck at
Union Oil Company of California's Well Site,
DX 63, at The Geysers, California.

GEO THERMAL NOISE

The DA 607P v.03 is a self contained monitoring system capable of sampling the sound pressure level every eighth of a second. An internal microprocessor was programmed to calculate and print the following data every hour:

- a) Equivalent continuous sound pressure level, L_{eq}
- b) Maximum sound pressure level
- c) Average sound pressure level
- d) Minimum sound pressure level
- e) Standard deviation
- f) Level exceeded 0.1 % of the time, $L(0.1)$
- g) Level exceeded 1 % of the time, $L(1)$
- h) Level exceeded 5 % of the time, $L(5)$
- i) Level exceeded 10 % of the time, $L(10)$
- j) Level exceeded 33 % of the time, $L(33)$
- k) Level exceeded 50 % of the time, $L(50)$
- l) Level exceeded 90 % of the time, $L(90)$
- m) Level exceeded 99 % of the time, $L(99)$

Every 24 hours the following data was also calculated and printed:

- a) 24 hour L_{eq}
- b) Community noise equivalent level, CNEL
- c) Day night noise level, L_{dn}

The vehicle was placed such that the well site sump was between the vehicle and the drilling rig (Loffland Bros. # 50). On the opposite side of the vehicle the ground dropped off for hundreds of feet thus the microphone was placed in a free field environment. The location of the well is shown in Fig. 4.1 and the layout of the well site is illustrated in Fig. 3.1. The distances from the vehicle to the major pieces of noise producing equipment are:

- a) Wellhead - 120 ft.
- b) Three D398 Caterpillar engines, turbocharged, with Kittell Hospital Mufflers, operating 1 or 2 at a time, 850 BHP, 1200 RPM, supplying electric power to 2 mud pumps (1000 HP each) and the drawworks (2 motors, 1000HP each) - 145 ft.
- c) Three D398 Caterpillar engines supplying power to the air compressors - 180 ft.
- d) Sump pump - 145 ft.
- e) Blooie silencer - 120 ft.

SOURCE: UNION OIL

Figure 4.1 The Geysers Area

GEOHERMAL NOISE

All measured data is given in Vol. II of the report. Figs. 4.2 to 4.12 contain the equivalent continuous sound pressure level (L_{eq}) for the entire operation. Fig. 4.13 displays the 24 hour, L_{eq} and the day-night noise level, L_{dn} . The major activities monitored were:

- a) Drilling rig erection
- b) Mud drilling operations
- c) Air drilling operations
- d) Air drilling with steam production
- e) Production testing with rig in place
(290,000 psig/hr)
- f) Final venting through a 3 in. Vannee
Muffler, Model 521-24A-M3-3M3H-F

With the data contained in this section and Section 3.0 it is possible to assess accurately the impact of any of the current operations connected with geothermal development. The report is not concerned with the effects occurring during sound propagation due to terrain, weather, wind temperature, inversion layers or humidity. The attempt was to collect, measure if necessary, and standardize all acoustical measurements of noise associated with geothermal activities at each source.

Figure 4.2 Long Term Noise Monitoring at 120 Feet Day 1-5

Figure 4.3 Long Term Noise Monitoring at 120 Feet Day 6-10

Leq, Equivalent Sound Level - dBA re $20 \times 10^{-6} \text{ N/m}^2$

Figure 4.4 Long Term Noise Monitoring at 120 Feet Day 11-15

Leq, Equivalent Sound Level - dBA re 20×10^{-6} N/m²

Figure 4.6 Long Term Noise Monitoring at 120 Feet Day 21-25

Leq, Equivalent Sound Level — dBA re 20×10^{-6} N/m²

Figure 4.7 Long Term Noise Monitoring at 120 Feet Day 26-30

Leq, Equivalent Sound Level - dBA re 20×10^{-6} N/m²

Figure 4.8 Long Term Noise Monitoring at 120 Feet Day 31-35

Leq, Equivalent Sound Level - dBA re $20 \times 10^{-6} \text{ N/m}^2$

Figure 4.9 Long Term Noise Monitoring at 120 Feet Day 36-40

Figure 4.10 Long Term Noise Monitoring at 120 Feet Day 41-45

Leq, Equivalent Sound Level - dBA re 20×10^{-6} N/m²

90T

Figure 4.13 Long Term Noise Monitoring at 120 Feet 24 Hour L_{eq} , L_{dn}

GEOHERMAL NOISE

5.0 Noise Control Standards

Noise control standards, regulations, ordinances, and policies may be attributed to three sources - the federal government, the state governments, and county and local community governments. The federal government gave most of the control of environmental noise to the state and local governments but kept control of four special categories. In addition the federal government has kept control of noise produced on lands leased from the federal government as well as occupational noise. Some states have also created noise standards with which geothermal activities must comply. Finally county and community regulations apply directly or indirectly (through usage permits) to geothermal activities.

5.1 Federal Standards

The federal government has two sets of standards which are applicable to geothermal operations. The first set is concerned with environmental noise and is limited in its scope. The second set is occupational noise and is quite broad in scope. The environmental noise standards are concerned with the effect of noise on the environment including those persons not directly connected with the noise producing operation while the occupational standards are concerned with the employees who work in and around the sources of noise.

5.1.1 Environmental Noise Standards

The Noise Control Act of 1972 gave primary control of environmental noise to the states and local governments. The federal government retained authority at the point of manufacture over new construction equipment, transportation equipment, motors and engines (including any equipment of which the engine is an integral part), and electrical or electronic equipment. Drafting and enforcement of product standards are entrusted to the Environmental Protection Agency. Currently no EPA environmental noise regulations are being enforced (private communication, John Pope, 1981, USEPA).

The Noise Control Act of 1972 also entrusted to the federal government regulation of geothermal leases, on federal land controlled by the Bureau of Land Management, and when enforced require that geothermal operations comply with the United States Geological Survey: Geothermal Re-

GEOHERMAL NOISE

sources Operations Order No. 4 - General Environmental Protection Requirements. On land leased from the federal government:

- a) Noise levels cannot exceed 65 dBA at a distance of 1/2 mile from the source or at the lease boundary line, whichever is greater.
- b) Noise levels may exceed 65 dBA if all residents within the 1/2 mile limit agree, or if an emergency arises

This restriction corresponds to an A-weighted sound pressure level of 93.4 dBA at 100 feet, assuming a perfect hemispherical distribution of sound energy from the source. This is a maximum value which is difficult to measure since monitoring equipment must be recording data continuously to record any infraction. It is also difficult to monitor at close range since shifts in environmental conditions may suddenly cause a change in the noise level at 1/2 mile. It is also quiet permissive since 93.4 dBA at 100 feet is a very loud noise level.

5.1.2 Occupational Noise Standards

The Occupational Safety and Health Act of 1970 (OSHA) establishes the following standards for employers:

To reduce sound levels or provide personal protection equipment for employees, when sound levels exceed the following limits:

Duration per day hours	A-weighted SPL (slow response)
8	90
6	92
4	95
3	97
2	100
1 1/2	102
1	105
1/2	110
1/4 or less	115

The standards listed in this and the previous section are the only federal noise standards which apply to geothermal operations.

5.2 State Standards

Since this report is concerned with the geothermal

GEOHERMAL NOISE

development in the fifteen western states specified in Section 2.1 known to have geothermal resource areas, the following sections summarize the existing statutes and regulations in each of those states. Within each state there may be three types of regulations which are applicable to geothermal operations. One type is concerned with noise emanating from any source including geothermal sources, a second type concerned specifically with geothermal development but containing language pertaining to noise, and finally a third type is concerned with environmental impact from any cause. Only the first type is usually specific in its content. The second type is usually of a general nature and not specific in its control language. The third type has the net result of bringing to light the impact of any action which is to be taken and which might affect the environment. It is especially useful in drafting use permits since it allows local control to specify local constraints.

5.2.1 Alaska

As of December 1980 there have been no geothermal wells drilled in Alaska nor does Alaska have any state statutes or regulations governing noise.

Lands owned by the state are governed by the provisions of Title 38 of the Alaska Statutes - Public Lands. Sec. 38.105.181 of that document gives broadbased powers to the Commissioner and the Director to enforce conservation practices and pollution control measures.

The Department of Environmental Conservation reviews and comments on projects that may potentially affect the state's environment. Alaska does not have an environmental impact act

5.2.2 Arizona

As of December 1980 there have been no geothermal wells drilled in Arizona nor does Arizona have any state regulations or statutes governing noise.

Under Title 27, Chapter 4, Arizona Revised Statutes - Geothermal Resources, the Oil and Gas Commission oversees geothermal activity. Their Rules and Regulations require that well drilling operators minimize noise when conducting air drilling operations or when the well is allowed to produce while drilling.

GEOTHERMAL NOISE

Environmental Impact Statements are required.

5.2.3 California

As of December 1980 there have been 266 geothermal wells drilled in California. The California Noise Control Act of 1973 established the Office of Noise Control in the California Department of Health. At the current time there are no noise regulations concerning geothermal development. Neither are there noise restrictions specifically pertaining to state owned land.

Under Title 14, Natural Resources, California Administrative Code, Division 6, Chapter 3, Guidelines for Implementation of the California Environmental Quality Act of 1970, guidelines were established which must be followed by all state agencies, boards, commissions, counties, cities, regional agencies and subdivisions of the state. The guidelines, called the State EIR Guidelines establish the requirements for the creation of an Environmental Impact Report (EIR), the agency responsible, the preparation, and the review process.

5.2.4 Colorado

As of December 1980 there have not been any geothermal wells drilled in Colorado however Colorado has a noise statute: Title 25, Article 12, Noise Abatement. This statute prohibits noise which is objectionable because of intermittence, beat frequency or shrillness. A-weighted sound pressure levels at a distance of 25 feet or more from the property line in excess of the following are a public nuisance:

Zone	7 AM - 7 PM	7 PM - 7 AM
Residential	55	50
Commercial	60	55
Light industrial	70	65
Industrial	80	75

During daylight the levels may be increased for a fifteen minute period in any hour. Periodic, impulsive or shrill noises are a public nuisance when they are 5 dB less than the above.

The geothermal lease form used by Colorado has the usual compliance with law section as an indirect reference to environmental obligations.

GEOHERMAL NOISE

Colorado has a law which allows the public to attend and comment on geothermal leasing. They have no environmental quality act.

5.2.5 Hawaii

There have been 4 wells started on the island of Hawaii as of December 1980. Although the island of Oahu has very stringent noise regulations, there are none which apply to the island of Hawaii.

Chapter 182, Reservation and Disposition of Government Mineral Rights, requires that the resource be removed by means reasonable and satisfactory to the Board of Land and Natural Resources.

Hawaii has an Environmental Quality Commission and enacted an Environmental Policy Act which in many cases requires an environmental impact statement which is viewed by the public. The governor or mayor of the county has final approval as to the environmental acceptability of any proposed action.

5.2.6 Idaho

There have been 19 geothermal wells drilled in Idaho as of December 1980. They have no particular state noise statutes or regulations.

Sections 42-4001-4015 of the Idaho Code, Drilling for Geothermal Resources Rules and Regulations and Minimum Construction Standards confer upon the Department of Water Resources the authority to regulate the drilling, operation, and maintenance of all geothermal wells in the state.

Idaho does not have any environmental impact requirements.

5.2.7 Louisiana

There have been some exploratory wells drilled in Louisiana for geopressed-geothermal development. They do not have any state noise regulations or statutes.

Louisiana's Act No. 735 of 1975, Louisiana Geothermal and Geopressed Energy Research and Development Act, gave the State Department of Conservation full regulatory authority over all geothermal exploration, drilling, devel-

GEOTHERMAL NOISE

opment, and production.

Louisiana has no environmental impact requirements.

5.2.8 Montana

While Montana does not have any geothermal wells, their Department of Health and Environmental Sciences is the agency for administering noise controls. At this time there are no state statutes or regulations.

Montana Geothermal Rules and Regulations apply only to leases on state lands. These regulations are administered by the Department of State Lands and noise pollution is covered under the regulations.

The State Department of Health and Environmental Sciences Regulation's 16-2.2(2)-P2000 through P2080 implement Chapter 65, Title 69, of the Montana Environmental Policy Act. Montana requires environmental impact statements.

5.2.9 Nevada

As of December 1980, there have been 49 wells drilled in Nevada. The Department of Human Resources administers noise control regulations but there are no regulations yet.

Sections 2 - 5, Title 48 of Nevada Revised Statutes, authorizes the State Engineer to adopt regulations to insure the proper development, control, and conservation of the state's geothermal resources.

Nevada has no environmental impact guidelines.

5.2.10 New Mexico

As of December 1980 there have been 13 geothermal wells drilled in New Mexico. The Environmental Improvement Board is the state agency that is concerned with noise however there are no noise specific state statutes or regulations.

New Mexico Rules and Regulations, Geothermal Resources, adopted pursuant to Chapter 75, Laws of 1973 are not very definitive in terms of environmental requirements. Noise abatement equipment, approved by the Oil Conservation Commission is required during drilling or production of

GEOHERMAL NOISE

wells within 1500 feet of a residence, school, or church.

New Mexico has no environmental impact guidelines.

5.2.11 Oregon

There have been 13 wells drilled in Oregon as of December 1980. They have specific state noise regulations. Noise Control Regulations (Chapter 340, Oregon Administrative Rules Compilation) states that industrial noise sources are limited to the following A-weighted sound pressure levels:

Allowable Statistical Noise Levels in Any One Hour

	7 AM - 10 PM	10 PM - 7 AM
L(50)	55 dBA	50 dBA
L(10)	60 dBA	55 dBA
L(1)	75 dBA	60 dBA

In addition the level cannot increase the ambient statistical noise levels (before the advent of the new source) L(10) and L(50) in any one hour by more than 10 dBA. If a "quiet area" is established the levels become:

	7 AM - 10 PM	10 PM - 7 AM
L(50)	50 dBA	45 dBA
L(10)	55 dBA	50 dBA
L(1)	60 dBA	55 dBA

Impulse sounds exceeding 100 dB during the hours of 7 AM to 10 PM and 80 dB during the hours of 10 PM to 7 AM are prohibited. The following octave band sound pressure levels are also considered to be maximum values:

Octave Band Center	7 AM - 10 PM	10 PM - 7 AM
31.5 Hz	68	65
63 Hz	65	62
125 Hz	61	56
250 Hz	55	50
500 Hz	52	46
1000 Hz	49	43
2000 Hz	46	40
4000 Hz	43	37
8000 Hz	40	34

(Construction sites are exempt from these regulations)

In addition to the state noise specific regulations the Oregon Geothermal Regulations, Oregon Administrative Code - Chapter 632, Sections 20-005-20-170, administered by the State Department of Geology and Mineral Industries, requires lessees to use all reasonable means at their dis-

GEOTHERMAL NOISE

posal to prevent any environmental pollution.

Oregon has no environmental impact legislation.

5.2.12 Texas

Geopressured-geothermal wells have been drilled in Texas but Texas does not have any state noise regulations.

Texas has complicated sets of geothermal regulations which interact with each other. The Geothermal Resources Act vests regulatory powers in the State Railroad Commission and leasing powers in the General Land Office. The Commissioner of the General Land Office is requested to incorporate in its leases the Railroad Commission's Conservation Rules for "protection of correlative rights". The General Land Office Rules and Regulations include geothermal development activities indirectly.

Texas' Interagency Council on Natural Resources and the Environment published the Texas Policy on the Environment and thus does consider environmental impact.

5.2.13 Utah

There are 22 geothermal wells which have been drilled in Utah as of December 1980. The state has no noise specific statutes or regulations.

Rule 30 of the Rules and Regulations Governing the Issuance of Mineral Lease provides for geothermal leases which are issued by the Division of Lands, Department of Natural Resources on lands where the state owns both the mineral and surface rights. Written into the lease is the requirement to control noise.

Every state agency is required to issue an environmental impact statement for every state action that it proposes. The statement is reviewed by two agencies and is finally approved or rejected by the governor.

5.2.14 Washington

Washington has no geothermal wells. The Noise Control Act of 1974 provides Maximum Environmental Noise Levels, Chapter 173-60 WAC which establish "environmental designations for noise abatement" (EDNA). Three classes of property are established - A, for human habitation; B, for property requiring protection against noise interference

GEOHERMAL NOISE

with speech; and C, for warehouse, industrial use etc. The following A-weighted sound pressure levels are established:

Source	Receiver		
	A	B	C
	---	---	---
A	55	57	60
B	57	60	65
C	60	65	70
Between 10 PM and 7 AM			
A	45		
B	47		
C	50		

These levels may be exceeded by 5 dBA for 15 minutes in any one hour, 10 dBA for 5 minutes in any one hour, or 15 dBA for 1.5 minutes in any one hour. Construction sounds are exempt except in class A between 10 PM and 7 AM. However enforcement is undertaken only on the complaint of an affected person and the state encourages noise control at the local level.

The Department of Natural Resources administers the Geothermal Resource Act to provide a nearly pollution-free development of the state's geothermal resources. The Act preempts local regulation of the drilling and operation of geothermal wells.

Washington requires environmental impact statements under the Environmental Policy Act of 1971.

5.2.15 Wyoming

Wyoming has no geothermal wells or noise specific state regulations or statutes.

Wyoming's Rules and Regulations Governing the Issuance of Geothermal Resource Permits and Leases is administered by the State Board of Land Commissioners. Permit and lease applications require that all drilling and production operations be conducted in such a manner as to eliminate "as far as practical" noise.

Wyoming does not have an environmental impact reporting procedure for geothermal resource development.

5.3 County and Community Standards

Nine of the fifteen western states with known geo-

GEO THERMAL NOISE

thermal resource areas have geothermal or geopressed-geothermal wells. These wells are distributed among 41 counties. The following counties among those 41 have indicated that they do not have any noise ordinances nor any other local applicable ordinances for geothermal operations:

California	- Lassen County
Hawaii	- Hawaii County
Idaho	- Ada, Caribou, Cassia, Franklin, Fremont, Madison, Owyhee, Washington Counties
Louisiana	- Cameron, Calcasieu Parishes
Nevada	- Churchill, Elko, Eureka, Lander, Lyon, Nye, Washoe, White Pine Counties
New Mexico	- Dona Ana, Sandoval Counties
Oregon	- Clackamas, Crook, Hood River, Klamath, Mathew Counties
Texas	- Brazoria County
Utah	- Beaver, Iron, Millard Counties

The following Sections summarize by county specific noise regulations which could affect geothermal development.

5.3.1 Deschutes County, Oregon

Ordinance No. 203.11, An Ordinance for the Control of Noise, requires certain types of equipment not to disturb the sleep, peace, quiet, comfort, or repose of persons more than 30 feet away. In addition, persons can not make noise which disturbs, injures, or endangers the comfort, repose, health, peace or safety of others within the legal boundaries of Deschutes County. Variances can be granted by the Board of County Commissioners.

5.3.2 El Paso City, County of El Paso, Texas

Article XI of Chapter 12 of the El Paso City Code limits the sound pressure levels to the following values:

Use	10 PM - 7 AM	7 AM - 10 PM
Residential	50 dBA	55 dBA
Commercial	60 dBA	65 dBA
Industrial	65 dBA	70 dBA

GEOTHERMAL NOISE

5.3.3 Imperial County, California

Imperial County does not have a noise ordinance but does have an elaborate application procedure and a Noise Element in its General Plan (which does not address itself to geothermal operations except in a general way).

5.3.4 Inyo County, California

Ordinance 239, Regulations, Procedures, and Performance Standards for the Development of Geothermal Resources requires that any operator that is developing a geothermal project must limit the continuous generation of wide band noise at the parcel boundary to conform to the Noise Level Curves shown in Fig. 5.1. The Planning Commission directs which curve is applicable.

5.3.5 Lake County, California

Zoning requirements are such that the sound level from geothermal operations shall not exceed 80 dBA at one half mile (and that wells cannot be drilled within one half mile of any ten dwelling units established within a quarter-mile diameter area). This value corresponds to a value of 108 dBA at 100 feet from the well.

A Geothermal Element of the General Plan states that the County should promote use of the best available noise abatement techniques as well as to encourage the development of new technology to further reduce noise impacts.

The Public Health and Safety section of the General Plan states that the Air Pollution Control Officer enforces noise standards in the County.

5.3.6 Lake County, Oregon

The Comprehensive Land Use Plan expresses the County's policy "to maintain or improve the quality of air, water and land resources" and "that Lake County will comply with all applicable State and Federal air, water, land quality, and noise statutes". It also states "that as such time as any excessive noise is identified by the State Department of Environmental Quality . . . , such information will be taken into account in future decisions." Mining and processing of geothermal resources is a conditional use requiring County review and approval, any noise concerns are addressed during the review process. Exploration activities do not require County review.

Figure 5.1 Noise Level Curves, Inyo County, California

GEOTHERMAL NOISE

5.3.7 Mono County, California

Ordinance 79-478, Chapter 12.16, Mono County Code concerning Offences Against Health and Safety states that it is unlawful to create noise which is so annoying, harsh, or prolonged as to be injurious to the health, peace and comfort of any reasonable person of normal sensitivities.

Mono County has a Noise Element in its General Plan which does not now address the problem of geothermal development

5.3.8 Pershing County, Nevada

There are miscellaneous city ordinances which prevent persons from disturbing the peace, causing unnecessary noises in a zone of quiet, or allowing noises to adversely affect the properties in the vicinity or be detrimental to the public health, safety and general welfare.

5.3.9 Salt Lake County, Utah

Ordinance No. 601 - Noise Ordinance states that stationary sources of sound cannot create a ninetieth percentile sound pressure level, L(90), during any 10 minute or more period which exceeds

Use District	9 PM - 7 AM	7 AM - 9 PM
Residential	50 dBA	55 dBA
Commercial-Agricultural	55 dBA	60 dBA
Industrial	75 dBA	80 dBA

L(10) may not be greater than the above values plus 15 dBA. In any location L(10) cannot be greater than 15 dBA above the ambient L(90). Relief from the restrictions may be obtained from the Director of the Salt Lake County Health Department under certain conditions.

5.3.10 Sonoma County, California

Noise mitigation standards are required in Sonoma County. In the geothermal area a maximum of 45 dBA nighttime and 65 dBA daytime noise levels at the boundary of the leasehold is the allowable limit.

GEOTHERMAL NOISE

5.4 Use permits

It is important to realize that at the local level much of the control of noise is contained in the use permits required of developers and operators. For example, in Lake County, California, a requirement of 55 dBA L_{dn} is specified for the community. A developer must agree to allow the Air Pollution Control Officer access to the well site if a violation is suspected. Without correction, the officer could at his or her discretion close down the geothermal operations at that site.

6.0 Compliance with Current Noise Standards

This section of the report will discuss compliance of geothermal operations with environmental and occupational standards to the extent that meaningful implications may be assessed.

6.1 Environmental

It is a difficult task to adequately describe the conditions necessary to insure compliance with the varied environmental noise standards at the three levels of government. Many of those standards depend on an individual's assessment of what comprises an objectionable noise level. Other standards are not specific enough to legally decide if compliance is taking place. In addition, there are many factors which influence the propagation of sound at distances appropriate for geothermal activities. As a result the approach taken here will be to predict in a general manner the noise level associated with a given geothermal activity at a specific distance and leave it to the reader to make comparisons with an appropriate standard.

Generally one may assume as a basis for all calculations a decrease of the sound pressure level of 6 dB per doubling of distance. Added to this value is additional excess attenuation factors (which decrease the sound level). The terrain which may produce shielding of the communities from the sound by intervening hills, trees, and ground cover - all these factors will decrease the sound and are frequency dependent. In addition atmospheric conditions such as humidity, wind and temperature are also influential. Wind and temperature gradients may produce "shadow zones" where no sound can penetrate or, conversely, allow the sound to propagate over much further distances than might be expected. Various models have been suggested which try to take into account some of these factors. This report will indicate the expected decrease in sound pressure level due only to the normal expansion of a spherically symmetrical energy front i.e. the 6 dB attenuation per double distance. Thus Table 6.1 may be used as a first approximation of the level of sound which will be heard at the various distances indicated for each of the geothermal operations specified.

TABLE 6.1

Noise Levels from Geothermal Sources as a Function of Distance (dBA)

NOISE SOURCE	100 ft.	1/8 mi.	1/4 mi.	1/2 mi.	1 mi.	2 mi.	4 mi.
Well Site Drilling Operations							
Site preparation	81	65	59	53	47	41	35
Drilling rig erection	64	48	42	36	30		
Mud drilling	76	60	54	48	42	36	30
Air drilling without steam	78	62	56	50	44	38	32
Air drilling, steam, blooie line	103	87	81	75	69	63	57
Air drilling, steam, blooie line, silencer	92	76	70	64	58	52	46
Air drilling, steam, blooie line, silencer, water	88	72	66	60	54	48	42
Production testing, free venting	111	95	89	83	77	71	65
Production testing with rock muffler	91	75	69	63	57	51	45
Well Site Maintenance							
Bleed lines	72	56	50	44	38	32	
Bleed lines with rock muffler	55	39	33				
Pipe Lines							
Steam passage (acoustic line source)	50	41	39	36	33	30	
Drag valves (emergency only)	86	70	64	58	52	46	40

TABLE 6.1 (cont'd)

Noise Levels from Geothermal Sources as a Function of Distance (dBA)

NOISE SOURCE	100 ft.	1/8 mi.	1/4 mi.	1/2 mi.	1 mi.	2 mi.	4 mi.
Plant Construction							
Ground clearing	78	62	56	50	44	38	32
Excavating	83	67	61	55	49	43	37
Foundation construction	72	56	50	44	38	32	
Building erection	81	65	59	53	47	41	35
Finishing operations	83	67	61	55	49	43	37
Plant Operations							
Turbine building, exterior	66	50	44	38	32		
Steam jet gas ejectors	89	73	67	61	55	49	43
Steam jet gas ejectors with acoustic treatment	65	49	43	37	31		
Cooling tower	78	64	58	52	46	40	34
Transformer	65	49	43	37	31		
Rock muffler, plant tripped, stacking steam	60	44	38	32			

6.2 Occupational

The Department of Labor Occupational Noise Standard as set forth in the Code of Federal Regulations Title 29 in May, 1971 limits the noise exposure to which employees may be subjected in the work place. It was adopted under the Occupational Safety and Health Act (OSHA) and is the same standard as the Department of Labor noise exposure standard first promulgated under the Walsh Healy Public Contracts Act. The law limits permissible exposure in the work place by a combination of level and duration which is set forth in Section 5.1.2 of this report. When employees are subjected to sound levels exceeding those listed then feasible administrative or engineering controls must be exercised to lower the sound exposure at the receptor. Such controls frequently take the form of ear protectors which must be worn by employees in the areas where there are elevated noise levels.

For geothermal drilling operations sound pressure levels in and around the drilling site frequently exceed 90 dBA and are, for the most part, continuous. Assuming an 8 hour work shift and continuous proximity to levels of this magnitude OSHA would require that ear protection or other administrative controls be implemented. Calculations have been carried out using typical source data to determine the distance from each type of source where hearing protection would be required under OSHA standards. Table 6.2 gives the distance between the source and the point at which the noise level, for the time specified, exceeds the acceptable standards. Thus, for example, in site preparation anyone who remains within 35 ft. of a typical noise source such as a crawler tractor for 8 hours a day or closer than 28 ft. for 6 hours a day would be required to wear hearing protection. Where no distances are given, levels are below 90 dBA.

Table 6.2 assumes geometrical spreading only in the calculation of noise levels. At large distances it is likely that other factors such as ground attenuation, topographical shielding, air absorption, and directivity could reduce the distances considerably.

TABLE 6.2

Unacceptable Zones in the Vicinity of Geothermal Operations without Ear Protection (Ft.)

NOISE SOURCE	Hours/Day Of Exposure									
Well Site Drilling Operations	8	6	4	3	2	1 1/2	1	1/2	1/4	
Site preparation	35	28	20	16	11					
Drilling rig erection	8									
Mud drilling	20	16	11							
Air drilling without steam	25	20	14	11						
Air drilling, steam, blooie line	446	354	251	199	141	112	79	44	25	
Air drilling, steam, blooie line, silencer	125	100	71	56	40	32	22	13		
Air drilling, steam, blooie line, silencer, water	79	63	45	35	25	20	14			
Production testing, free venting	1122	891	630	501	354	281	199	112	63	
Production testing with rock muffler	141	89	63	50	35	28	20	11		
Well Site Maintenance										
Bleed lines	13	10								
Bleed lines with rock muffler										
Pipe Lines										
Steam passage (acoustic line source)										
Drag valves (emergency only)	63	20	14	11						

TABLE 6.2 (cont'd)

Unacceptable Zones in the Vicinity of Geothermal Operations without Ear Protection (Ft.)

NOISE SOURCE	Hours/Day Of Exposure									
Plant Construction	8	6	4	3	2	1 1/2	1	1/2	1/4	
Ground clearing	25	20	14	11						
Excavating	45	35	25	20	14	11				
Foundation construction	13	10								
Building erection	35	28	20	16	11					
Finishing operations	45	35	25	20	14	11				
Plant Operations										
Turbine building, exterior										
Steam jet gas ejectors	89	70	50	40	28	22	16			
Steam jet gas ejectors with acoustic treatment										
Cooling tower										
Transformer	89	70	50	40	28	22	16			
Rock muffler, plant tripped, stacking steam										

7.0 Control of Geothermal Noise

It should be acknowledged at the outset that with current technology all noise created by geothermal operations can be adequately controlled if the desire and the money is available to do so with the possible exception of free venting noise occurring during valve changes. Drilling operations occasionally take place near residential neighborhoods and as the availability of energy decreases and the cost increases, pressure for energy development at the site of the energy resource irrespective of the surrounding land uses will also increase. It will become increasingly important for industry to have the necessary noise abatement tools available when they are needed.

7.1 Well Site Preparation, Plant Construction Noise

Construction equipment, in spite of the variety of types and sizes, can be divided into two basic categories -equipment powered by internal combustion engines and impact equipment. The first category can be further subdivided into earth moving equipment, materials handling equipment, and stationary equipment. Figure 3.18 summarizes the range of noise levels generated by typical construction equipment.

Most noise generated by equipment in the first category is created by the engine itself with exhaust noise predominating and inlet noise, mechanical or hydraulic systems, and cooling fans, secondary. The easiest means of quieting equipment powered by internal combustion engines are to use adequate exhaust mufflers, intake silencers and engine enclosures. One cannot overstress the importance of maintaining the integrity of the noise abatement systems. Development of electric motors to replace reciprocating engines would be a long term but most effective solution.

For the second category, impact equipment, little can be done to quiet the operations other than that which was mentioned for the first category and to shield the operations from the surroundings. It is sometimes possible to substitute a different form of the same equipment for a particular purpose than that currently in use. For example the sonic pile driver has been a successful substitute for the conventional impact type. The sonic piledriver creates practically no noise whatsoever.

GEOTHERMAL NOISE

7.2 Drilling Noise

The mechanical sources of noise associated with the drilling of geothermal wells may be treated by use of properly designed mufflers and enclosures. These are the normal methods employed in silencing gasoline or diesel powered engines mentioned in Section 7.1. Recently in urban areas such as Los Angeles where oil drilling activities abut residential areas, extraordinary measures have been taken to quiet drilling noise. All electric drill rigs and mud pumps have been used with engines and derrick wrapped in specially designed acoustic materials and plywood. Such measures have led to A-weighted sound pressure levels as low as 67 dBA at 100 ft.

As steam is reached in the drilling process the problem of noise becomes more complex. Given sufficient quantities of water, the large blow-off line separators can be made into effective silencers. There are still significant design differences between types of cyclone separators now in use and attenuations differ by as much as 20 dBA. These separator/silencers are still the best design for blow-off line silencing, since the rock chips must be separated from the flow. Noise from these separators comes primarily from the steam flow.

Some degree of noise control may be achieved by redirecting the sound through the use of barriers and reflectors. There are commercial companies that sell noise barriers which are modular in design and therefore can be assembled and disassembled on the job site. Making use of local topology whenever possible may also be helpful. The use of a high acoustic "prism" surrounding drilling operations could redirect noise in a non-objectionable direction. The use of acoustic prisms in noise abatement practices is an area for future research.

7.3 Venting Noise

Noise levels generated by high velocity gas flows emerging from pipes (jets) is caused primarily by the turbulent mixing that occurs along the boundary between the high-velocity gas jet and the quiescent atmosphere. The acoustic intensity of the noise produced by the jet depends on the eighth power of the velocity and the exit area of the nozzle and has a maximum value in the far field at about 40 degrees from the jet axis.

The attenuation of noise generated by jets is a subject which has received a great deal of attention due to recent research concentration on aircraft noise problems.

GEOHERMAL NOISE

Several approaches are used. Since there is an extremely strong dependence of the noise on the flow velocity, slowing of the jet should be most effective. However due to the very high pressures associated with geothermal wells this can be a tricky process. With high velocity flows in pipes the smallest open area in the pipe system determines the maximum amount of gas which can be transferred through the pipe. The flow velocity will be Mach 1 or the local speed of sound at the smallest area when the ratio of the back pressure to atmospheric pressure is greater than about 2. Downstream from the smallest area the flow can accelerate or decelerate depending on the shape of the pipe, the flow conditions, and a number of other factors. From the pressures which occur in geothermal wells the velocities in the pipes during free venting are undoubtedly supersonic and when a tapered diffuser is used the flow will contain a shock wave across which the velocity is abruptly decreased, probably near the diffuser exit.

In order for a diverging pipe to be effective as a velocity deceiver, a converging-diverging nozzle, specifically designed for the flows and pressures present, must be placed ahead of it. This would allow the increasing area of the pipe to slow the flow velocity and reduce the noise output. The design of such a nozzle is complex and depends on the details of the geometry of the pipe and valves in use on the wells. The nozzle would also be subjected to constant wear which erode the wall surfaces and change its characteristics. Due to instabilities in the flow the precise location of the shock wave is difficult to control and could relocate into the diffuser under certain conditions. The converging-diverging nozzle with a diffuser method of attenuation theoretically holds the greatest promise for noise reduction (about 50 dBA) but has the highest uncertainty.

Since the velocity dependence of the sound level is so strong, other methods have been tried to slow the flow. This can be accomplished by an expansion of the flow, cooling the steam with water (thus shrinking the volume of steam), or by blowing it through a porous medium. The former approach is generally used during drilling while the latter is used after drilling is completed. Expansion type bloopie mufflers have been used with water injection and have been effective.

GEOHERMAL NOISE

Perhaps overlooked by the geothermal industry are the many methods used by airline manufacturers to reduce jet noise from aircraft. Considering the lack of thrust and weight constraints in the geothermal industry these methods might be highly effective. Worth trying might be the following:

- a) use of bypass nozzles where some of the steam is shunted off and made to form an annular low velocity stream around the main jet core.
- b) use of toothed devices around the inside of the lips of the exit nozzles to increase the thickness of the mixing zone and to shift the frequency of the noise higher where acoustic absorption from various causes is greater
- c) use of corrugated nozzles which have the same effect as the tooth devices
- d) use of multiple nozzles of small diameter in order to shift the noise to higher frequencies
- e) use of screens normal to the flow and downstream to slow and breakup the flow
- f) waterspray into the jet stream
- g) use of baffle silencers with one or more of the above

The most recent approach of the geothermal industry to the control of venting noise has been rock mufflers. Portable rock mufflers are reasonably effective for use in testing wells where large volumes of water are not available. Considering the amount and size of the equipment already in use for drilling operations, a portable rock muffler should be a permanent part of that equipment. The rock mufflers have the advantage of ruggedness and are not affected by rocks ejected by the well.

7.4 Plant noise

At the plant site the most dominant source of noise is the cooling tower along with sound radiating out through the side louvers from the fans. Taking into account the size of the cooling towers the most effective means of reducing noise would be to erect sound barrier walls around them. They would have to be at least as high as the cooling towers themselves. Plants in general are no more noisy than other industrial facilities of comparable size.

8.0 Conclusion

The conclusion of this study can be summarized by saying that virtually all noise problems associated with geothermal development including well drilling, testing, power plant construction and operations can be controlled to meet most environmental standards with existing technology. The only source of noise for which current solutions do not exist is the free venting during valve changes and this is a relatively short term operation, a few hours in duration which occurs once every two years for each well. The reason that this hasn't been controlled is that there is no methodology to divert the flow while the valve is being changed since the valve is necessary for any flow diversion. Other than that particular operation virtually all other sources can be controlled given the technological development to date.

Whether or not the sources are being controlled is another matter. This depends to a great extent on the geothermal developer and the particular standard which the developer is asked to meet. It also depends on the cost of meeting the standard. As with most problems in a modern society, even where it is feasible technically to solve the problem, economic considerations and other non-technical factors are often the most important reasons in determining whether or not solutions are implemented.

GEOTHERMAL NOISE

Data Sources

1. Marshall Long/Acoustics, 1629 Stanford St., Santa Monica, Ca. 90404, Telephone: (213)829-4311
2. "Salton Sea Anomaly Master Environmental Impact Report and Magma Power Plant # 3 (49 MW) Environmental Impact Report. Vol. I," WESTEC Services, Inc., 3211 Fifth Ave, San Diego, Ca. 92129, May 1981
3. "Noise from Construction Equipment and Operations, Building Equipment, and Home Appliances," NTID 300.1, U. S. Environmental Protection Agency, Washington D. C. 20460, Dec. 1971
4. Whitescarver, O. D., Union Oil Company of California, 2099 Range Ave., P. O. Box 6854, Santa Rosa, Ca. 95406
5. Fraser-Smith, "The Effect of Drilling a Geothermal Well on the Behavior and Reproduction of Sage Grouse," prepared for Republic Geothermal, Inc., by Enviros, Los Altos Ca.
6. Leitner, P., Data referenced in "Draft EIR - Wildcat Geothermal Prospect." Occidental Geothermal & Republic Geothermal prepared by Gennis and Associates, June 1979
7. Leitner / Ecoview "EIR, Union Oil Company of California - Unit # 17 Development Area," Lake County, Ca., Dec. 1977
8. "Heber Geothermal Demonstration Project EIR," Imperial County Planning Department #170-77. VTN Consolidated, Inc.
9. Salter, C., "Long Ridge Geothermal Leasehold, Final EIR", Environmental Impact Planning Corp., Aug. 1977
10. "Lake County APCD Final EIR, McCulloch Oil Corp. - Cobb Valley Geothermal Leasehold," prepared by Gennis and Associates, May 1976
11. Capuano, L. E., Santa Rosa, Aminoil USA, interoffice memo
12. Buhl, R. F., Tech Memo to Olin Whitescarver, 12 Sep. 1974 from Research Dept., Union Oil Company of California, Brea, Ca., Sep. 1974
13. Bush, R. C., "An Overview Of PG & E's Audible Noise Measurement Program at The Geysers," Geothermal Environmental Seminar - '76, Lake County, Ca. also PG & E, San Francisco, also PG & E, Unit # 17 NOI, 1978
14. Fluid Kinetics Corporation, Ventura Ca.
15. Illengworth, R. R., California Department of Health, Office of Noise Control
16. Ebbeson, H., APCD, quoted in EIR for Ford Flat Geothermal Steam Area, Atlantis Scientific, July 1976. Noise section by Marshall Long/Acoustics
17. Norris, T. R., Wayne, P. E., McDonald, B., "Analysis and Design for Vibration and Noise Control," Aminoil USA, Unit # 13 Blowdown, Santa Rosa, Ca.

GEOHERMAL NOISE

18. Webb, R., PG & E. San Francisco, Ca. "Practical Application of Noise Reduction Techniques," Proceedings 2nd Instrument Society of America, Feb. 1973
19. Smith, W., and Fraser, P. Union Oil Company of California, Geothermal Division

Bibliography

1. Berge, C. W., Lund, J. W., Combs, J., and Anderson, D. N., "Geothermal Resources," Bulletin, American Association Of Petroleum Geologists, 65(10), 1981 pp 2264-2273
2. "Geothermal Energy," Union Oil Company Of California, 1981
3. Muffler, L. J. P., Editor, "Assessment Of Geothermal Resources Of The United States - 1978," U. S. Geological Survey Circular 790, 1979
4. Smith, J. L., Matlick, J. S., "Summary Of 1975 Geothermal Drilling - Western United States, Geothermal Energy 4(6), 1976, pp 28-31
5. Smith, J. L., Isselhardt, C. F., Matlick, J. S., "Summary Of 1976 Geothermal Drilling - Western United States," Geothermal Energy 5(5) 1977, pp 8-17
6. Smith, J. L., Isselhardt, C. F., Matlick, J. S., "Summary Of 1977 Geothermal Drilling - Western United States," Geothermal Energy 6(5) 1978, pp 11-19
7. Smith, J. L., Matlick, J. S., Isselhardt, C. F., "Summary Of 1978 Geothermal Drilling - Western United States," Geothermal Energy 7(5) 1979, pp25-37
8. Smith, J. L., Matlick, J. S., Ehni, W. J., "Summary Of 1979 Geothermal Drilling - Western United States," preprint
9. Ehni, W. J., "Summary Of 1980 Geothermal Drilling - Western United States," preprint
10. Reed, M. J., Campbell, G. E., "Environmental Impact Of Development In The Geysers Geothermal Field, USA," Proceedings - Second United Nations Symposium On The Development And Use Of Geothermal Resources, San Francisco, Ca. Vol. 3, pp 20-29, May 1975
11. Wang, J. S., "Prediction And Control Of Induced Draft Cooling Tower Noise," Noise Control Engineering, 12(2) 1979
12. "Survey Of Environmental Regulations Applying To Geothermal Exploration, Development And Use," EPA-600/7-78-014, Feb. 1978
13. Chapter 33, "Aircraft Noise Sources," Henning E. von Gierke, in Harris: Handbook Of Noise Control," 1957

Acknowledgements

The authors are deeply grateful to the Union Oil Company of California, Union Geothermal Division, for allowing us to make measurements on their site. In particular, the help of Agustin (Al) L. Viesca and Alvin (Sam) S. Timmons cannot be expressed enough. They made themselves available whenever we needed them and many of their suggestions were instrumental in completing this report. Special mention should be made of Sam Timmons who took care of our equipment for two long winter months.

Others who gave us valuable information were David N. Anderson (Geothermal Resources Council), Otto Bixler (Bio-Acoustical Engineering), Robert F. Buhl (Union Oil Company), Ronald C. Bush (Pacific Gas and Electric), Jerry Hutterer (Republic Geothermal), Donald F. Johnson, AIP, Frank Kingery (WESTEC Services), Phillip Leitner (St. Mary's College), Albert E. Theberge (National Oceanic and Atmospheric Administration), and Olin D. Whitescarver (Union Oil Company). We are grateful to them also.