

**HAWAII
ENERGY
RESOURCE
OVERVIEWS**



volume

1

GEO THERMAL

NOISE

JOHN C. BURGESS

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OVERVIEWS OF GEOTHERMAL DEVELOPMENT IN HAWAII

Potential Noise Issues with Geothermal Development in Hawaii

John C. Burgess, Professor of Mechanical Engineering, University of Hawaii

VOLUME 2

The Impact of Geothermal Development on the Geology and Hydrology of the Hawaiian Islands

Carol Feldman, Department of Oceanography and

B. Z. Siegel, Professor Pacific Biomedical Research Center, University of Hawaii

VOLUME 3

The Hawaiina Ecosystem and its Environmental Determinants with Particular Emphasis on Promising areas for Geothermal Development

S. M. Siegel, Chairman and Professor of Botany, University of Hawaii

VOLUME 4

The Impact of Geothermal Resource Development In Hawaii (Including Air and Water Quality)

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The Social and Economic Impacts of Geothermal Development in Hawaii

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Property Rights to Geothermal Resources in Hawaii

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VOLUME 7

The Impact of Geothermal Development on the State of Hawaii — An Executive Summary

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POTENTIAL NOISE ISSUES WITH
GEOTHERMAL DEVELOPMENT IN HAWAII

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SUMMARY

Normal major operations planned for the Hawaii Geothermal Project (HGP-A) at Puna will probably consist of

- venting of geothermal fluids through a "silencer" for 10% of the time
- power generation using a turbogenerator with a steam condenser and cooling towers for 70% of the time
- operation of the cooling towers alone for 20% of the time.

The estimated equivalent simple source sound levels at 50 ft for these major operational modes are 84 dBA, 74 dBA, and 74 dBA respectively.

If well fluids are accidentally vented directly to the atmosphere, the equivalent simple source sound level expected is 125 dBA at 50 ft. All sources are expected to radiate broad band noise. The turbogenerator and its building are expected to radiate, in addition, a noticeable 60 Hz tone.

Normal weather conditions consist of nearly constant northeast trade winds about 9 months of the year. During the other 3 months (winter), clear windless nights occur often. During tradewind weather, normal noise sources are not likely to be audible more than about 2000 ft upwind or more than about 5000 ft downwind. During clear, windless nights, the range of audibility for normal operations is likely to be about 10,000 ft in all directions. In the case of accidental venting directly to the atmosphere, the venting noise may be audible at ranges of seven miles or more from the HGP-A.

During normal operations, residents or prospective residents in areas proximate to the HGP-A can be expected to be annoyed. Within

about 400 ft of the HGP-A, 50% to 100% of prospective residents (there are none now) can be expected to be highly annoyed (i.e., sufficiently annoyed to complain vigorously, threaten legal action, or institute legal action). The expected percentage highly annoyed decreases to about 20% to 50% at 1000 to 2000 ft from the HGP-A. In the range 4000 to 5000 ft, where the nearest existing residences are located, it is likely that about one person in ten will be highly annoyed. In the case of accidental venting directly to the atmosphere, the range at which 1 person in 10 can be expected to be highly annoyed is 3 to 5 miles, depending on weather conditions. At the HGP-A Visitors' Center sound levels from the three normal operations are expected to be distinctly noticeable at 68 dBA, 58 dBA and 58 dBA. In the event of accidental direct venting, the sound level at the Visitors' Center could be an intolerable 108 dBA.

There appear to be no current legal limits to noise emissions from operations of the HGP-A. Hawaii County* has the statutory authority to develop and enforce noise regulations. In the event that the HGP-A proves, as expected, the commercial viability of the Kapoho Geothermal Field, both residents and developers would be protected from the effects of excessive noise if Hawaii County places appropriate noise regulations in effect prior to initiation of design efforts.

The conclusions stated in this report are tentative since they are not supported by an adequate data base. While the development of appropriate noise regulations does not require additional information, reasonably accurate predictions of sound levels, community impact and

* The State of Hawaii has similar, but independent, statutory authority.

community response requires the acquisition of definitive data. These data should include, at least, existing ambient sound levels, sound levels and spectral characteristics of all sound sources, and community attitudes towards noise from geothermal power generation. Sufficient data should be acquired to be statistically significant.

1.0 INTRODUCTION

1.1 HISTORICAL PERSPECTIVE

Hawaii presently depends on imported petroleum products to meet over 90% of its energy needs. Geothermal energy is one of the most promising alternate forms of natural energy available to Hawaii. The Hawaii Geothermal Project (HGP-A) was initiated in 1973 to coordinate the research and development necessary to move geothermal energy in Hawaii from a dream to commercial reality¹.

There are three prime areas for potential geothermal development, all in active volcanic areas on the Island of Hawaii. One of these areas, the east rift zone of Kilauea volcano was selected for initial exploration. The HGP-A well was drilled April 1976. The flow testing showed that the HGP-A well has the potential to develop about 3.5 MW of electrical power (MWe) with a 3-in. diameter orifice.

1.2 PRESENT DEVELOPMENT

Present development plans are limited to the construction and operation of the HGP-A well site. Current plans call for the generation of approximately 3.5 MWe over a two year period. During this time, flow parameters will be measured to evaluate the extent of the underlying geothermal reservoir, sometimes called the Kapoho geothermal field. Plans include selling about 2 MWe to Hawaii Electric Lighting Company (HELCO), operation of a Visitors' Center, and, if funds become available, testing a variety of non-electrical applications of geothermal fluids.

1.3 FUTURE DEVELOPMENT

The pace of future development will depend importantly on the

results of the planned two-year operation of HGP-A. Extensive development in the Puna area is likely if the geothermal field is found to be large enough to warrant the required investment. Private groups appear already to be accumulating geothermal lease rights in the Puna area.

Development is also possible in two other areas of the Island of Hawaii thought to be most promising. These are the southwest rift zone of Kilauea and the southwest rift zone of Mauna Loa². While there are many other areas in the State of Hawaii where local warm spots have been found, serious plans for their development are premature at the time of this report (July 1979).

1.4 SCOPE OF REPORT

This report concerns primarily the environmental noise expected to arise from construction and operation at HGP-A. The report includes a brief discussion of expected noise effects if the geothermal field is developed. Some of this discussion is applicable to noise problems that may arise if other geothermal fields are found and developed, but site-specific discussion of other fields can be formulated only when exact locations are identified.

Time and funding limitations made it impossible to conduct the complete information search necessary to prepare a comprehensive report. There is much information concerning noise at other geothermal fields, especially the Geysers. This report includes only second-hand references to such information. No measurements of ambient sound levels near the HGP-A are available, no reliable and carefully checked sound level measurements from the HGP-A well operation are available, and the making of such measurements was not possible during the pre-

paration of this report. Numerical data in this report concerning sound sources and sound levels thus require experimental verification. Numerous changes in engineering structures and equipment at HGP-A, some significant, have been made, and may continue to occur. Time did not allow for a comprehensive discussion of all changes.

2.0 DESCRIPTION OF HAWAII GEOTHERMAL RESEARCH STATION AND PROXIMATE AREAS (2,3)

2.1 SITE

2.1.1 Location

The site for the HGP-A is a 4.1 acre parcel (approx. 600 x 330 ft) in the Puna district of the Island of Hawaii. It is located approximately 20 miles SSE of Hilo, about halfway (4 miles) between the towns of Pahoa and Pohoiki (seashore), on the northeast side of the Pahoa-Pohoiki Road. The elevation is about 600 ft above sea level.

2.1.2 Topography (See Geology Section of 'Overview' Report)

The surface material of the site, and of much of the surrounding area as well, is rough volcanic material resulting from a lava flow in 1955*. The surface contours are gentle with an average slope of about 150 ft per mile.

2.1.3 Climate (See Environmental Section of 'Overview' Report)

The mean temperatures expected at the site vary from about 69°F (January) to about 74°F (August). Daily temperatures are expected to vary by 8 to 15°F between early morning and late afternoon extremes.

The rainfall at the site is expected to be about 115 in. per year. Humidity is expected to be moderate to high with 8/10 cloud cover about 50% of daylight hours.

The site location is moderately exposed to the normal (9 months of the year) northeast tradewinds, which frequently exceed 12 mph. Variable winds, including a nearly quiescent atmosphere, are probable frequently during the winter season and are possible at other times**.

*See footnote to Sec. 2.1.5

**Personal observation on Hawaiian weather by author.

2.1.4 Biota (See Environmental Section of 'Overview' Report)

Ground cover near the HGP-A site is gypical of that on recent lava flows. It consists primarily of scattered, small ohia saplings less than 4 ft high and some ferns. The mostly blockly lava is covered with a dense growth of lichens.

Animals are expected in the area only as transients or as domesticates. Some birds inhabit the area.

2.1.5 Land Use (See Hawaii Legal Aspects Section of 'Overview' Report)

Land use has been described as follows³: "The area surrounding the project site is predominantly ohia forests of various ages. There are two forest reserves within a few kilometers of the site - Malama Ki and Nanewale. About 2.8 miles west of the site, land is cultivated for sugar. Papaya orchards lie a similar distance east of the site... The nearest prime farmland is close to Pahoa, approximately 3 miles northwest of the site. The University of Hawaii Agricultural Experiment Station is 0.5 miles from the site.

"Directly adjacent to the site (to the south across Pohoiki Rd.), land that was covered by the 1955 lava flow has been subdivided into 1-acre homesites*. The majority of these lots are vacant; there are only about one dozen residences within a 1-mile radius of the site². The nearest occupied residence is 0.7 mile from the site and is located in Leilani Estates. The Nanewale Estates, a subdivision with a number of occupied residences, is about 1.6 miles northwest of the site."

*The Leilani Estates. Figure 7 in Ref. 2 shows the lava flows of 1955 near the Leilani Estates as entirely to the north of the Pohoiki Road, and therefore suggests that the Leilani Estates were not covered by the 1955 lava flow.

There is also an area called "Lanipuna Gardens" immediately east of the HGP-A site, north of the Pohoiki Road. This area appears to be assigned an urban land use by Hawaii County².

2.2 PLANNED COMPONENTS AND STRUCTURES⁴

The major components of the planned power plant consist of

- the well head
- a flash tank to separate steam and liquids
- a steam turbine with condenser and generator
- a power transformer
- a gas ejection system
- cooling towers
- H₂S scrubbers
- piping for well fluids, steam, and liquids².

A separate noise abatement system (humorously called a "silencer") is planned for use when well fluids are not directed to the turbogenerator or to the cooling towers. These components and ancillary structures are planned for construction along the southeast and northeast boundaries of the site.

The major structures for the power plant are

- a turbogenerator building (approx. 78' long x 26' wide x 40' high) with attached control, office, laboratory, and storage rooms
- cooling towers (approx. 50' long x 24' wide x 30' high)
- a Visitors' Center (approx. 76' long x 38' wide x 25' high)
- smaller structures include a wellhead platform, a steam treatment tower, and an H₂S abatement system.

The Visitors' Center is planned for construction along the west end of the site, adjacent to the Pahoa-Pohoiki Road.

2.3 PLANNED OPERATING PROCEDURES

2.3.1 Flow Testing

Engineers in charge of HGP-A construction and operations state that flow testing will be accomplished only when wellhead liquids are exhausted to the atmosphere through a "silencer" and steam-liquid separator stacks. The engineers do not intend to exhaust wellhead fluids directly to the atmosphere.

2.3.2 Power Generation

During power generation, plans call for all steam to be condensed and only liquids to be exhausted to the atmosphere (via pumps and cooling towers).

2.3.3 Turbogenerator Outages

Should it be necessary to shut down the turbogenerator, plans call for wellhead liquids to be diverted to the "silencer"-separator stacks. If the turbogenerator downtime is expected to exceed two days, plans call for the well to be shut down. The two-day time period appears to be set by the limited capability of off-line H₂S scrubbers.

3.0 MAJOR NOISE SOURCES

3.1 DIRECT VENTING

Direct venting of geothermal fluids or steam to the atmosphere results in the most serious noise source expected at HGP-A. No measurements of sound pressure level (SPL) appear to have been made during direct venting of the current well. Measurements made during direct venting of similar wells at the Geysers field has shown SPL's as high as 125 decibels A-weighted (dBA) at 50 feet⁵.

3.2 VENTING VIA "SILENCER"⁶

To reduce the SPL resulting from direct venting, test engineers installed a device called a "silencer/separator". Measurements made during flashing with the "silencer/separator" installed showed the SPL to be about 96 dBA at 50 feet when a 3-inch diameter orifice was used. By modifying somewhat the "silencer/separator", the SPL was reduced by about 5 dB, to about 91 dBA at 50 feet. The SPL was further reduced by approximately another 7 dB, to about 84 dBA at 50 feet, by reducing the orifice size (and hence the flow rate) from 3 inches in diameter to 1-3/4 inch*.

In the case of an accident, such as well blowout or pipe rupture, the free venting well fluids should be expected to create an SPL of about 125 dBA at 50 ft⁵. Because the HGP-A site is an active earthquake zone, accidental structural failures are possible at any time.

*The data were reported ⁶ without comment concerning instrumentation or measurement procedures. The values given here are averages of the data reported reduced to 50 feet by the inverse square law. Evaluation of the reported data suggest that the averages may be accurate within + 5 dBA.

3.3 TURBOGENERATOR AND TURBOGENERATOR BUILDING

The turbogenerator can be expected to be noise^{5,7}. An SPL in the range of 65 to 85 dBA should be expected inside the turbogenerator building*. The noise from the turbogenerator will probably include a prominent pure tone at about 60 Hz.⁸

The planned turbogenerator building is a large structure (see Sec. 2.2)⁴. It has a corrugated metal roof, corrugated metal siding, and large openings to the outside atmosphere not only along its sides, but at the very top of the 40-ft high structure as well. The hard interior surfaces can be expected to allow noise emitted by the turbogenerator to build up. Some of this noise will escape via the openings. The high interior sound levels, particularly those at low frequencies, can be expected to cause the metal roof and siding to vibrate, thereby making them efficient sound generators. Unless architectural changes are made to reduce sound buildup in the building and vibration of the building surfaces, the turbogenerator and its building could become a major source of noise at HGP-A. The plans suggest that the architects are aware that a noise problem exists, since acoustic insulation (for transmitted sound, not reflected sound) is specified for the office which adjoins the turbogenerator room.

A secondary source of noise results from the design which incorporates undamped sheet metal for the roof of the turbogenerator building. Sound levels created by heavy rainfall can be sufficiently

*No direct information was obtainable at the time this report was prepared. The estimate is based on a reported⁷ noise level of 93 dBA near a 100 MW steam turbine. After this report was prepared, a recent reference³⁹ was found which suggests that a 3.5 MW steam turbogenerator may have an equivalent SPL as low as 53 dBA at 50 ft. A 22 dB SPL buildup due to reverberation effects in the turbogenerator building would place the resulting SPL at about 75 dBA inside the building.

high to stop conversations in and near the building.

With the present design⁴ equivalent* exterior sound levels can be expected in the range of 60 to 80 dBA at 50 ft, with a pronounced tone at 60 Hz.

3.4 COOLING TOWERS

Cooling towers are known to be major operational noise sources at geothermal power generating units^{3,5}. Typical cooling towers are reported to create a sound level of about 80 dBA at 10 ft⁹. Since the cooling towers are large sources, the inverse square law cannot be applied directly to the reported sound level. However, the reported value can be used to estimate the field sound pressure levels¹⁰. This turns out to be equivalent** to about 75 dBA at 50 ft. This noise is reported to be primarily "high-frequency 'white' noise"⁹.

3.5 PIPING FOR WELL FLUIDS, STEAM, AND LIQUIDS

Fluid flow in piping is known to represent a significant possible source of noise^{11,12}. Where the pipes are only a few inches in diameter, little noise is likely to be radiated directly from the pipe walls. The pipe walls act, however, as excellent acoustic transmission lines. If the pipes are attached solidly to larger surfaces, these surfaces can become important radiators of sound. The specific sources of noise are turbulence and (in liquids) cavitation in the flowing fluid where flow changes take place. Such noise is highly sensitive to flow velocity. The well fluids, being a mixture of steam and liquid,

*The turbogenerator building is an extended source, and the inverse square law does not apply until one is more than about 300 ft from the building. The SPL range given here is intended to represent an equivalent simple source, thus allowing use of the inverse square law for estimation at larger distances.

**Equivalent simple source, see last footnote re: turbogenerator building. The author does not regard this as a dependable estimate.

can be expected to provide a third source of noise as liquid particles impact piping components at valves and pipe walls whenever there is change in flow direction. Current construction plans ⁴ show that a small portion of the piping system will be underground and enclosed in an "acoustic valve box". The plans also show that some pipes above ground will be wrapped with insulation. The effects of these treatments on fluidborne and structureborne sound to radiating surfaces is not clear at the time of writing this report.

No estimate can be made at this time about the sound levels to be expected from noise generated as a result of fluids flowing in pipe lines.

3.6 OTHER OPERATING NOISE SOURCES

It is possible that the flash tank, gas ejection system, H₂S scrubbers, and other components may emit noise. An early plan of the HGP-A shows an air compressor¹³. Air compressors are well known as noise sources. The air conditioning equipment for the office area of the turbogenerator building may be a minor source of noise. No estimate can be made at this time about the sound levels to be expected from other operating noise sources.

3.7 CONSTRUCTION NOISE SOURCES

Some heavy materials-moving equipment will be necessary during site preparation and construction. Construction specifications appear to include attempts to control noise emissions. Numerical performance specifications on noise emissions are absent, however, and the specifications refer to state noise regulations that have no effect on the Island of Hawaii.* Use of noise controls appears to be at the option of the Construction Manager.

Fabrication of metal components (including roof and siding for the turbogenerator building) and materials handling can be expected to result in sporadic high impact sound levels.

Noise levels created by diesel-powered equipment can be expected to be about 90 dBA at 50 ft from each source¹⁵. If pneumatic impact tools are used in fabricating metal structures, the sound levels at 50 ft from each source can be expected to vary from 70 to 90 dBA depending on the sound radiation characteristics of the structure being fabricated. It is likely, but not certain, that most construction activity will take place during daylight hours.

3.8 NON-HGP-A NOISE SOURCES

Buses catering to Hawaii's tourist industry use the Pahoa-Pohoiki Road frequently during the daytime. These buses are distinctly audible as they use lower gears in climbing from the seashore (Pohoiki) toward Pahoa. The sound levels emitted by these buses is probably about 80 dBA at 50 ft. There are no other significant noise sources at or near the HGP-A site.

3.9 AMBIENT NOISE LEVEL

The ambient noise level is the level resulting from all those activities that are indigenous or customary in an area. At the HGP-A site, buses (Sec. 3.8) might be considered part of the ambient. Since the primary concern of this report is with the environmental effects at locations that may be remote from traffic, the buses are treated here as intruding noise sources.

*See Sec. 5.3.2

There appears to be very little human or animal life currently resident within several miles of the geothermal site. The prevailing current ambient sound level is, therefore, set primarily by birds, insects, wind, and rain.

No measurements of ambient sound levels near the HGP-A appear to have been made¹⁶. One estimate is that the ambient sound level is probably less than 45 dBA¹⁶. In the absence of bird and insect sounds, the ambient level will depend on wind and rain. Because the ground cover is low and sparse, the sound level from wind effects of moderate tradewinds on foliage and land forms probably is in the range 35 to 45 dBA. The sound level from moderate rain impacting on rock and sparse foliage is probably in the same range. During times of very light winds and rain the ambient sound level is probably about 20 to 25 dBA^{17,18}. Bird and insect sounds could, if present, cause higher ambient sound levels.

4.0 EXPECTED NOISE ENVIRONMENT

4.1 AT THE HAWAII GEOTHERMAL PROJECT (HGP-A), PUNA DISTRICT

On the basis of presently known construction and operating plans, the noise environment of the HGP-A could be unpleasant. The known major noise sources ("silencer" venting, turbogenerator operation, and cooling tower operation) can all be expected to contribute to this environment.

Normal operation calls for venting steam to the atmosphere only via the "silencer" and only when both the turbine and the H₂S abatement system are off line¹⁹. Such "venting should last less than one day until the well can be partially shut in"¹⁹.

The H₂S abatement system currently planned requires use of the cooling system (towers). Operating experience at the Geysers²⁰, suggests that cooling system downtime resulting from using the planned H₂S abatement system should be about 10%, or about 72 hrs per month. During such downtimes, the U.S. Dept. of Energy states ²⁰ that "the HGP-A well flow must be maintained at a significant level to avoid unstable well operation and thermal stresses in the wellborne." It appears reasonable to expect, then, about three days per month of "silencer" operation. Thus, there will be, on average, a source of broadband noise of 84 ± 5 dBA at 50 ft for three days each month.

In another mode of operation, the turbogenerator is off line, and the steam is exhausted directly via the cooling towers. Operating experience at the Geysers²⁰ suggests that turbogenerator downtime at HGP-A will be in the range 13% to 24%, or, on average, between 95 and 170 hrs per month. During this time, cooling water flow will increase about 24%²⁰. The cooling towers during this time will probably create about 75 dBA at 50 ft.

In the normal mode of operation, both the turbogenerator and the cooling towers will create sound. The sound level from the cooling towers will be about 75 dBA at 50 ft while that from the turbogenerator and its building will be between 60 and 80 dBA at 50 ft with a pronounced 60 Hz tone.

During all of the above, some contributions can be expected from other sources of noise. Their effects cannot be evaluated without more information.

The major noise sources will be clearly evident at the Visitors' Center, and they will provide an impressive demonstration of the noise-producing capability of geothermal power generation. The planned Visitors' Center is basically a covered, open-air structure.⁴ It is located about 320 ft from the "silencer", about 360 ft from the turbogenerator building, and about 340 ft from the cooling towers. There are no intervening large structures. The foregoing three operating methods (other than well shut-down or accidental free venting) can be expected to create sound levels in the Visitors' Center of about 68 dBA about 10% of the time from venting well fluids via the "silencer" during cooling tower downtime, about 58 dBA with an audible Hz tone about 70% of the time from turbogenerator plus cooling tower operation, and about 58 dBA about 20% of the time from cooling tower operation during turbogenerator downtime. All sounds are steady (i.e., not time-varying).

4.2 SOUND PROPAGATION IN THE ATMOSPHERE

It is well known that sounds in the atmosphere are attenuated with increasing distance from a sound source. Although a great many site specific measurements of sound attenuation have been made, it is

possible only to make approximate advance estimates of attenuation for any site. Attenuation depends not only on distance, but also on frequency, relative humidity, temperature and wind, as well as on temperature gradients, wind gradients, and turbulence in the atmosphere. Attenuation also varies with the source height, receiver height, topography, the porosity of the ground between source and receiver, and to a minor extent, on vegetation. When distances are large (1000 ft or more), temporal variations in wind and temperature (turbulence) in the atmosphere can cause noticeable fluctuations in sound level.

At distances greater than about 300 ft, each of the noise sources on HGP-A can be regarded as a point source. In a quiet, perfect atmosphere, the normal attenuation expected is 6 decibels per doubling of distance (6 dB/dd) from the acoustic center of the source (spherical spreading rule). Measurements have shown that the attenuation actually experienced is greater than 6 dB/dd. Such additional attenuation is called "excess" attenuation. For practical purposes in estimating normal excess attenuation, standardized attenuation curves can be used for daytime^{*21}. Approximate values for daytime attenuation are given in Table I.

Table I. APPROXIMATE DAYTIME EXCESS ATTENUATION IN A QUIET REAL ATMOSPHERE AT 70°F AND 70% RELATIVE HUMIDITY²¹

Frequency, f (Hz)	Excess Attenuation, A_e (dB/1000 ft)
500	0.8
1000	1.7
2000	3.3
4000	6.6
8000	13.2

*A new American National Standard (Proposed ANSI Standard S1.26) on calculation of sound absorption in the atmosphere has been in preparation²³. This standard may provide values preferable to those used in this report.

Regression analysis shows the values in Table I can be represented to good accuracy by the equation

$$A_e = 1.59 \times 10^{-3} f^{1.005} \text{ dB/1000 ft.} \quad (4.1)$$

During the nighttime, especially on still nights, there is less turbulence in the air, and there is less attenuation at large distances. A reasonable estimate of attenuation at 70°F and 70% relative humidity under such conditions can be obtained by using ²²

$$A_e = 3.22 \times 10^{-7} f^2 \text{ dB/1000 ft.} \quad (4.2)$$

Wind and temperature gradients in the atmosphere act to bend the sound rays emanating from a source. With the normal decrease in temperature with increase in elevation, sound rays are bent upwards. The result in a quiescent atmosphere is that excess attenuation increases dramatically (28 dB or more)²⁴ beyond the region of grazing incidence, in the acoustic shadow zone. When there is a wind, friction with the earth's surface creates a wind gradient in which wind velocities increase up to about 500 ft above the surface. Sound rays propagated upwind are bent upwards; those propagated downwind are bent downwards. The result is that the shadow zone created by a temperature gradient (when one exists) is modified. The upwind shadow zone is moved closer to the source; the downwind shadow zone may be removed entirely²⁵.

The region of grazing incidence is, of course, influenced by the height of the source. Source heights at the HGP-A can be estimated as 10 to 50 ft for direct venting from the "silencer" (with the low frequency portion of the source at the greater height), about 40 ft for the turbogeneration building roof-level openings and 0 to 30 ft for the cooling towers. It thus appears that there will be a range of areas of grazing incidence that depend on the mode of plant operation.

For a source height of 10-15 ft, a receiver height of 5 ft, and a 10-15 mph wind during an overcast day, the grazing area is about 400 ft upwind of the source. For source height of 30 to 40 ft, the grazing area is probably about 800 ft upwind of the source. There is no shadow zone in the downwind direction.

On cool, clear nights, which are often experienced during the winter in Hawaii, there is a temperature inversion near the ground. This inversion acts to bend sound rays downwards. With the light winds (0-4 mph) characteristic of such times, there will be no shadow zone in any direction along reasonably flat terrain.

The porosity of the ground surface is known to have an effect on attenuation. The effect is dependent on source height, receiver height, source receiver distance, and frequency. At the HGP-A, source heights are variable and the sound is broad-band. Thus ground porosity should have little noticeable effect on attenuation.

The foregoing discussion is summarized in Table II. The values given are approximate, and site specific measurements are warranted to validate or improve them.

4.3 SOURCE NOISE CHARACTERISTICS

To predict a-weighted sound levels in the area proximate to HGP-A, it is necessary to know the spectral distribution of sound energy for the sources. While some data have been obtained at similar plants^{8,9,27}, little of it was directly available to the author at the time this report was prepared. For lack of better information, the sound spectra for all these major sound sources can be taken as white over the audible frequency range* with a low frequency (60 Hz) tone added from turbo-

*Taken here as the frequency range of the preferred series of octave bands with center frequencies from 63 to 8000 Hz.

generator operation and having SPL (unweighted) about the same as the overall A-weighted turbogenerator SPL⁸. Adequate prediction also requires better information about spectral intensities than was available. The source sound levels used in this report are those described earlier (Sec. 4.1) with the added spectral assumptions described above. For the purpose of this report, sounds as 250 Hz or less are assumed to propagate with negligible excess attenuation except in shadow zones.

Table II. TOTAL EXPECTED ATTENUATION RELATIVE TO SPL AT
50 FT FROM SOURCE; SOURCE HEIGHT 30 TO 40 FT;
RECEIVER HEIGHT 5 FT; TEMP $70 \pm 5^{\circ}\text{F}$ APPROX.,
RELATIVE HUMIDITY $70 \pm 20\%$ APPROX.

Distance (ft)	Frequency (Hz)	Daytime, Upwind* (dB)	Daytime, Downwind** (dB)	Nights*** (dB)
500	63	20	20	20
	125	20	20	20
	250	20	20	20
	500	20	20	20
	1,000	21	21	20
	2,000	22	22	21
	4,000	23	23	23
	8,000	27	27	30
1,000	63	36	26	26
	125	36	26	26
	250	36	26	26
	500	37	27	26
	1,000	38	28	26
	2,000	39	29	27
	4,000	43	33	31
	8,000	49	39	47
2,000	63	60	32	32
	125	60	32	32
	250	61	33	32
	500	62	34	32
	1,000	63	35	33
	2,000	67	39	35
	4,000	73	45	42
	8,000	87	59	73
4,000	63	66	38	38
	125	67	39	38
	250	68	40	38
	500	69	41	38
	1,000	73	45	39
	2,000	79	51	43
	4,000	83	65	59
	8,000	119	91	121
8,000	63	73	45	44
	125	74	46	44
	250	75	47	44
	500	79	51	45
	1,000	85	57	47
	2,000	99	71	54
	4,000	125	97	85
	8,000	179	151	209

16,000	63	80	52	50
	125	81	53	50
	250	85	57	50
	500	91	63	51
	1,000	104	76	55
	2,000	131	103	71
	4,000	184	156	133
	8,000	291	263	380

*Overcast, winds 10-15 mph; spherical spreading plus A_e per Eq. 4.1 plus shadow zone effects

**Overcast, winds 10-15 mph; spherical spreading plus A_e per Eq. 4.1

***Clear, winds 0-4 mph; spherical spreading plus A_e per Eq. 4.2

4.4 NOISE PREDICTIONS FOR AREAS PROXIMATE TO HGP-A

Once source noise spectra in octave bands are known, we can use the attenuation values in Table II to estimate the A-weighted SPL at various distances from HGP-A. We first calculate correction factors (Table III) to apply to A-weighted SPL's at 50 ft.* The procedure follows that described by Peterson and Gross²⁸.

Table III. CORRECTION FACTORS TO BE SUBTRACTED FROM A-WEIGHTED SOUND PRESSURE LEVELS AT 50 FT (EQUIVALENT) DISTANCE FROM NOISE SOURCES HAVING A WHITE SPECTRUM

Distance (ft)	Daytime, Upwind* (dB)	Daytime, Downwind* (dB)	Nights (dB)
50	0	0	0
500	24	24	24
1,000	42	32	31
2,000	70	42	39
4,000	81	53	47
8,000	93	65	56
16,000	106	78	64

*See footnotes to Table II.

Using the estimated source SPL's (Sec. 4.1), with the assumption that all sources have white spectra, we can now estimate the A-weighted

*Note that the correction factors calculated here apply only to white source spectra. Their application to sounds having source spectra other than white can result in significant error.

SPL at various distances from HGP-A (Table IV).

Table IV. A-WEIGHTED COMMUNITY NOISE LEVELS, L_A , EXPECTED DURING VENTING VIA "SILENCER".* TOLERANCE IS ESTIMATED AS APPROXIMATELY ± 5 dB.

Distance (ft)	Daytime, Upwind** (dB)	Daytime, Downwind** (dB)	Nights** (dB)
50	84	84	84
500	60	60	60
1,000	42	52	53
2,000	14	42	45
4,000	-	31	37
8,000	-	19	28
16,000	-	-	20

*Increase all levels by about 40 dB for free venting; white source spectrum assumed

**See footnotes Table II.

Table V. A-WEIGHTED COMMUNITY NOISE LEVELS, L_A , EXPECTED DURING TURBOGENERATOR OPERATION OR COOLING TOWER ONLY OPERATION*. TOLERANCE IS ESTIMATED AS APPROXIMATELY ± 10 dB.

Distance (ft)	Daytime, Upwind** (dB)	Daytime, Downwind** (dB)	Nights** (dB)
50	75	75	75
500	51	51	51
1,000	33	43	44
2,000	-	33	36
4,000	-	22	28
8,000	-	-	19
16,000	-	-	-

*White source spectrum assumed

**See footnotes Table II.

Although the A-weighted SPL (L_A) is a good descriptor for steady community noise, it has some drawbacks when used to describe time-varying noise. Accordingly, the U.S. Environmental Protection Agency (EPA) has introduced the concept of day-night sound level (L_{dn}) in its "levels" document²⁹. For the steady noises typical of HGP-A operation,

L_{dn} is 6.4 dB greater than L_A . For completeness, the expected L_{dn} values are given in Tables VI and VII.

Table VI. DAY-NIGHT SOUND LEVELS, L_{dn} , EXPECTED DURING VENTING VIA "SILENCER".* TOLERANCE IS ESTIMATED AS ± 5 dB.

Distance (ft)	Daytime, Upwind** (dB)	Daytime, Downwind** (dB)	Nights** (dB)
50	90	90	90
500	66	66	66
1,000	48	58	59
2,000	20	48	51
4,000	-	37	43
8,000	-	25	34
16,000	-	-	26

*Increase all levels by 40 dB for free venting; white source spectrum assumed

**See footnotes Table II.

Table VII. DAY-NIGHT SOUND LEVELS, L_{dn} , EXPECTED DURING TURBO-GENERATOR OPERATION OR COOLING TOWER ONLY OPERATION.* TOLERANCE IS ESTIMATED AS APPROXIMATELY ± 10 dB.

Distance (ft)	Daytime, Upwind** (dB)	Daytime, Downwind** (dB)	Nights** (dB)
50	81	81	81
500	57	57	57
1,000	39	49	50
2,000	-	39	42
4,000	-	28	34
8,000	-	-	25
16,000	-	-	-

*White source spectra assumed

**See footnotes Table II.

5.0 CRITERIA FOR COMMUNITY NOISE LEVELS

5.1 EFFECTS OF NOISE ON PEOPLE

There are three sound level related effects of noise on people most important to operation of HGP-A: damage to hearing, speech interference, and sleep interference³⁰. There is a risk of damage to hearing when L_A exceeds about 75 dB. Speech interference depends not only upon the ambient sound level, but on the distance between speaker and listener and the vocal effort of the speaker. Normal communication becomes difficult at distances greater than 20 ft in ambient sound levels greater than 50 dBA³¹. There is some evidence that noise levels greater than about 30 dBA result in sleep modification³². All noise levels just stated are those at the ears of the listener.

Very important to operation of HGP-A may be the psychological effects of noise. An audible noise reminds a listener of the presence of the noise source. If that source is acceptable or desirable to the listener, the noise has a reassuring effect. If the noise recalls to the listener fears related to the source, it can trigger a negative response. Miller³⁰ presents a good description of psychological response to noise.

5.2 EXPECTED RESPONSE OF PEOPLE TO NOISE

A comprehensive review of surveys of sound levels and community response has been presented by Schultz³³. Schultz points out that such surveys have been presented in terms of outdoor sound level in northern (cool) countries. The responses, however, are inferred to be those of people inside their houses. A typical attenuation for the walls of northern homes is 28 dB³³. The attenuation of homes typical of low-evaluation in Hawaii is approximately 12 dB³⁶. Schultz's results³⁴ are presented in Table VIII together with the outdoor L_{dn} expected to

result in a similar response at tropical locations in Hawaii.

Table VIII. SUMMARY OF EXPECTED COMMUNITY RESPONSE TO NOISE

<u>Outdoor L_{dn}</u>		<u>% Highly Annoyed (Approx. Range)³⁴</u>
<u>Cold Climate³³ (dB)</u>	<u>Near HGP-A (dB)</u>	
50	34	0-9
60	44	3-21
70	54	13-39
80	64	37-75
90	74	65-100

There is some evidence to suggest that, at outdoor sound levels above about $L_{dn}=65$ dB (50 dB in tropical Hawaii), people's response is dependent primarily on the absolute level of the intruding noise. At lower sound levels, response appears to be primarily dependent on the difference between the level of the intruding noise and the ambient noise that would exist if the intruding noise were absent. An intruding noise 10 dB above the ambient will sound twice as loud as the ambient sound level. Pure tones as much as 10 dB below the ambient are often clearly audible.

The "% highly annoyed" in Table VIII is of vital importance in estimating community response. This is the portion of the public exposed to the noise that can be expected to demonstrate definite and conscious response. Those who are simply aware of the noise, but do not respond to it, are not included in % highly annoyed. It is the % highly annoyed who can be expected to voice complaints, threaten legal action, and to initiate such action.

5.3 LAWS, STATUTES, ORDINANCES, REGULATIONS, AND GUIDELINES

5.3.1 County of Hawaii

There appear to be no Hawaii County ordinances or guidelines concerning noise criteria.*

5.3.2 State of Hawaii

There appear to be no State regulations concerning community noise applicable to Hawaii County. There are several statutes which apply to noise pollution; Hawaii Revised Statute (HRS) Chapters 342, 343, 344 and HRS Section 46-17.

Under HRS Chapter 342, "Environmental Quality", the Hawaii State Department of Health (DOH) has the authority to adopt rules and regulations controlling and prohibiting noise pollution in any part of the State. The statute defines excessive noise as "the presence of sound... which endangers human health, welfare or safety, animal life, or property or which unreasonably interferes with the comfortable enjoyment of life and property..." The DOH has adopted Chapter 44A, Public Health Regulations, "Vehicular Noise Regulation for Oahu," and Chapter 44B, "Community Noise Control for Oahu". These regulations are not in effect and are not enforced on the Island of Hawaii. As a matter of interest, Chapter 44B specifies excessive noise in residential and preservation districts as any noise that exceeds 55 dBA (45 dBA from 10 p.m. to 7 a.m.) more than 2 minutes in any 20 minute period of time. This is equivalent to $L_{dn}=55$ dB.

The title of HRS Chapter 343, "Environmental Quality Commission

*Noise provisions do appear in the Comprehensive Zoning Code of the City and County of Honolulu, but these do not apply in Hawaii County.

and Environmental Impact Statements" is adequate to describe its contents. The Hawaii State Environmental Impact Statement² was required under this statute.

HRS Chapter 344, "State Environmental Policy" identifies guidelines under which to "encourage productive and enjoyable harmony between man and his environment..."

HRS Section 46-17 was enacted by the State Legislature in 1974 to allow counties to adopt more stringent ordinances regulating noise (among other "nuisances") than those "embraced within any statute or rule of the State." The County of Hawaii thus has the statutory authority to adopt and enforce an ordinance on community noise control.

5.3.3 Federal

Two public laws that apply directly to the problem of community noise on the Island of Hawaii are the National Environmental Policy Act of 1969 (NEPA) (Public Law 91-190) and the Noise Control Act of 1972 (Public Law 92-574), as amended. The Federal EIA³ was required under NEPA. The EPA's Office of Noise Control and Abatement operates under provisions of the Noise Control Act of 1972. The most recent amendment to this Act is Public Law 95-609, the "Quiet Communities Act of 1978". Under this amendment, EPA may provide support to communities seeking help in setting up noise control programs.

5.3.3.1 U.S. Environmental Protection Agency

A great deal of information has been made available by the Office of Noise Abatement and Control of the EPA. Some of it has been used in preparing this report^{7,15,17,29,30}. The EPA has published recently³⁶ a version of its "levels" document²⁹ that summarizes that document in less technical terms. The gist of the "levels" document is a recommendation that $L_{dn} \leq 55$ dB outdoors in residential and other outdoor

areas where quiet is the basis for use, and that $L_{dn} \leq 45$ dB inside residences.

5.3.3.2 U.S. Department of Housing and Urban Development

With its Circular 1390.2 (August 4, 1971), HUD has published standards under which it will guarantee loans for housing. The portions of Circular 1390.2 pertinent to this report are summarized in Table IX.

Table IX. INTERIM EXTERNAL NOISE EXPOSURE STANDARDS FROM HUD CIRCULAR 1390.2 (edited for this report)

Unacceptable	Exceeds 80 dBA (64 dBA*) 60 min per 24 hrs Exceeds 75 dBA (59 dBA*) 8 hrs per 24 hrs
Normally unacceptable	Exceeds 65 dBA (49 dBA*) 8 hrs per 24 hrs
Normally acceptable	Does not exceed 65 dBA (49 dBA*) more than 8 hrs per 24 hrs
Acceptable	Does not exceed 45 dBA (28 dBA*) more than 30 min per 24 hrs

*HUD standard adjusted for 16 dB estimated difference between the average 28 dB exterior-interior attenuation expected for housing in cold climates and the average 12 dB attenuation expected in tropical Hawaii. The author prepared these adjustments to illustrate this report. They did not originate with HUD.

Circular 1390.2 also identifies the following as "acceptable" interim standards for noise exposure for sleeping quarters in new or rehabilitated residential construction:

- does not exceed 55 dBA for more than an accumulation of 60 minutes in any 24-hr period, and
- does not exceed 45 dBA for more than 30 minutes during nighttime sleeping hours from 11 p.m. to 7 a.m., and
- does not exceed 45 dBA for more than an accumulation of eight hours in any 24-hr day.

6.0 EXPECTED IMPACT AND COMMUNITY REACTION

The estimates of impact and reaction discussed in this section depend upon the sound levels and spectra identified in preceding sections. Since many of these sound levels are based on an inadequate data base, the estimated impact and reaction should be taken as approximate. The margin of error can be significantly reduced when an adequate data base is obtained.

6.1 AT HGP-A

Visitors to HGP-A will be acutely aware of noise from plant operation. Except during periods of heavy rain, the daytime ambient sound level (level in the absence of plant operation) should be in the range 25 to 45 dBA. Thus the noise resulting from any operation except well shut-down or free venting can be expected to be in the range of 13 to 43 dB above the ambient sound level.* The expected 68 dBA sound level from venting via the "silencer" (10% of the time) will require noticeably increased vocal effort to communicate in or near the Visitors' Center at distances from speaker to listener greater than about 4 ft. The expected 58 dBA sound level from turbogenerator and/or cooling tower operation (90% of the time) will cause the same effect at distances greater than about 9 ft.

In the unlikely event of accidental venting of well fluids directly to the atmosphere, the sound level at the Visitors' Center will probably be about 108 dBA, a level to which exposure for even short periods (e.g., a few minutes) can cause at least a temporary hearing loss³⁷.

*See last paragraph Sec. 4.1

6.2 AREAS PROXIMATE TO THE HGP-A

6.2.1 Current Residential Development

As mentioned earlier (Sec. 2.1.5), the nearest occupied residence is 0.7 mile (about 3,700 ft) from HGP-A, and there are only about a dozen residences currently within 1 mile (about 5,300 ft) of HGP-A (1-mile residences).

The day-night sound level (L_{dn}) from HGP-A operations during tradewind weather at the 1-mile residences will probably be in the range of not audible upwind to 27-32 dB downwind 90% of the time and 35-37 dB 10% of the time. Since the ambient sound level at night is expected to have a day-night level of about 35 dB, the probability of serious complaint is slight. Less than one person in ten is likely to be highly annoyed* during tradewind weather.

The day-night sound level from HGP-A operation during clear, still nights at the 1-mile residences will probably be in the range of 42-44 dB 10% of the time and 33-35 dB 90% of the time. Since the ambient level may be as low as 20 dB at night, HGP-A operating noise can be expected to be clearly audible. During turbogenerator operation, the 60 Hz tone can be expected to stand out, since sound at such a low frequency propagates with almost no excess attenuation. The probability of complaint for normal operations is highest during this time. A reasonable expectation is that one or two persons in ten may be highly annoyed.

In the event of accidental free venting of well fluids to the

*See Sec. 5.2 for discussion of % highly annoyed.

atmosphere, day-night sound levels at the 1-mile residences during tradewind weather can be expected to vary from about 50 dB upwind to about 75 dB downwind. During clear, still weather, day-night sound levels of about 83 dB can be expected. All residents living within 1 mile of the HGP-A are likely to be highly annoyed. The percent highly annoyed can be expected to be less than 1 in 10 only at distances greater than about 3 miles downwind during tradewind weather and greater than about 5 miles in all directions during clear, still weather.

6.2.2 Potential Residential Development

Two parcels of land contiguous to the HGP-A, Leilani Estates and Lanipuna Gardens, are already planned for urban use^{2,3}. Leilani Estates has already been subdivided into one-acre lots.

It is questionable practice to base decisions about allowable source noise levels on the noise level expected at the nearest existing residence^{2,3}. Property owners and potential residents can become very highly annoyed (i.e., litigious) if they perceive that noise has conferred economic disbenefits upon them. The history of noise control is replete with case histories of subdivisions developed near operating airports where new homeowners have created strong pressure on airport operations using noise as the vehicle for their objections. A prudent course of action is to specify the maximum allowable sound level at or beyond the property line of the property on which the source is located. As an example, Chapter 44B of Hawaii Public Health Regulations (see Sec. 5.3.2) specifies a 70 dBA sound level limit at the property line of an industrially zoned district except where it abuts a differently zoned district. If that district is

residential, the maximum allowable noise level* at the boundary between the two districts is 55 dBA during the daytime (7 a.m. to 10 p.m.) and 45 dBA during the nighttime (10 p.m. to 7 a.m.).

If the source sound levels and propagation factors for clear quiet nights discussed in earlier sections of this report are even approximately accurate, the region within about 400 ft of the HGP-A noise sources are in HUD's "normally unacceptable" range for noise exposure (see Sec. 5.3.3.2) 100% of the time (for 10% of the time the normally unacceptable range is 600 ft). If HUD's criteria are modified for Hawaii home styles, the effective normally unacceptable range would be increased from 400 and 600 ft to about 1,000 and 2,000 ft. For 100% of the time, the area within about 700 ft will have outdoor sound levels in excess of EPA's recommended maximum L_{dn} of 55 dB (for 10% of the time the range downwind would be about 1,400 ft).

The region within about one mile of the HGP-A may be analogous to new housing developments near airports used only on weekdays.** For 90% of the time during tradewind weather, probably about one person in ten would be highly annoyed by noise from the HGP-A, at distances greater than about 1/2 mile. And that person is most likely not to buy. Between about 1/4 and 1/2 mile from the HGP-A, one or two people in ten are likely to be highly annoyed. When the distance becomes 500 ft from the HGP-A, 2 to 5 people out of ten would be highly annoyed. For 10% of the time (venting via "silencer"), increased noise levels will result in an increased % highly annoyed.

*Level that must not be exceeded more than 2 minutes in any 20-minute period.

**The new owner inspects on weekends and buys on the basis of the "quiet" area. He complains later on the basis of the noise he hears after moving in.

Sales resistance by potential residents who hear the noise before purchase can be expected to elicit some reaction from property salesmen and developers. More importantly, those who bought on quiet days and found out about the noise later are likely to be more irate and vocal than the percentages just discussed would suggest.

6.3 POTENTIAL DEVELOPMENT OF KAPOHO GEOTHERMAL FIELD

Substantial development of the Kapoho geothermal field can be expected if operation of HGP-A successfully demonstrates the existence of a significant energy resource. Extensive drilling, grading, construction, and power generation will follow. Without controls, noise levels for these operations can be expected to equal or exceed those currently expected from construction and operation of HGP-A. The noise from free-venting wells can be expected to be significant. Experience at other geothermal steam fields, especially the Geysers, can be valuable in defining the expected noise exposures from various field development and operating components. At least one community organization³⁸ in Puna has already expressed great concern about the noise expected from development of the Kapoho geothermal field.

It is well known among noise control specialists that the easiest and least expensive way to control noise is by providing adequate performance specifications before design of potential noise sources has begun. It is much more difficult and expensive to "fix" a noise source after it has been built than to design noise control into it.

The County of Hawaii has the statutory authority to develop and adopt noise regulations. Alternately, the County of Hawaii might work with the Hawaii State Department of Health to have the protection of Chapters 44A and 44B of Hawaii Public Health Regulations extended to

apply in Hawaii County. If noise limits are properly set in advance, both the community and the developers will be protected.

7.0 CONCLUSIONS AND RECOMMENDATIONS

- 7.1 Noise levels at a proposed Visitors' Center on the site of the Hawaii Geothermal Research Station (HGP-A) can be expected to impress visitors with noise from geothermal power generation. Normal noise levels are expected to be in the range 58-68 dBA in the Visitors' Center. Accidental free venting of geothermal well fluids will create levels up to about 108 dBA.
- 7.2 Inadequate attention has been devoted to the impact of noise expected from operation of the HGP-A. Little attention appears to have been placed on noise control in the design of the turbo-generator building and the cooling towers. Both appear to be capable of creating noise levels that potential residents in the proximate community would be likely to find objectionable. The "silencer" used for recent flow tests is inadequate. Little effort appears to have been spent to design one that would reduce venting noise to a level acceptable to potential residents of proximate urban tracts.
- 7.3 Noise levels expected at the nearest existing residences from normal operations of the HGP-A appear to be low enough that substantial negative reaction should not be expected most of the year. During clear, still nights, one or two out of ten people in the existing residences are likely to be sufficiently highly annoyed to instigate action. Accidental free venting of geothermal well fluids can be expected to result in substantial negative reaction.
- 7.4 There appear to be no community noise regulations or ordinances applicable to geothermal development in Hawaii County. Both the

State and the County have independent statutory authority to develop regulations and/or ordinances. The immediate development and adoption of appropriate regulations and/or ordinances would be in the best interests of both residents and developers. To be cost effective, such adoption should precede further geothermal development.

- 7.5 The community reactions predicted in this report are based on an inadequate data base. There appear to be no existing measurements of ambient sound levels, no carefully documented measurements of sound levels created by the HGP-A well, and no firm data available concerning sound levels and spectra for the components and structures actually to be operated and built at the HGP-A. The predictions in this report are therefore only tentative. An improved data base is necessary to validate or improve them. Such a data base should include at least measurement of the ambient sound level, determination of source sound levels and spectra (at least octave band levels) for all sources on the HGP-A, and objective identification of attitudes in the Puna district towards noise from geothermal power generation.

REFERENCES

1. Hawaii Natural Energy Institute, "Summary, Geothermal Energy in Hawaii - Hawaii Geothermal Project", University of Hawaii, 2450 Dole street, Honolulu, Hawaii 96822, January 1978.
2. R.M. Kamins, "Revised Environmental Impact Statement for the Hawaii Geothermal Research Station Utilizing the HGP-A Well at Puna, Island of Hawaii", Department of Planning and Economic Development, State of Hawaii, P.O. Box 2359, Honolulu, Hawaii, 96804, March 1978.
3. U.S. Department of Energy, "Environmental Assessment, Hydrothermal Geothermal Subprogram, Hawaii Geothermal Research Station, Hawaii County, Hawaii", Washington, D.C., June 1979.
4. Research Corporation of the University of Hawaii, Wellhead Generator Feasibility Project, Blueprints approved for bid, early 1979.
5. P. Leitner, "An Environmental Overview of Geothermal Development: The Geysers - Calistoga KGRA", Volume 3, Noise, Report UCRL-52496, Lawrence Livermore Laboratory, University of California/Livermore, California 94550, August 16, 1978.
6. P. Yuen, et al., "well Tests and Reservoir Engineering" in "Phase III - Well Testing and Analysis". Progress Report for the Second Quarter of Federal FY 77, Hawaii Geothermal Project University of Hawaii, Honolulu, HI, Apr. 1, 1977.
7. L.S. Goodfriend and Associates, "Noise from Industrial plants", Report NTID300.2, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460, December 31, 1971, p. 44.
8. Ref. 7, p. 115.
9. Ref. 3, p. 81 (Refers in turn to data presented by R.C. Bush, "An Overview of Audible Noise Measurement at the Geysers," pp. 169-174 in Proceedings of the Geothermal Seminar 1976, M.D. Anderson and F.L. Tucker, Eds., Shearer Graphic Arts, Lakeport, Calif., 1976.
10. L.L. Beranek, "The Measurement of Power Levels and Directivity Patterns of Noise Sources," pp. 138-163 in Noise and Vibration Control, L.L. Beranek, Ed., McGraw-Hill, 1971.
11. Ref. 7, p. 43.
12. D.B. Callaway, "Noise in Water and Steam Systems," Chapter 26 in Handbook of Noise Control, C.M. Harris, Ed., McGraw-Hill, 1957.
13. Ref. 2, p. 14.

14. Environmental protection specification by Rogers Engineering Co., date not known.
15. Bolt, Beranek, and Newman, "Noise from Construction Equipment and Operations, Building Equipment, and Home Appliances"; Report NTID 300.1 U.S. Environmental Protection Agency, Office of Noise Abatement, Washington, D.C. 10460, December 31, 1971, pp. 18-24.
16. Ref. 3, p. 56.
17. Wyle Laboratories, "Community Noise," Report NTID 300.3, U.S. Environmental Protection Agency, Office of Noise Control and Abatement, Washington, D.C. 20460, December 31, 1971, pp. 18-24.
18. The author has measured an ambient daytime sound level of approximately 25 dBA at a rural location, out of the wind, on Kauai.
19. Ref. 3, p. 80.
20. Ref. 3, p. 20. For Geysers data, refers to O. Weres, K. Tsao, and B. Wood, "Resource, Technology, and Environment at the Geysers", LBL-5231, June 1977, p. VIII-28.
21. U. Kurze and L.L. Beranek, "Sound Propagation Outdoors", pp. 164-193 in Noise and Vibration Control, L.L. Beranek, Ed., McGraw-Hill, 1971, Figs. 7.4 and 7.5.
22. Ref. 21, Eq. 7.12.
23. L.C. Sutherland and H.E. Bass, "Practical Considerations for Atmospheric Absorption Losses of Filtered Bands of Noise," J. Acoust. Soc. Am. 63, S1, p. S59, Spring 1978.
24. Ref. 21, Fig. 7.17.
25. Ref. 21, Fig. 7.16.
26. Ref. 21, Table 7.2.
27. Ref. 5 refers to unpublished data obtained by P. Leitner at the Geysers.
28. A.P.G. Peterson and E.E. Gross, Jr., Handbook of Noise Measurement, General Radio Company, Concord, Mass., 1972, pp. 77, 78.
29. "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," Report 550/9-74-004, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460.

30. Miller, James D., "Effects of Noise on People," Report NTID 300.7, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460, December 31, 1971. Also (slightly revised) J. Acoust. Soc. Am. 56, pp. 728-764, Sept. 1974.
31. Ref. 30, Fig. 15.
32. Ref. 30, Fig. 17.
33. T.J. Schultz, "Synthesis of Social Surveys on Noise Annoyance," J. Acoust. Soc. Am., 64, pp. 377-405, August 1978.
34. Ref. 33, Fig 6.
35. Ref. 33, Fig 4.
36. "Protective Noise Levels, Condensed Version of EPA levels Document," Report EPA 550/9-79-100, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 10460, November 1978.
37. Ref. 30, Figs. 3, 4.
38. Puna Hui Ohana presentation at Hawaii Geothermal Overview Workshop, Hilo, Hawaii, May 3-4, 1978.
39. R.L. Bannister, "Vibration and Noise of Large Turbomachinery," Sound and Vibration, pp. 14-21, April 1979.

