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NOISE EMISSION LEVEL MONITORING AROUND OLKARIA GEOTHERMAL POWER PROJECT (Jan. 2005-May 2006)

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ABSTRACT

The results of environmental noise level assessment within Olkaria Geothermal Power Project and the staff residential estate for the period January 2005 to May 2006 are presented. Within Olkaria geothermal project setting noise can arise from high flow steam lines which generate high sound levels at the source due to steam flow which is reduced by insulation and cladding. Localized noise also arises from traps installed within steam supply lines that automatically eject condensate along with small amount of steam. Steam separators are also in general low noise emission devices with small amount of flow noise involved. From the actual electricity generation plants and related installations, the following noise sources have been identified: turbines, generators, gas extraction units, condensers, cooling towers, pumps, steam ejectors, power transformers, exhaust air fans, air conditioners, circuit breakers, and vehicle traffic. Noise emission was assessed by measuring sound pressure level in dB(A) at potential noise sources at both Olkaria I and II Power Station and the adjacent areas.

Results indicate that maximum noise emission level around all monitoring sites at both Olkaria I and II Power Stations fall within the 85 dB(A) World Health Organization 8 hr recommended occupational exposure limit. Maximum noise levels at Olkaria I powerhouse, Olkaria I Stores, Olkaria II powerhouse, Compressor room, Cooling towers and Hot Well Pits Unit I & II at Olkaria II Power Station exceeded the 70 dB(A) World Bank permissible noise levels for industrial installations. Noise emission level of the highest frequency of occurrence (mode) around Olkaria I and II Power Stations monitoring sites also within the 70 dB(A) World Bank permissible noise levels for industrial installations and the 85 dB(A) WHO recommended exposure limits with exception of Olkaria I powerhouse monitoring site. Noise emission levels around residential quarters (KWS staff quarters at Olkaria gate, Lakeview and Lakeside estates) was within the recommended 45-50 dB(A) and 55 dB(A) WHO and World Bank permissible noise level within the residential areas respectively. Use of hearing protective devices such as ear mufflers and earplugs by personnel working within locations where noise level approaches the recommended 85 dB(A) 8 hours occupational exposure limit should be encouraged.

1. INTRODUCTION

Noise, which is often referred to as unwanted sound, is typically characterized by the intensity, frequency, periodicity (continuous or intermittent) and the duration of sound. Sound is the result of pressure changes in the air caused by vibration (Thompson, 1994). Unwanted sound to some may be considered wanted sound by others, as in the case of loud music.

More people are affected by noise exposure than any other environmental stressor. However, because its associated health effects are not as life-threatening as those of air, water and hazardous waste, noise has been on the bottom of most environmental priority lists (Cowan, 1994). Traditionally, much of the scientific facts have been based on studies of occupational exposures. These noise exposures tend to be of greater intensity over long periods of time as compared with exposure to community noise. Noise annoys, awakens, angers and frustrates people in a working environment if it's in excess of tolerable limits. It disrupts communication and individuals' thoughts, and also affects performance capability. Numerous effects of noise combine to detract the quality of people's lives and the environment.

Noise emanates from different sources. Transportation noise, industrial noise, construction noise, household noise, and people and animal noise are large-scale offenders. The importance then should be given, to examine the total range and combination of noise sources not to focus on any one source

1.1 Noise emission data worldwide

The availability and comparability of data on noise pollution worldwide are generally poor. Available published data show that exposure to noise, which was fairly stable in early 1980s, had increased by the end of that decade in most countries. For sound levels greater than 65 dB(A), exposure appears to have stabilized in some cases and increased in others. However, within the range 55 to 65 dB(A), exposure has significantly increased, apparently as a result of the fast-growing volume of road traffic. In the highly industrialized countries, more than 50 per cent of the population is exposed to noise levels from road transport and industrial activities which are above 55 dB(A), which is the level at which people become seriously annoyed during the daytime (WHO, 1999). The UNCED (United Nations Conference on Environment and Development) in Rio in 1992, mentioned noise as an environmental problem of growing concern in the light of the incipient, rapid growth of road traffic and the expected development of industry.

2. NOISE EFFECTS

The nuisance effects of noise are difficult to quantify, as people's tolerance to noise levels and different types of noise vary considerably. Distinct variations in noise intensity and noise levels can occur from place to place (even within the same general area), and from one moment to the next. Similarly there can be large variations during each day, week or year. The main effects on people from noise occur along roads, in residential and industrial areas. The impact of noise on sensitive groups deserves particular attention (e.g., school children, the sick). The reaction of these groups may be considered as warning signals as to what may happen to other groups on exposure at higher noise levels.

2.1 Annoyance

This is perhaps the most common adverse effect of noise on people and complaints may be made about many different types of noise. The feeling of annoyance results not only from interference with communication and sleep disturbance, but also from less well-defined feelings of being disturbed and affected during all kinds of activities. There is, for example, evidence of a clear relationship between

degrees of individual annoyance and noise levels; for example, it has been demonstrated that less use is made of private gardens and public parks when there is too much noise (Suter, 1991).

Whether and to what extent such exposure is ultimately harmful to human health and well-being has not yet been fully and conclusively explored, except at very high sound levels, when it causes hearing loss and *tinnitus* (ringing in the ears). The present state of knowledge, however, clearly indicates that long-term health effects due to environmental noise exposure cannot be excluded. In addition, a number of well-defined harmful effects on the quality of sleep, communication and psycho-physiological behaviour have been identified. There is lack of evidence to indicate that such reactions to noise diminish with time, although within certain limits tolerances may be built up. However, it seems that complete physiological habituation to sleep-disturbing noise does not occur, not even after several years of exposure.

2.2 Sleep disturbance

Sleep disturbance is probably the most apparent effect of environmental noise. It can also be interpreted as a reduced quality of sleep, and may even occur when the people affected are not aware of it (Berglund & Lindvall, 1995). To ensure undisturbed sleep, single noise events should not exceed a maximum sound pressure level of approximately 55 dB(A).

2.3 Interference with communication

The degree of interference of noise with speech depends on the noise level in relation to the level that conveys the desired information (Table 1). An increasing noise level requires speakers to raise their voice and/or to get closer to the listener in order to be understood. Noise levels from about 35 dB(A) and above are seen to interfere with speech communication until, at noise levels of about 70 dB(A), normal speech communication becomes virtually impossible (ISO, 1974).

TABLE 1: Outdoor communication distances at various voice levels and specific sound levels

Speech interference level dB(A)	**Maximum distance at which normal conversation is considered satisfactorily intelligible (m)**	**Maximum distance at which conversation in raised voices is considered satisfactorily intelligible (m)**
35	7.5	15
40	4.2	8.4
45	2.3	4.6
50	1.3	2.6
55	0.75	1.5
60	0.42	0.85
65	0.25	0.50
70	0.13	0.26

Source: Adapted from, ISO (1974): Acoustics-Assessment of noise with respect to its effects on the intelligibility of speech.

2.4 Extra-auditory effects

A great number of psycho-physiological effects of noise have been reported in the literature (WHO, 1999). The most common responses are physiological stress, and at higher noise levels, cardiovascular reactions. Mental health effects and influences on performance and productivity have also been observed and documented. Intensive research on these subjects has been ongoing, but it can be generally concluded from the present state of knowledge that exposure to environmental noise acts as a stressor to health, as it leads to measurable changes in, for example, blood pressure and heart rate. But there is not sufficient evidence yet to relate the exposure to environmental noise levels directly to specific health effects, although such relationships can by no means be excluded. It is presumably the

total load of stressors, of which environmental noise is only one, that has a harmful and lasting effect on physical and mental health, seen as a statistical entity that allows great individual variations.

2.5 Potential noise effects on wildlife

The effects of noise on the natural environment have not yet been fully explored. Research results available point to extra-auditory effects, mainly unspecific stress reactions, on animals with an acute sense of hearing, under extremely high noise exposures from low-flying aircraft (Gladwin et al., 1987; Krausman et al., 1993).

A study by Gladwin et al (1987) of the National Ecology Research Center (USA) on the effects of low-altitude aircraft operations on fish and wildlife species, population and habitat utilization revealed that aircraft noise disturbance to fish and wildlife existed over a large geographical area. Various types of aircraft were responsible for disturbing wildlife on and near service installations by causing flight/fright response. Waterfowls were by far the most frequently reported animal group disturbed by aircraft. The reported impacts on wildlife ranged from minor behavioural responses to severe changes in the use of the area.

Another study by Krausman et al (1993) on the effects of simulated aircraft noise on heart rates and behaviour of desert ungulates, showed a change in heart rate and behaviour in relation to the ambient temperature, number of simulated over-flights and the noise levels (range of 92-112 dB(A) the animals were exposed. The heart rates increased during over-flights but returned to resting rates in (less than or equal) 2 minutes.

Studies of effects of aircraft noise and sonic booms on domestic animals and wildlife by the Engineering Service Center, U.S Air Force (1988) showed varied responses from different avian species of raptors, water birds, songbirds, poultry and laboratory birds, the severity, which was dependent on the intensity, and duration of the noise. The response ranged from alarmed reaction to nest desertion. However, noise effects of major proportions or of lasting harmful consequences on nature have not been reported (Suter, 1978; White et al., 1979).

3. REGULATORY FRAMEWORK RELEVANT TO NOISE EMISSION AND EXPOSURE LIMITS

The legislative controls relevant to noise emissions associated with any development is outlined in the Public Health Act and Environmental Management and Co-ordination Act 1999 (EMCA). The EMCA 1999 recognizes the fact that any person emitting noise in excess of noise emission standards commits an offence. It legalizes the process of Environmental Impact Assessment and compliance with the set emission goals, permissible standards, and control strategies and technologies for noise emission as mandatory. With establishment of noise emission standards, it will be a requirement to obtain a temporary permits from the National Environmental Management Authority (NEMA) allowing for emissions of noise in excess of established standards for a period not exceeding three months. According to the National Environmental Management Authority (NEMA), the national standards on noise emission are at their final stage of preparation for gazettment or publication. Thus in the absence of national standards on air quality, International Guidelines were used. For this assessment, World Bank and World Health Organization (WHO) standards on noise emission were adopted (Table 2).

Occupational Heath and Safety Act of Kenya also specify limits on maximum occupational exposure for noise emissions in work environment. Different categories of ear protection mufflers have been recommended for use under different noise emission levels (see Table 3).

TABLE 2: International Ambient Noise Levels Criteria at Workplaces and Residential areas

Receptor	**Maximum allowable Leq (hourly) in dB(A)**			
	World Bank		World Health Organization	
	Day time 0700-2200 hrs	Night time 2200 – 0700 hrs	Day time 0700-2200 hrs	Night time 2200 – 0700 hrs
Residential, Institutional and Educational	55	45	50	45
Industrial and Commercial	70	70	85	85

TABLE 3: Occupational Health and Safety Exposure Limits for Noise Emissions

Sound Level dB (A)	**Maximum Permitted Duration (hours/day)**
80	16
85	8
90	2
100	1
105	0.5
110	0.25
115	1/8
>115	0
Hearing Protectors (Ear Mufflers)	
Sound Level dB(A)	**Maximum Class of Hearing Protectors**
85-95	C
96-105	B
106 and over	A

4. METHODOLOGY

4.1 Measurement of noise

There are two main ways of assessing the influence of noise: by physically measuring sound pressure levels, and by recording the discomfort or annoyance caused by noise. The former approach has been adopted and measurements have been done based on the International Standards Organisation (ISO, 1996). Physically noise is treated as an acoustic phenomenon called sound. A sound event as a physical phenomenon can be fully described by the following parameters:

1. The strength or sound pressure, mostly expressed in terms of the amplitude of the sound pressure waves, and is usually measured as sound pressure levels in decibels (dB);
2. The frequency or pitch, measured in Hertz (most noises consist of a mixture of sounds with various pitches and frequencies, and hence do not have a recognisable pitch in any musical sense);
3. The fluctuation of sound with time (also known as the time history), measured as sound pressure level as a fluctuation of time.

4.2 Potential noise sources within Olkaria geothermal project

Noise, within Olkaria geothermal project, arises from both natural and anthropogenic sources. In either case, geothermal fluids and gases from underground reservoir are released naturally as surface manifestations or through extraction for the purpose of energy extraction for generation of electricity. Production wells also produce noise during production testing carried out to monitor changes in well

performance. This is a two-phase type of discharge that uses a separator and a simple wellhead silencer to reduce noise impacts.

Within the steam field, high flow steam lines can also generate high sound levels at the source due to flow noise. Examples of generating mechanism within the pipe networks are control valves and flow restricting devices. Both serve to introduce turbulence and mixing downstream. Another mechanism is due to interaction between turbulence and the complex flow. Heavy wall thickness, thermal insulation and exterior cladding have a positive effect on reducing noise emission from pipelines. Localized noise also arises from steam traps installed within the supply lines that automatically eject condensate along with small amount of steam.

At the electricity generation power plants, a number of noise sources are involved. Depending on the degree of enclosure within the power station building, the following sources have been identified to generate noise: turbines, generators, gas extraction units, condensers, cooling towers, pumps, power transformers, circuit breakers, condensate reinjection wells and vehicle traffic. For power plants, cooling tower noise can be significant

4.3 Noise emission level assessment sites

The locations of noise monitoring stations were based on the potential noise sources around Olkaria I and II Power Stations and the potential receptor sites (Figure 1). In Olkaria East field the sites included Olkaria I administration offices, Power Station, Motor Vehicle and Rig Workshops, Scientific laboratories, General and Rig Stores, Well OW-10 and Well OW-22. Within Olkaria North East field, sites assessed were Olkaria II Administration Offices, Power House, Hot Well Pit Unit 1, Hot well Pit Unit 2, Cooling Tower, Compressor room and Control room. Other sites monitored were Kenya Wildlife Service Olkaria Gate, Lakeview and Lakeside Housing Estates.

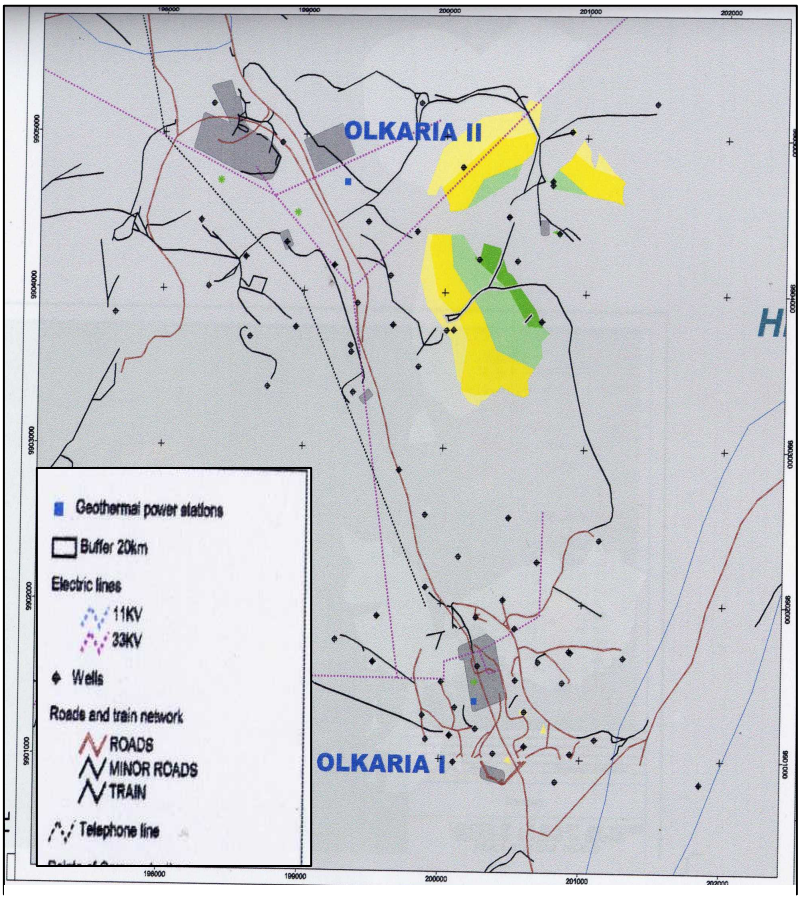

FIGURE 1: Location of Olkaria I and II Power Stations and geothermal wells

4.4 Noise level measurement procedure

The noise levels were measured by use of a hand held integrating averaging sound level meter (Bruel & Kjaer Type 2225) set to frequency-weighting 'A'. The sound levels measurements were done from January 2005 to May 2006 at least 1.0 meter from the walls and 1.5 m above the ground level during day only. Microphones were held by hand positioned as far from the body as possible facing the noise sources.

5. RESULTS AND DISCUSSIONS

The results of noise level assessment (Table 4 & 5) indicate that ambient noise levels for all sites assessed fall below the WHO Guidelines for Occupational Exposure Limits and community noise of 85 dB(A) and 50 dB(A) respectively. The noise levels also fall within World Bank Maximum Allowable Leq (hourly) Limits of 55 dB(A) for residential, institutional and educational facilities and 70 dB(A) for commercial and industrial premises during day time (0700-2200 hrs) with exceptions as shown in tables 4 and 5.

TABLE 4: Noise emission level around Olkaria I Power Station and the surrounding areas (January 2005 – May 2006)

	MV	**OLK1P**	**ADMIN BLK**	**OW-10**	**OW-22**	**Stores**	**KWS OLK Gate**	**LVE**	**LSE**
Mean **dB(A)**	33.8	70.9	50	44.7	34.7	45.1	32.1	28.4	29.7
Median **dB(A)**	35	72	52	42.5	34.5	44	32	27	29
Mode **dB(A)**	25(8)	74(14)	58(7)	42(6)	38(5)	45(5)	30(10)	25(7)	37(5)
Min. **dB(A)**	20(1)	62(1)	34(1)	30(1)	22(2)	28(1)	20(1)	20(1)	20(1)
Max. **dB(A)**	55(1)	78(3)	68(1)	68(1)	53(1)	77(1)	50(1)	38(1)	48(1)
WB Limits[1)] **dB(A)**	70	70	70	70	70	70	55	55	55
WHO TLV[2)] **dB(A)**	85	85	85	85	85	85	45-50	45-50	45-50
Abbreviations	MV=Motor vehicle workshop; OLK1P=Olkaria I power station; ADMIN BLK=Administration block; KWS OLK Gate= Kenya Wildlife Service Olkaria Gate; LVE=Lakeview Estate; LSE=Lakeside Estate								

[1)]World Bank maximum permissible noise level for industrial/ commercial and residential/institutional/ educational areas are 70 dB(A) and 55 dB(A) respectively.
[2)]WHO maximum permissible noise level in workplaces assuming 8-hr shifts, 5-day weeks and residential areas are 85 dB(A) and 45-50 dB(A) respectively

TABLE 5: Noise emission level (dB(A)) around Olkaria II Power Station (January 2005 – May 2006)

	OLK II P	**OFF BLK**	**HWPU1**	**HWPU2**	**COOLT**	**COMPRM**	**CNTLRM**
Mean	68.5	39.8	63.9	64	63.1	63.7	40.2
Median	69.5	39	63.5	64	63.5	64	42
Mode	70(16)	35(10)	60(8)	60(12)	63(9)	64(15)	42(2)
Min.	57(1)	28(1)	54(2)	54(1)	55(5)	48(1)	33(1)
Max.	78(1)	69(1)	78(1)	74(1)	76(2)	77(1)	48(1)
World Bank Limits	70	70	70	70	70	70	70
WHO TLV	85	85	85	85	85	85	85
Abbreviations	OLK II P=Olkaria II Power station; OFF BLK=Office block; HWPU1=Hot well pit Unit 1; HWPU2=Hot well pit Unit 2; COOLT=Cooling Tower; COMPRM=Compressor Room; CNTLRM=Control Room						

5.1 Environmental noise emissions based on Mode and Maximum levels

Evaluation of noise emission impacts from the operational activities require examination of mode and maximum noise levels recorded in a given impact site. Their evaluation over along period of time is of relevance especially when assessing the impact of noise on human health. The mode and maximum noise emission levels around Olkaria I Power Station & Olkaria II Power Station monitoring site is as

shown in table 4 and 5 respectively. For both places noise emission level of highest occurrence (mode) was 74 dB(A) and 70 dB(A) around Olkaria I and Olkaria II Powerhouses respectively.

5.1.1 Environmental noise emissions based on Mode

Noise emission level (mode) around Olkaria I Power Station monitoring sites indicate that noise emission levels at all sites were within the 70 dB(A) World Bank maximum permissible noise level for industrial installations and the 85 dB(A) WHO Threshold Limit Value except at the powerhouse where the mode noise levels was 74 dB(A), which is above the recommended World Bank Limits. Around Olkaria II Power Station monitoring sites, noise emission level of the highest occurrence (mode) was both within the World Bank and WHO permissible noise emission criteria. Mode noise emission level around residential areas (KWS Olkaria gate, Lakeview and Lakeside Estates) was with the World Bank and WHO permissible noise emission criteria of 55 dB(A) and 45-55 dB(A) respectively for residential areas (Figures 2, 3 and 4).

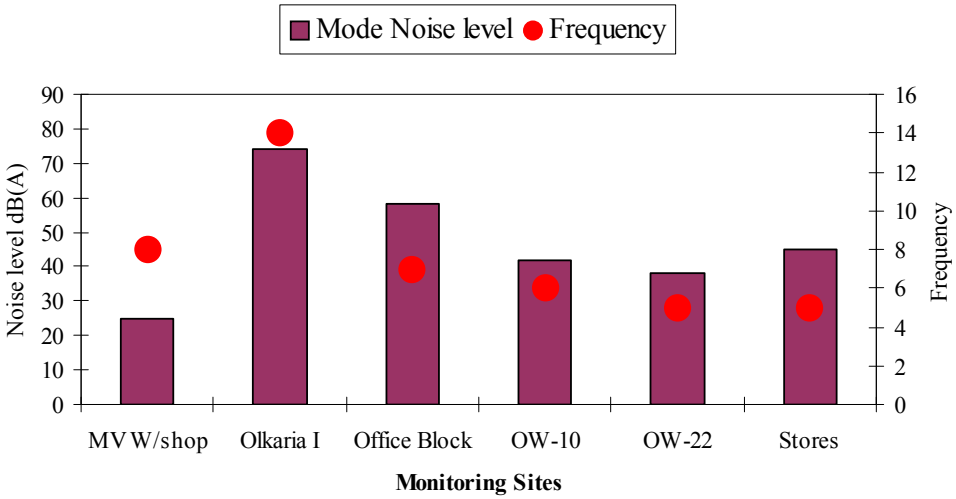

FIGURE 2: Noise level around Olkaria I Power Station based on the highest frequency of occurence

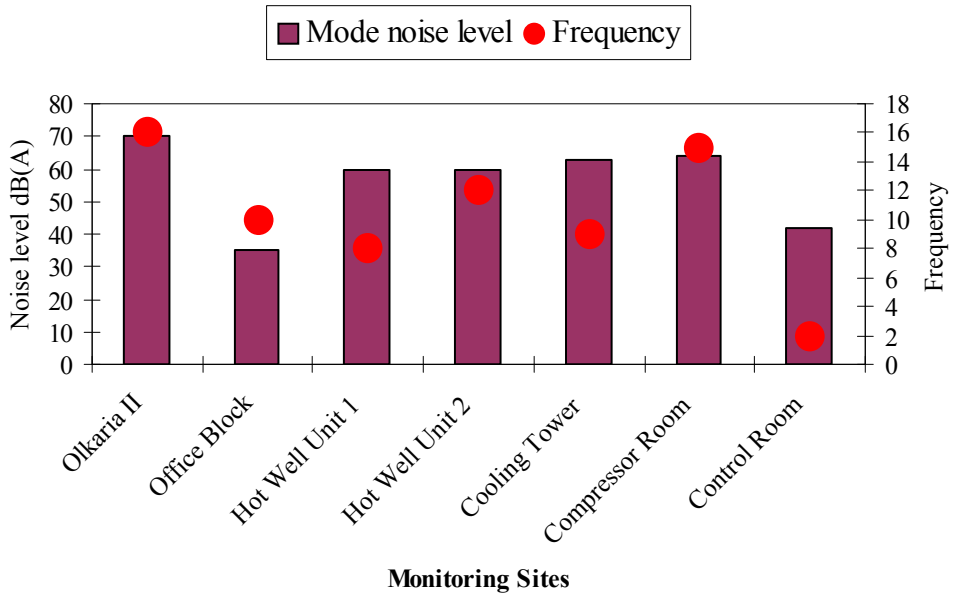

FIGURE 3: Noise level around Olkaria II Power Station based on the highest frequency of occurence

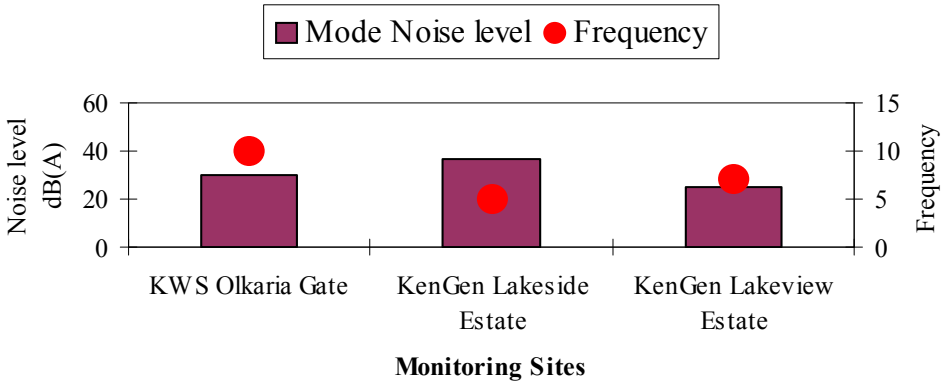

FIGURE 4: Noise level around residential areas based on highest frequency of occurence

5.1.2 Environmental noise emissions based on maximum levels

Maximum noise emission level was 78 dB(A) with a frequency of 3 and 1 around Olkaria I and Olkaria II Powerhouse respectively. Noise emission levels based on the maximum noise levels recorded around Olkaria I Powerhouse, Olkaria II Powerhouse, Olkaria I Stores, Olkaria II Hot Well Pit Unit I & II, Olkaria II Cooling Towers and Compressor room were above the 70 dB(A) World Bank maximum permissible noise level for industrial/commercial installations but within the 85 dB(A) WHO maximum permissible noise level in work places assuming eight hours shift (Figures 5 and 6).

Maximum noise levels around residential areas (KWS Olkaria Gate Staff houses, KenGen's Lakeview and Lakeside Estates) was in the range of 48-50 dB(A). All within the World Bank and WHO maximum permissible noise level for residential areas. Noise emission levels of highest occurrence was 30 dB(A), 25 dB(A) and 37 dB(A) for KWS Olkaria Gate, Lakeview and Lakeside estates respectively (Figure 7).

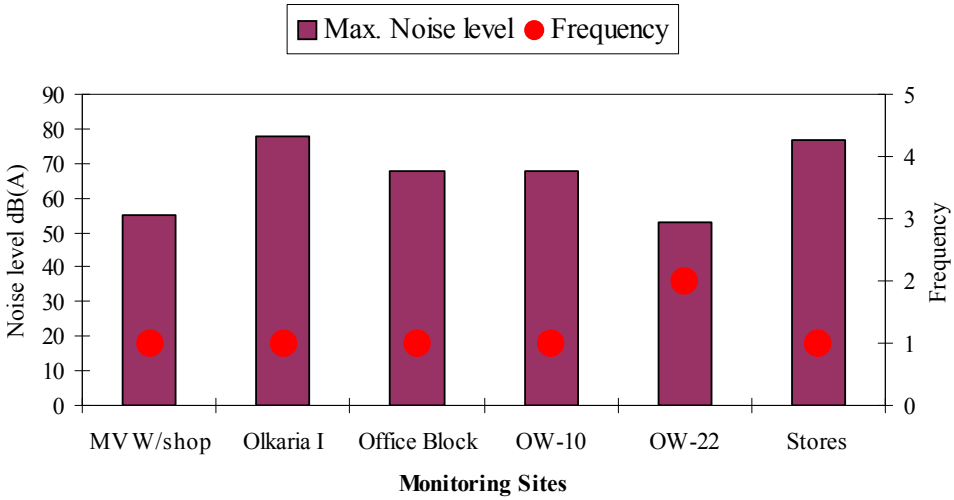

FIGURE 5: Noise level around Olkaria I Power station based on maximum level

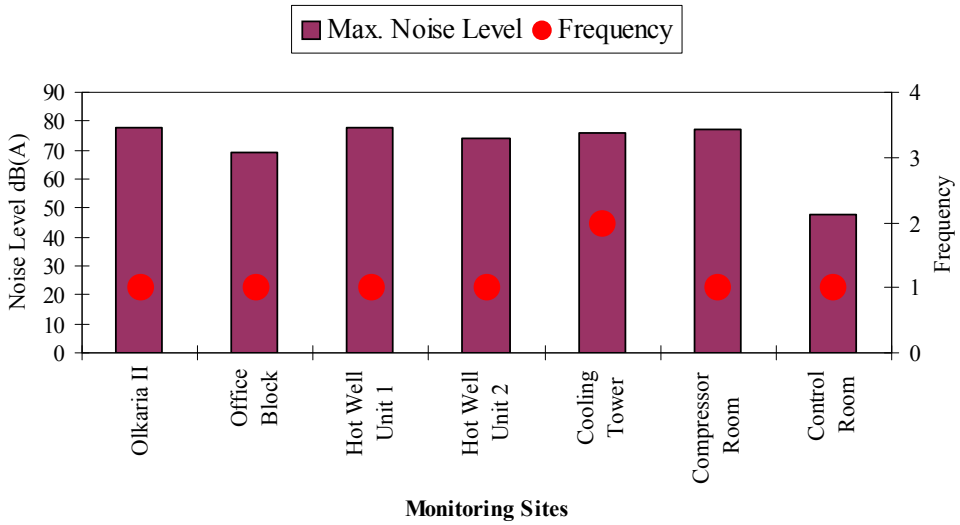

FIGURE 6: Noise level around Olkaria II Power station based on maximum recorded level

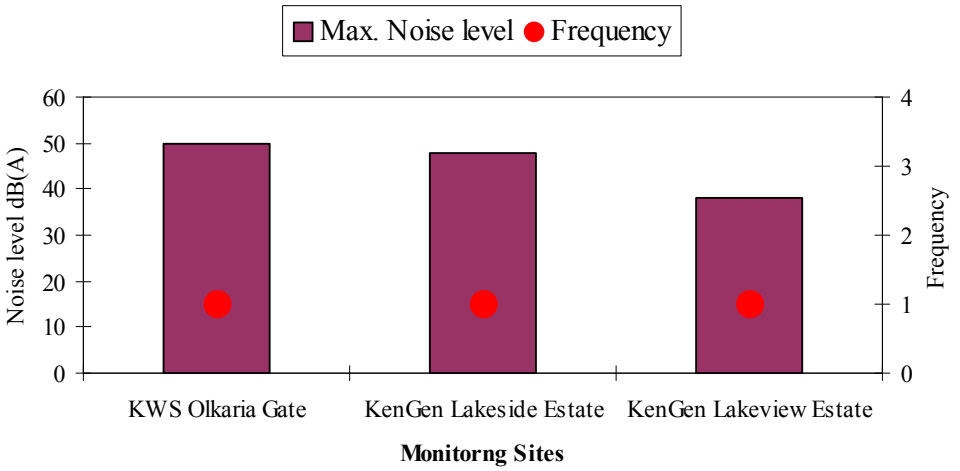

FIGURE 7: Noise level around residential areas based on maximum recorded level

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Noise emission levels within the Olkaria Geothermal Power Project were within the acceptable Occupational Health and Safety exposure limits of 85 dB (A) for eight working hours. In areas where noise emission will be in excess of established standards depending on the type of activities being undertaken, workers exposed to excessive levels of noise will need to be adequately protected. In residential areas, the levels recorded were within the recommended 45-50 dB (A) and 55 dB(A) noise level criteria for World Health Organization and World Bank respectively.

6.2 Recommendations

1. Use of hearing protective devices such as ear mufflers and earplugs by personnel working within locations where noise level approaches the recommended 85 dB(A) 8 hours occupational exposure limit. Such sites include areas outside Olkaria I & Olkaria powerhouses.

2. There is need to create noise effects awareness among staff working in noise prone environment so that they exercise personal safety through regular use of protective devices. Awareness can be enhanced through training.

REFERENCES

Berglund, B., and Lindvall, T. (1995). Community noise. In Health effects of Noise. Siu Fong and Marina Johnston, Toronto Public Health. City of Toronto, March 2000.

Cowan, J.P. (1994). Educating the public on environmental and recreational noise exposure. *In Health effects of Noise. Siu Fong and Marina Johnston, Toronto Public Health. City of Toronto, March 2000.*

Environmental Management and Coordination Act (1999). Government Printer.

Gladwin, D.N., D. A. Asherin, and K. M. Manci (1987). Effects of aircraft noise and sonic booms on fish and wildlife: results of a survey of U.S. Fish and Wildlife Service Endangered Species and Ecological Services Field Offices, Refuges, Hatcheries, and Research Centers. National Ecology Research Center, Fort Collins.

ISO (1974): Acoustics-Assessment of noise with respect to its effects on the intelligibility of speech.

Krausman P.R, et al (1993). Effects of simulated aircraft noise on heart rates and behavior of desert ungulates, University of Arizona.
http://www.sound.media.mit.edu/~dpwe/AUDITORY/asmtgs/asa93ott/4pAB/4pAB3.html

Suter, G.W., 1978: Geothermal development and wildlife behavior.

Suter, A.H. (1991). Noise and its effects. Prepared for the Consideration of the Administrative Conference of the United States.

Thompson, S.J. (1994). Noise and public health. *In Health effects of Noise. Siu Fong and Marina Johnston, Toronto Public Health. City of Toronto, March 2000.*

White, C.M. et al, (1979). Effects of controlled disturbance on ferruginous Hawks as may occur during geothermal energy development.

WHO (1999). Guidelines for Community Noise